Cost benchmarking of Network Rail's maintenance and renewals expenditure

Annual report: year 3 of Control Period 6 (2021-22)

14 November 2022

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Executive summary

Context

1. The Office of Rail and Road holds Network Rail to account for its management of the rail network in Great Britain. Understanding the main drivers of Network Rail's expenditure (including the reasons expenditure changes from year to year) and assessing the scope for it to improve its efficiency are central to this work. To achieve this, we use different analytical approaches, ranging from a bottom-up assessment of Network Rail business plans, projects and efficiency improvement measures to top-down cost benchmarking using statistical methods.

2. This report presents our latest cost benchmarking statistical analysis, which compares maintenance expenditure and conventional track renewals unit costs (in simple terms, renewals expenditure divided by work volume) over time and across Network Rail's regions, routes and maintenance delivery units (MDUs), after normalising[1] for the effect of the observable underlying differences between them[2].

3. The methodology in this year's report is broadly similar to the methodology in our year 2 of CP6 cost benchmarking report that we published in July 2021.

4. Our cost benchmarking was one part of the evidence that informed our initial advice to the UK and Scottish governments over the summer, as they prepare their funding and high-level output specifications for the next control period (control period 7 or CP7). We will undertake a similar analysis next year to assess Network Rail's strategic business plans for CP7. This will inform ORR's PR23 work on efficient costs.

Key messages

Maintenance expenditure

Key message 1: There has been an average annual increase in maintenance expenditure of 6% per year (in real terms[3]) since 2013-14, after normalising for

[1] By normalising, we mean we take account of some of the underlying differences between regions that affect expenditure, e.g. length of the network.

[2] For renewals, we have also analysed average unit costs (expenditure divided by work volume) separately by the main asset classes and for different types of renewals activity.

[3] In real terms means after adjusting for the effect of inflation (measured by the Consumer Price Index (CPI)).

factors such as traffic and network complexity. This may be due to inefficiency, or other factors.

5. Our analysis suggests that there has been an average annual increase in maintenance expenditure of 6% per year (in real terms) since 2013-14, after normalising for factors such as traffic and network complexity. This may be due to inefficiency, or other factors. This long-run trend of maintenance expenditure rising has reduced from the last two years (from 9% in 2019-20 and 8% in 2020-21) but it is not clear if this reflects actual cost changes (e.g. inefficiency) or other factors, such as a change in the accounting of maintenance expenditure in the years from 2019-20.

6. However, inconsistencies in the data, especially regarding how centrally managed expenditure is treated, make comparisons difficult. In particular, before 2019-20, Network Rail used to provide us the data with its centrally managed expenditure allocated to the routes within each region. From 2019-20 onwards, Network Rail told us that it was not able to do that anymore, so our model (and comparisons) do not include this expenditure. The excluded costs were £79m (4% of maintenance expenditure) in 2019-20, £399m (20%) in 2020-21 and £391m (20%) in 2021-22. This means it is difficult to robustly compare Network Rail's maintenance expenditure in 2021-22, with the historic/background trend.

7. Network Rail has not provided clear guidance on what should be included in the maintenance and renewals expenditure that we use in our analysis, especially at a route and MDU level. This may mean an inconsistent approach has been used across Network Rail. We will work with Network Rail to agree on a process that will allow regional teams to be clearer on what should be in these expenditure categories, and to validate the data before we can analyse it.

Key message 2: Maintenance expenditure at **regional** level this year is between -17% and +17% of what our model would expect. This range is slightly larger than that implied in last year's analysis (-18% to +12%). Similar to last year, **Scotland'**s unexplained difference is the lowest (least costly) and **Eastern'**s is the highest (most costly).

8. Figure 1 below presents our results, comparing the outturn and modelled maintenance expenditure by Network Rail's regions, in 2021-22.

Figure 1: Deviation between outturn and expected (modelled) maintenance expenditure by Network Rail region, 2021-22[4]

9. The figure shows that maintenance expenditure at the regional level, was between -17% and +17% of that predicted by our model for 2021-22. Similar to last year, **Scotland** and **Eastern** are the largest outliers.

10. The **Eastern** region's actual maintenance expenditure was 17% above the model's prediction. Last year it 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. We will work with Network Rail to better understand this issue.

11. It is also not clear why **Scotland's** maintenance expenditure continues to be below the model prediction compared to other regions (-17% in 2021-22 from -18% in 2020-21). Network Rail Scotland said the variance may be explained by improved co-ordination in the planning and delivery of maintenance and renewals,

[4] Given the uncertainty associated with any statistical model, we consider any region that is within +/−10% of our modelled prediction (as shown by the x-axis at zero) is not an 'outlier'. These regions are marked grey. Regions that are marked blue are considered 'outliers'. The lines surrounding the central estimate of a given region'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 number representing the deviation between outturn and modelled cost.

though it is unclear to what extent Network Rail Scotland did this better than other regions, to the point where it can justify this unexplained difference. We will continue to work with Network Rail to better understand this issue.

Conventional track renewals unit costs

Key message 3: There has been an average annual increase in the average unit costs of conventional track renewals of 2.0% per year (in real terms) since 2014-15, after normalising for factors such as traffic and network complexity. This may be due to inefficiency, or other factors.

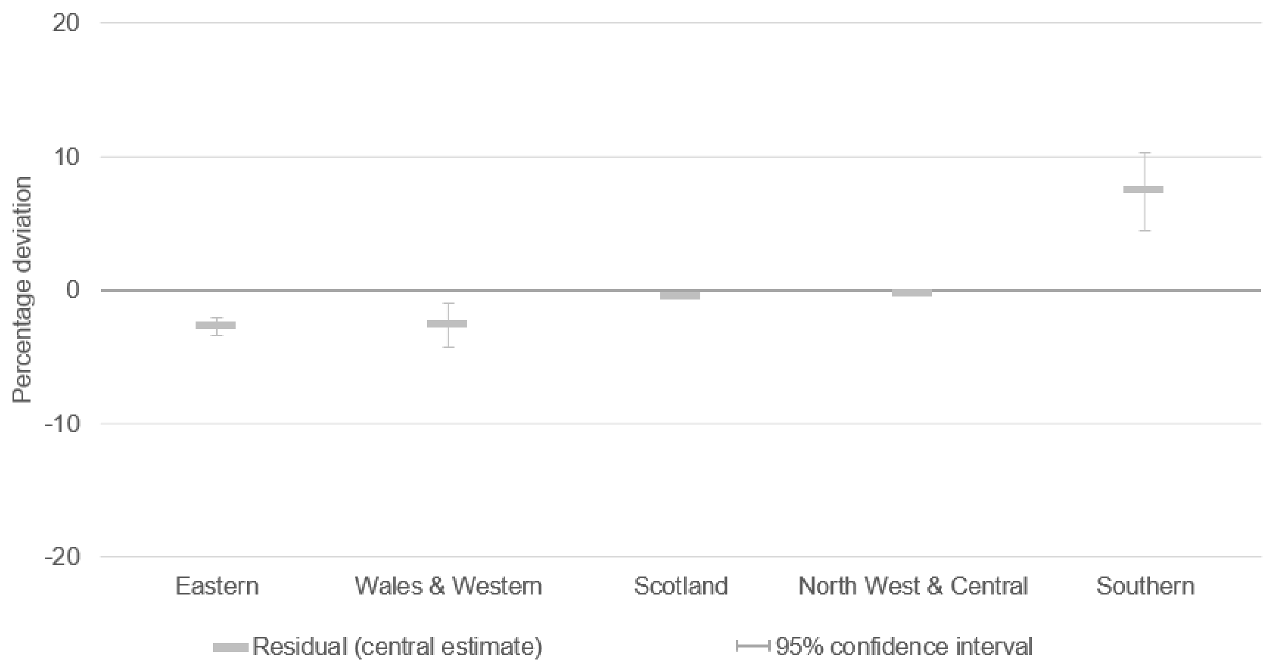
12. After normalising for factors such as traffic and network complexity, the analysis shows that there has been an average annual increase in the average unit costs for conventional track renewals of 2.0% per year (in real terms) during the period from 2014-15 to 2021-22 (same as for the period 2014-15 to 2020-21, in the year 2 of CP6 report).

13. In 2021-22, the rate of growth in the average unit costs for conventional track renewals increased to 2.7% compared to the long-term trend of 2.0%. According to last year's report, this rate of increase (from the long-term trend) was 2.6% in 2020-21, which means the increase in conventional track renewals unit costs was well above the trend in each of the last two years. We consider that this may be due to inefficiency, headwinds or some other factors including some project-specific factors (e.g. project location), which cannot be taken account of in a top-down analysis of this sort. For example, some of this increase may be due to rising input price inflation (i.e. changes in prices above the Consumer Price Index (CPI)) as discussed in our 2021-22 Annual Efficiency and Finance Assessment report.

Key message 4: Conventional track renewals' average unit costs at the regional level are between -3% and +7% of what our model would expect. This range is smaller than in last year's analysis (-10% to +10%). Compared to last year, **Eastern** is still at the lower (least costly) end of the range, whilst **Southern** has replaced **Wales & Western** at the top (most costly) end of the range.

14. Figure 2 below presents our results, comparing the outturn and modelled unit costs for conventional track renewals by Network Rail's regions, in 2021-22.

Figure 2: Deviation between outturn and expected (modelled) unit costs for conventional track renewals by Network Rail region, 2021-22



15. The figure shows that conventional track renewals' average unit costs at the regional level are between -3% and +7% of what our model would expect. This range is smaller than in last year's analysis (-10% to +10%).

16. Compared to last year, **Eastern** is still at the lower end of the range (-3%), whilst **Southern** has replaced **Wales & Western** at the top end of the range (+7%). While in our analysis last year, Wales & Western's average conventional track renewals unit costs appeared to be 10% more than our model prediction, this has reduced to 3% less than our model's prediction.

17. It is important to note that the unit costs of renewals are 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 regions.

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

1. Introduction

1.0 The Office of Rail and Road holds Network Rail to account for its management of the rail network in Great Britain. Understanding the main drivers of Network Rail's expenditure (including the reasons expenditure changes from year to year) and assessing the scope for it to improve its efficiency are central to this work. To achieve this, we use different analytical approaches, ranging from a bottom-up assessment of Network Rail business plans, projects and efficiency improvement measures to top-down cost benchmarking using statistical methods.

1.1 This report presents our latest cost benchmarking statistical analysis, which compares maintenance expenditure and conventional track renewals unit costs (in simple terms, renewals expenditure divided by work volume) over time and across Network Rail's regions, routes and maintenance delivery units (MDUs), after normalising for the effect of the observable underlying differences between them[5].

1.2 Our previous reports demonstrated that it is possible to build a statistical model that can explain the majority of the variation in some types of expenditure between Network Rail business units as a function of a few key cost drivers. We noted that these results should be seen strictly as a comparison of maintenance or renewals unit cost expenditure across business units rather than as an indication of Network Rail's overall efficiency. The same caveat applies to this year's analysis.

1.3 The methodology in this year's report is broadly similar to the methodology in our year 2 of CP6 cost benchmarking report that we published in July 2021. 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 important it is to understand what is different about the business unit in question relative to others and relative to previous years, be it efficiency, inefficiency, headwinds (cost increases outside of Network

[5] For renewals, we have also analysed average unit costs (expenditure divided by work volume) separately by main asset classes and for different types of renewals activity. Whilst part of this analysis is discussed in the "Context" section of chapter 2, we are only publishing our detailed analysis on conventional track renewals as this compares better with last year's analysis.

Rail's control), tailwinds (cost reductions outside of Network Rail's control), data reporting or some other factor.

1.4 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.

1.5 The methodology and most of the data that is the basis of this report formed the basis for the cost benchmarking analysis that we undertook on the CP7 plans that Network Rail submitted to us in March 2022, as part of PR23. Firstly, using Network Rail historical data and CP7 forecasts, we estimated both the maintenance expenditure and conventional track renewals average unit costs for CP7 for each region. Secondly, we used the findings in our year 2 of CP6 report together with other studies (both in the literature and those commissioned by Network Rail) to form a view about potential savings that Network Rail could make in CP7, following the reduction in traffic brought about by the coronavirus (COVID-19) pandemic. The findings of that analysis were used as one element of the evidence that informed ORR's initial advice to the UK and Scottish governments over the summer, as they prepare their funding and high-level output specifications for the next control period (CP7). We will undertake a similar analysis next year to assess Network Rail's strategic business plans for CP7. This will inform ORR's PR23 work on efficient costs.

What is cost benchmarking?

1.6 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 statistical models.

1.7 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.

1.8 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

1.9 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 model), or too small a sample size, can all weaken the robustness of results.

1.10 Despite some outstanding issues as discussed in para 1.23 below, 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 regions. This evidence base is also able to provide a reasonable range of estimates of future expenditure and renewals unit costs to benchmark business plans.

1.11 On the other hand, we have only partly been able to resolve the issues around Network Rail's 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. We have identified a workaround in collaboration with Network Rail but this will 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.

1.12 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

1.13 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.

1.14 From PR18, ORR decided to focus on Network Rail's regions. As part of that our cost benchmarking approach also shifted towards comparing Network Rail's business units (i.e. its regions, routes and MDUs), building on internal analysis undertaken by Network Rail during PR13.

1.15 In our PR18 final determination, we committed to updating this evidence base annually and stated our intention to make greater use of comparative regulation in control period 6 (CP6), with cost benchmarking playing an important role.

1.16 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. This analysis has also produced more meaningful discussions with Network Rail, including with its regions, where possible reasons for higher or lower than modelled expenditure and potential actions for improvement are discussed.

1.17 We published our year 2 of CP6 cost benchmarking report in July 2021 and the present document is the third report in this series.

Reporting our results

1.18 The key focus of this analysis is the comparison of outturn maintenance expenditure and conventional track renewals average unit costs in 2021-22, 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 costs – 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.

1.19 We present results at the level of Network Rail's regions, routes and MDUs, and highlight the largest outliers.

1.20 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.

1.21 Whilst we have sought to reflect Network Rail's input in this report, we would note that it 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; on the factors that could explain our results; and on possible actions that it could undertake to continue to improve both its cost information and efficiency.

Data improvements in our future reports

1.22 Since we published our PR18 cost benchmarking report, we have continued to improve both the modelling and the quality of the underlying data. This was recognised by Deloitte when reviewing our year 2 of CP6 report on behalf of Network Rail which stated that within the econometric literature, the ORR's year 2 of CP6 study offers the most relevant evidence on the relationship between Network Rail's maintenance expenditure and traffic. Although Deloitte also considered there were some weaknesses in our analysis and stated that its findings should not be thought of as being directly suitable for making decisions on funding arrangements.

1.23 After publication of this report, we will work with Network Rail and its regional teams to resolve the remaining data issues, and agree on a process that will allow regional teams to validate the data before we can analyse it. In particular, we will work together to resolve the following data issues in order to improve the relevance of this analysis further, especially for the purpose of informing ORR's PR23 work on efficient costs. These are:

(a) **accounting for centrally managed maintenance expenditure**: before 2019-20, Network Rail used to provide us with the data with its centrally managed expenditure allocated to the routes within each region. From 2019-20 onwards, Network Rail told us that it was not able to do that anymore, so our model (and comparisons) do not include this expenditure. The excluded costs were £79m (4% of maintenance expenditure) in 2019-20, £399m (20%) in 2020-21 and £391m (20%) in 2021-22. Moreover, centrally managed expenditure represents a different proportion of total maintenance expenditure for different regions. For example, in 2021-22, centrally managed expenditure was 7% of Eastern's maintenance expenditure, whilst it was around 20% of North West & Central's maintenance expenditure. This means that we have been able to model 93% of Eastern's maintenance expenditure, whilst only modelling 80% of North West & Central's maintenance expenditure. We did not find a credible way to allocate these costs to routes. So, we decided to exclude them from the analysis and we controlled for this change by adding a dummy variable for 2019-20 in the model. The issues with centrally managed maintenance expenditure mean that it is difficult to robustly compare Network Rail's expenditure in 2021-22 with the historic/background trend.

(b) **data recording**: in our discussions with regions, they identified hosting arrangements (i.e. whereby one MDU undertakes maintenance activities on some infrastructure (e.g. overhead line) on behalf of other MDUs but the costs continue to be paid by the hosting MDU and are not charged to the MDU where the asset is located) as one main reason for the large unexplained differences that we observed in our MDU analysis. In our future analysis, we will work with Network Rail to identify where these hosting arrangements exist and to agree on ways to allocate the costs to the MDUs where the infrastructure maintained is located.

(c) **expenditure classification**: in our discussions with regions, we identified some potential issues with expenditure classification. We will work with Network Rail to better understand them.

(d) **lack of clear guidance:** Network Rail has not provided clear guidance on what should be included in the maintenance and renewals expenditure that we use in our analysis, especially at a route and MDU level. This may mean an inconsistent approach has been used across Network Rail. We will work with Network Rail to agree on a process that will allow regional teams to be clearer on what should be in these expenditure categories, and to validate the data before we can analyse it.

Quantitative context

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

1.25 In this report, we cover maintenance and a proportion of renewals. As shown in Figure 3, maintenance represents 19% of Network Rail's total expenditure (excluding financing costs) for 2021-22; renewals represent (in total) 38%. The proportion of renewals that we concentrate on in this report (conventional track renewals) represents 12% of both the renewals expenditure for 2021-22 and average renewals expenditure over 2014-15 to 2021-22.

1.26 Figure 4 shows the trends in total maintenance and renewals expenditure, in 2021-22 prices. Maintenance expenditure has fallen slightly in 2021-22, after having been on a steady upward trend since 2013-14. Renewals expenditure has fluctuated considerably since 2013-14.

Figure 3: Breakdown of expenditure categories (excl. financing costs), 2021-22[6]

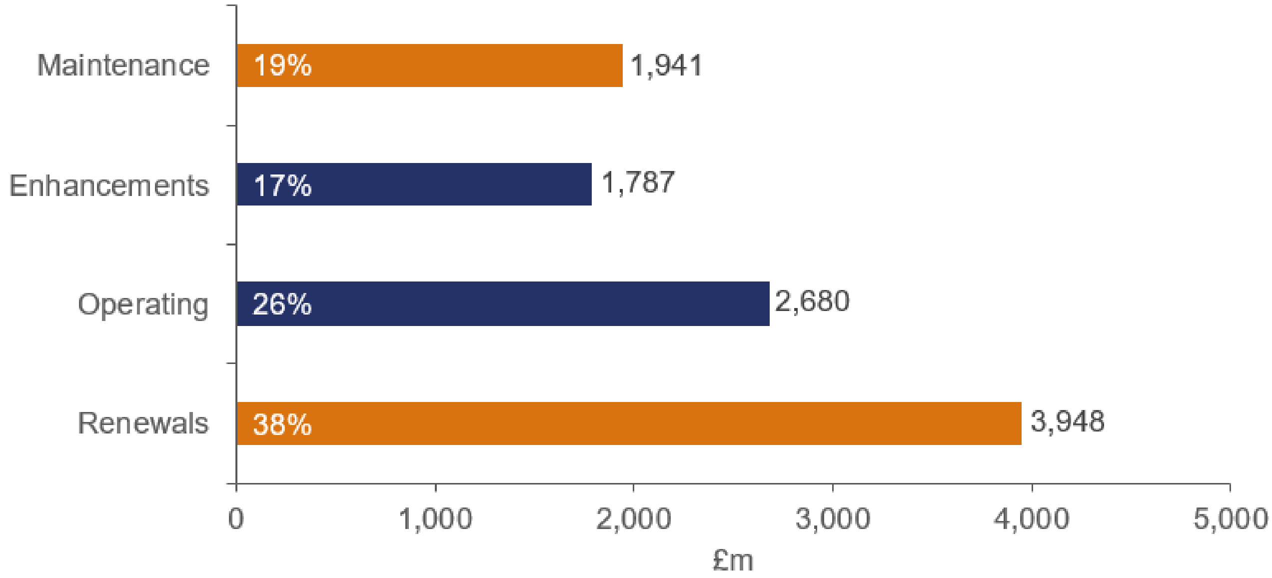
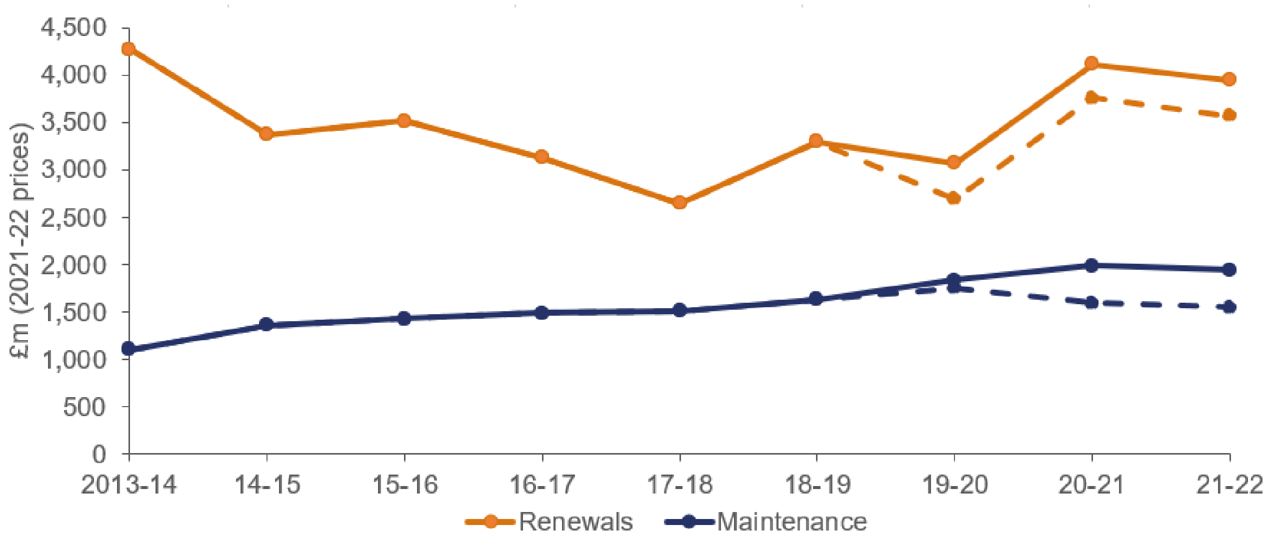


Figure 4: Total maintenance and renewals expenditure, 2013-14 to 2021-22 (2021-22 prices)

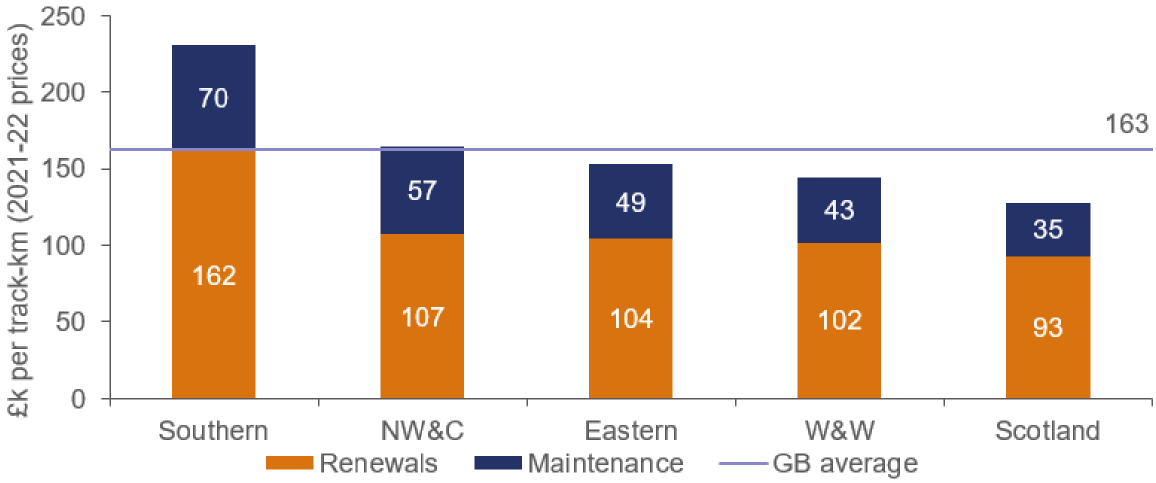


Note: Prior to 2019-20, Network Rail was able to allocate all of its central expenditure to the 10 routes. It is now not able to do that. The dashed lines show the lower level of expenditure that excludes the element of central expenditure that cannot be allocated to routes. We use the dashed line for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

[6] Maintenance and renewals figures are based on the bespoke data that we received directly from Network Rail for the purpose of this analysis in June 2022. Maintenance figures do not match the figures in the 2021-22 Annual Efficiency and Financial Assessment (AEFA) as that report uses the latest information. Enhancements and operating expenditure figures were taken from the AEFA. The enhancements expenditure figure excludes third-party funded expenditure. The operating expenditure figure includes Schedule 4 & 8 payments, network operations costs, support costs, traction electricity and industry costs and rates.

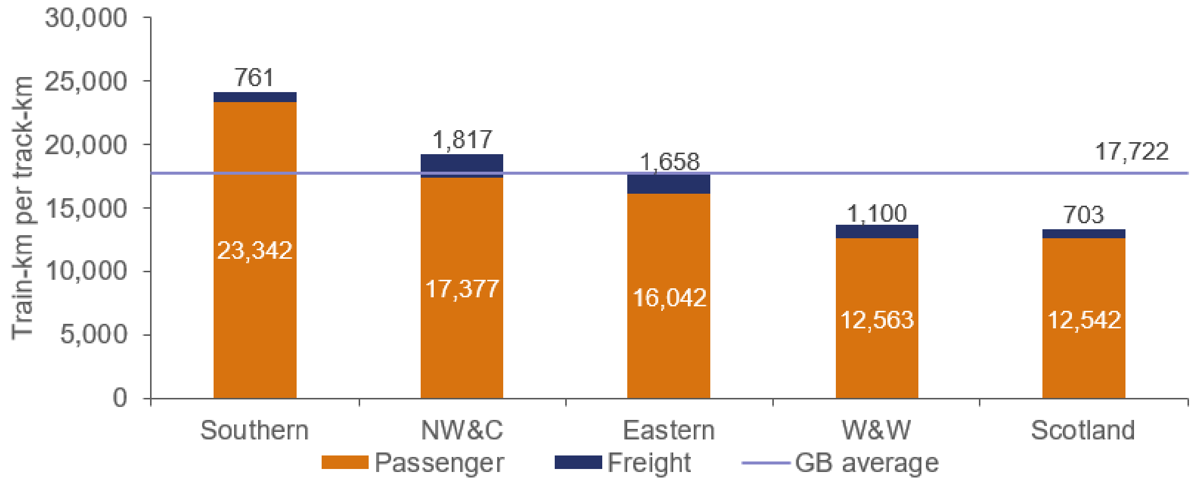
1.27 Figure 5 shows the breakdown of average annual maintenance and renewals expenditure by region, normalised by network size (expressed in track-kms). There is considerable variation across regions. A key purpose of cost benchmarking is to control for the proportion of this variation that is due to observable factors, so that comparisons across regions are made on a more like-for-like basis.

Figure 5: Breakdown of average total maintenance and renewals expenditure per track-km, 2013-14 to 2021-22 (2021-22 prices)



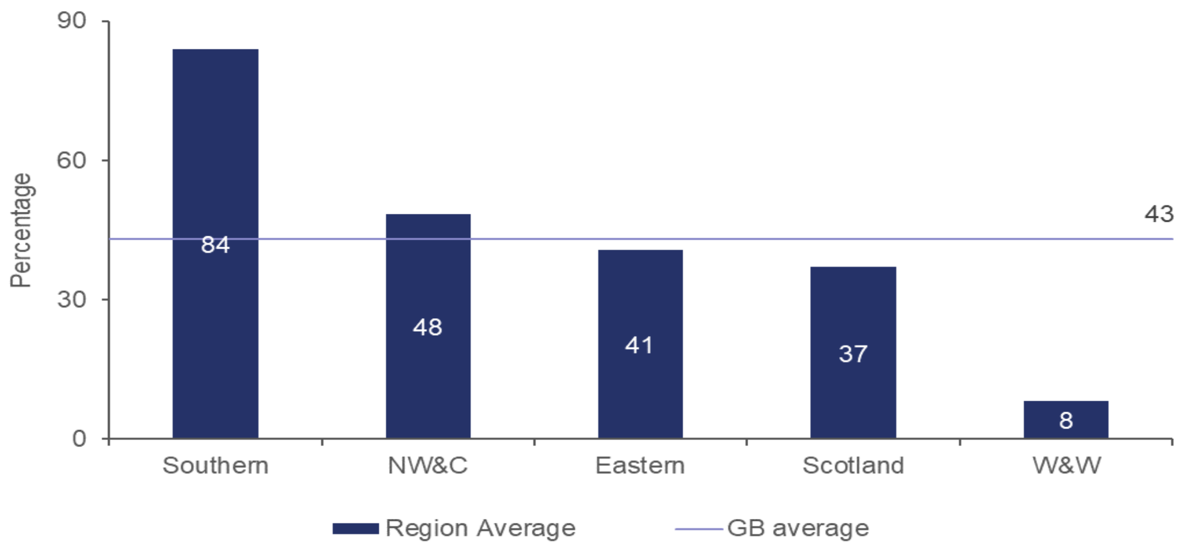
1.28 One of the key drivers of maintenance and renewals expenditure is traffic. Figure 6 shows average annual traffic density across regions (split into passenger and freight traffic). It can be seen that there is a strong correlation between this variable and the expenditure per track-km (as shown in Figure 5 above).

Figure 6: Average traffic density (train-km per track-km), 2013-14 to 2021-22



1.29 Figure 7 shows the average proportion of electrified track for the period from 2013-14 to 2021-22. We observe that there is a high degree of variation in the proportion of electrified track between regions and that there is some correlation between this variable and the expenditure per track-km (as shown in Figure 5 above).

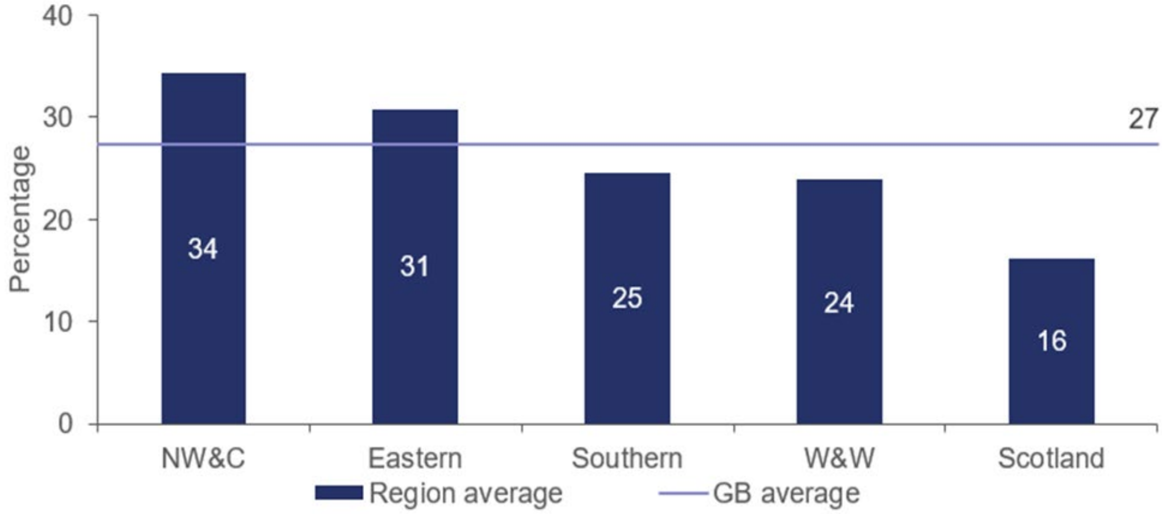
Figure 7: Average proportion of electrified track, 2013-14 to 2021-22



1.30 The network is classified into five criticality bands[7]. Figure 8 shows the proportion of track-km that is classified into either criticality band 1 or 2. We observe that according to our data, there is no clear correlation between this variable and the expenditure per track-km (as shown in Figure 5 above).

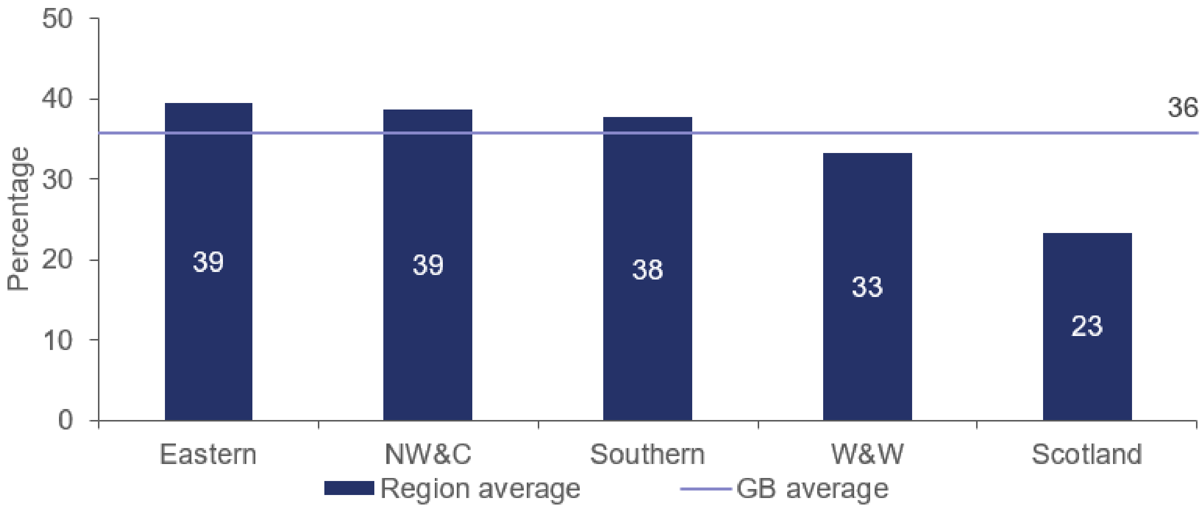
[7] Network Rail defines route criticality as a "measure of the consequence of the infrastructure failing to perform its intended function, based on the historic cost of train delay per incident caused by the track asset". Using this measure, each strategic route section (SRS) of the network has been 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.

Figure 8: Criticality 1 and 2 track-km as a proportion of total track-km, average 2013-14 to 2021-22



1.31 The network is also classified into seven track category bands[8]. Figure 9 shows the proportion of track-km that is classified into criticality bands 1A, 1 or 2. We observe that according to our data, there is no clear correlation between this variable and the expenditure per track-km (as shown in Figure 5 above)

Figure 9: Category 1A, 1 and 2 track-km as a proportion of total track-km, average 2013-14 to 2021-22



[8] Each track line is assigned a category from 1A to 6 based on a function related to its Equivalent Million Gross Tonnes per Annum (EMGTPA). The EMGTPA measures the annual tonnage carried over a section of track but takes into account variations in track damage caused by different types of rolling stock. Category 1A is the highest - 125mph or higher and Category 6 is the lowest – 20mph and below.

1.32 Our analysis aims to control for the effect of cost drivers including those described above on maintenance expenditure and average renewals unit cost across Network Rail's business units.

2. Maintenance

Introduction

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

2.1 Most maintenance activity on Network Rail's infrastructure is carried out by Maintenance Delivery Units (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.

2.2 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 67% of total network maintenance expenditure during the period covered by our analysis. The remaining 33% was centrally managed, covering activities such as structures examination, major items of maintenance plant and other HQ managed activities.

2.3 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 control period 4 (CP4) ten routes level is the level at which we conducted the analysis underpinning the regional comparisons. However, given the CP4 ten routes no longer match the current organisational structure of Network Rail, we have presented only the regional and MDUs comparisons in the main report, with the route comparisons made available in Annex A. The regional level analysis is more robust than the MDU-level analysis, but the MDU-analysis is more local and granular. Whilst the two types of analysis broadly agree in their conclusions, there are some differences which we discuss at the end of this chapter.

Route-level analysis

Introduction

2.4 In this part of the chapter, we describe our route-level analysis and results. This is for the ten routes that were introduced in CP4. At the start of control period 5 (CP5), the number of routes fell to eight as the result of a re-organisation. 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[9]. Apart from this year, Network Rail has continued to supply us with the data at the CP4 ten routes level, despite these changes. The reasons we have continued to base our statistical model on ten 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.

2.5 These route-level results are then aggregated and reported at regional level in order to be consistent with the current Network Rail's organisational structure. In future, we aim to base our model on regional level data as it becomes available and large enough to inform a robust statistical model. We successfully did this in our analysis that informed our PR23 advice to UK and Scottish governments. This was possible because we were able to increase the size of our dataset by combining historical data and forecast data. However, this was not possible for this report as the size of the dataset (covering only historical data) is still very small at regional level.

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

Route Analysis

Data

2.7 The analysis is based on data for financial years 2013-14 to 2021-22, recorded at the level of the ten routes that were introduced by Network Rail in CP4.

Dependent variable

2.8 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. In 2021-22, Network Rail provided us with the data at regional level only, as it no longer reports expenditure at route level. To be consistent with our historical data, we allocated this regional expenditure to the ten routes by giving to

[9] Annex B compares the CP4 ten-route organisational structure and the current CP6 14-route structure

each route the same proportion of expenditure as last year[10]. All expenditure data is inflation-adjusted to 2021-22 prices, using the Consumer Price Index (CPI).

Independent variables

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

2.10 During our discussions with regions after we published our year 2 of CP6 report, some of them suggested that we use track category as an explanatory variable in lieu of track criticality. In last year's analysis of maintenance expenditure we did not include either. This year, we tested both variables and decided to retain track category as it gave us more meaningful results.

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 is more complex and therefore requires more costly 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

[10] This has probably introduced some errors in the analysis but it was the best way forward available. We minimised the impact of this allocation by aggregating the route level results back to regions and then basing our conclusions on these regional results. We attempted to analyse the existing regional level data but this analysis did not provide reliable estimates as the dataset was too small.

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

[12] This model specification gives us similar results as when we use the absolute number of passenger and freight train-kms. We have chosen to retain this density variable for ease of comparison with last year's analysis.

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

Variable	Expected direction for relationship	Reason for relationship
		may also make it more difficult to undertake infrastructure work.
Average days per Possession (Number of possession days/number of possessions)[14]	Positive	More longer possessions of the network mean that Network Rail would be likely to spend more in terms of labour costs, materials, etc.
Average number of tracks (track-km/route-km)	Negative	Time windows for maintenance activities may be wider on multiple track sections of the network, which means the teams can do the work more efficiently. In addition, there may be relatively 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 (Network Rail's average wage in £ per year)	Positive	It is expected that maintenance expenditure will be higher in areas where maintenance work is done by staff on higher wages.
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.
Renewals expenditure (£m)	Positive	Undertaking additional work (frequently a different type of work) on the network at the same time may create for example additional pressure on supply chains, which may lead to increased costs.
Proportion of track category 1A, 1 and 2[15] (category 1A, category 1 & category 2/track-km)	Positive	A network with higher proportion of track in category 1A, 1 and 2 is 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 on such sections of the network (for

[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.

[15] See footnote 8 for the definition.

Variable	Expected direction for relationship	Reason for relationship
		example, due to higher train speeds and usage) and their access time window may be narrower. This effect may also be covered, in part, by the traffic variable.
Year	N/A	The purpose of this term is to separate out the common annual trend in maintenance expenditure 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 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. Given the pandemic was an event that significantly affected Network Rail's operations, especially during the year 2020-21, we use a dummy for year 2020-21 to isolate its impact.
Year-specific dummy variable (applies to 2021-22)	N/A	The purpose of this term is to separate out the common change in expenditure across routes due to the 2021-22 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.

Descriptive statistics

2.11 Table 2 below presents some summary statistics that describe the variables in our model:

Table 2: Summary of variables

Variable	Mean	Std. Dev.	Min	Max
Maintenance expenditure (£m)	149	88	55	427

Variable	Mean	Std. Dev.	Min	Max
Track-km (km)	3,109	1,707	1,124	6,917
Passenger traffic density (train-km/track-km)	17,669	5,870	6,588	31,999
Freight traffic density (train-km/track-km)	1,178	564	171	2,229
Switches and crossings density (number of S&C/track-km)	0.6	0.1	0.4	0.9
Average rainfall (mm)	85	29	41	150
Average days per possessions (number of possession days/ number of possessions)	0.2	0.1	0.0	1.1
Average number of tracks (track-km/route-km)	2.0	0.2	1.6	2.6
Average Wage levels (£/year)	35,333	1,728	31,317	3,9258
Proportion of electrified track (%)	48%	31%	0%	96%
Renewals expenditure (£m)	336	172	86	1,019
Proportion of track category 1A, 1 & 2 (%)	36%	12%	8%	54%

Model specification

2.12 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.

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

[16] A bold font means the variable is new relative to our year 2 of CP6 report.

$$\begin{aligned}\ln(cost) = \beta_0 \\ &+ \beta_1 \ln(track\ km) \\ &+ \beta_2 \ln(passenger\ traffic\ density) \\ &+ \beta_3 \ln(freight\ traffic\ density) \\ &+ \beta_4 \ln(switches\ \&\ crossings\ density) \\ &+ \beta_5 \ln(average\ rainfall) \\ &+ \beta_6 (average\ days\ per\ possessions\ ) \\ &+ \beta_7 \ln(average\ number\ of\ tracks) \\ &+ \beta_8 \ln(wage\ levels) \\ &+ \beta_9 (proportion\ of\ electrified\ track\ ) \\ &+ \boldsymbol{\beta_9 (proportion\ of\ track\ category\ 1A, 1\ \&\ 2)} \\ &+ \beta_{11} \ln(\boldsymbol{renewals\ expenditure}) + \beta_{12}(year) \\ &+ \beta_{13}(dummy_{2020-21}) + \beta_{14}(dummy_{2021-22}) + error\ term\end{aligned}$$

2.14 Relative to last year's report, we have made changes to our model to reflect feedback from Network Rail following publication of last year's report. These include controlling for the proportion of track category 1A,1 and 2 (i.e. (track category 1A + category 1 + category 2)/track-km) as an additional cost driver. Moreover, we have now modified the way we measure the possession duration. Instead of calculating it as number of possession days/ track-km we now calculate it as number of possession days/number of possessions. Network Rail consider this to be a better measure of average possession duration as it also reflects efficiency in each possession. This is because the number of possession days/ track-km effectively only measures the volume of work carried out whilst the number of possession days/number of possessions reflects both the volume of work and that shorter possessions are less efficient as the amount of actual working time between setting up and handing back is squeezed.

2.15 Another improvement comes from the way we have measured wage levels. In our previous reports, we used weekly wages data from the ONS, which we collected by mapping local authorities to Network Rail's MDUs and then aggregating it at route level. This data was used as a proxy for Network Rail's wage levels but in reality, the data only reflected the level of wages (in general) in each MDU's geographical area of operation rather than the actual wages paid by Network Rail. In this year's analysis at route level, we have used Network Rail's specific maintenance average wage data. However, whilst this constitutes an improvement, 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.

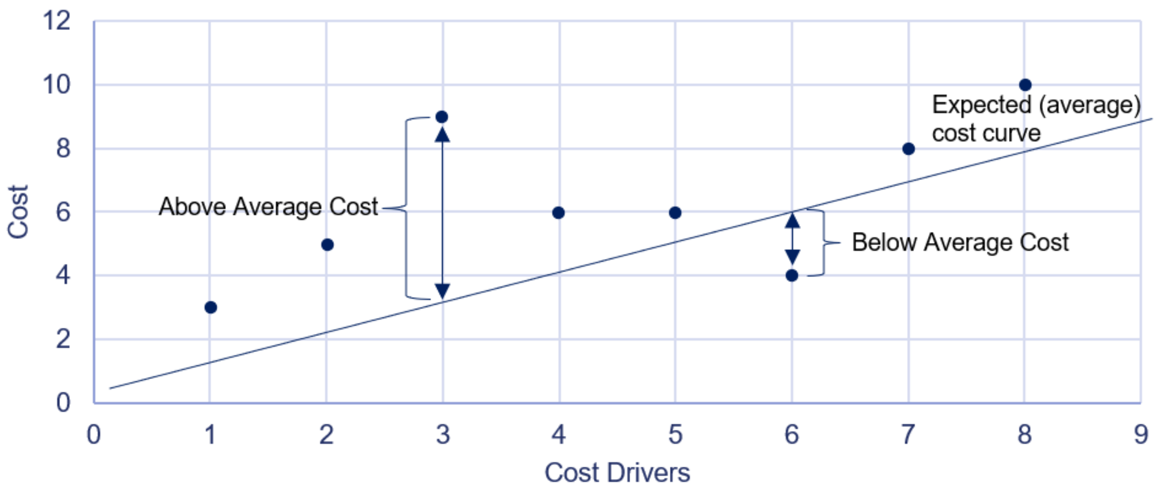
Estimation approach

2.16 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.

2.17 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 the business unit's performance relative to the average of the peer group, after controlling for differences in relevant cost drivers[18].

2.18 This is illustrated in Figure 10 below. Observations above the line imply that the business unit in question spent more than expected, while those observations below the line mean that the business unit spent less than expected. The larger the distance between the individual observation and the line (i.e. the residual) the more important it is to find out 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.

Figure 10: Theoretical OLS regression line and cost performance (for illustration only)



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

[18] See our previous reports for more details on how this is done.

Model estimates

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

Table 3: OLS coefficient estimates results for maintenance expenditure model

Variable	Coefficient
Track-km	0.83***
Passenger traffic density	0.36**
Freight traffic density	0.11***
Switches and crossings density	0.53***
Average rainfall	-0.04
Average days per possession	0.03***
Average number of tracks	-0.25
Average wage levels	0.67
Proportion of electrified track	0.06
Proportion of track category 1A, 1 & 2	0.09
Renewals expenditure	0.09
Year (average annual unexplained growth rate in maintenance expenditure)	0.06***
Dummy for 2020-21 (deviation from the annual growth rate due to COVID-19)	-0.10
Dummy for 2021-22 (deviation from annual growth specific to the year 2021-22)	-0.27***
Constant[19]	-13*
Number of observations	90
R^2	0.96

[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.

Variable	Coefficient
	*** Statistically significant at the 99% confidence level[20] ** Statistically significant at the 95% confidence level * Statistically significant at the 90% confidence level

2.20 Table 3 above shows that there is a statistically significant relationship (at the 95% 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); the average days per possession; and the density of switches and crossings.

2.21 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 expenditure 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 expenditure across routes and over time, which suggests that the model is a very good predictor of outturn maintenance expenditure.

2.22 Our results suggest no clear relationship between maintenance expenditure and: average rainfall, average number of tracks, average wage levels, proportion of electrified track, track category or renewals 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. Issues such as measurement errors, correlation between other variables already in the model might be behind this lack of statistical significance.

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

(a) increasing track length by 1%, is associated with 0.36%[21] higher maintenance expenditure. This suggests that there are economies of scale in

[20] Technically, statistical significance (as produced by the model and 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/magnitude 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.

[21] We calculate this as the difference between the track-km coefficient and the sum of the traffic density coefficients [0.83 - (0.36 + 0.11)] = 0.36. 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

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 0.36%; also, an independent 1% increase in freight traffic increases maintenance expenditure by 0.11%. These results show economies of density – costs increase less than proportionally with traffic;

(c) increasing the density of switches and crossings by 1% increases maintenance expenditure by 0.53%. It is likely that this variable is picking up the effect of network complexity more generally; and

(d) 10% longer network possessions are associated with 0.3% higher maintenance expenditure.

2.24 Our analysis suggests that there has been an average annual increase in maintenance expenditure of 6%[22] per year (in real terms) since 2013-14, after normalising for factors such as traffic and network complexity. This may be due to inefficiency, or other factors. This long-run trend of maintenance expenditure rising has reduced from the last two years (from 9% in 2019-20 and 8% in 2020-21) but it is not clear if this reflects actual cost changes (e.g. inefficiency) or other factors, such as a change in the accounting of maintenance expenditure in the years from 2019-20, as mentioned in chapter 1.

2.25 Note that the main purpose of the present work is to compare maintenance expenditure across business units in the most recent year, whilst controlling for differences in observable cost drivers, rather than to measure business units against an external efficiency benchmark or to examine performance changes over time. We therefore do not have a 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 sets out our expectations for Network Rail's efficiency improvement over CP6.

Regional benchmarking results

2.26 The present analysis compares outturn maintenance expenditure against expected spend as predicted by our model, given each region's characteristics. As mentioned earlier, whilst the underlying analysis was conducted using route level

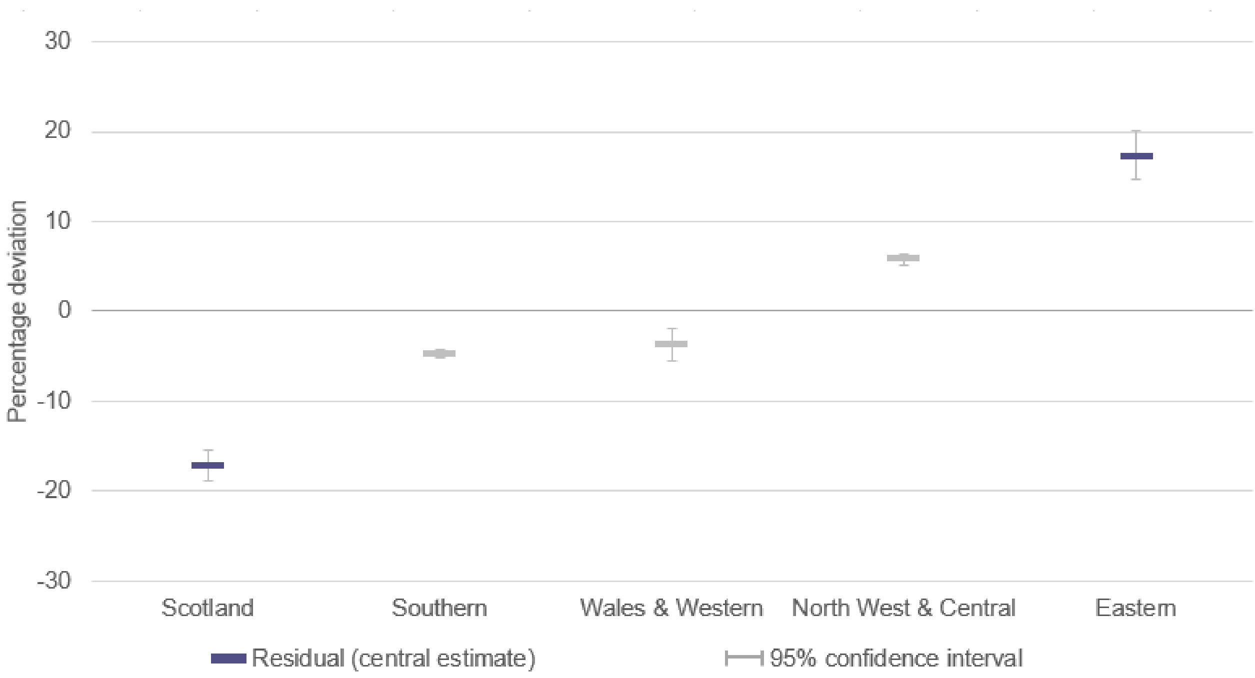
elasticity of maintenance expenditure with respect to track-kms equals the coefficient on track-kms minus the sum of the coefficients on the traffic density variables.

[22] Calculated as $(e^{0.06} - 1)$.

data, we have aggregated our route level results to the regional level and that is what we present in this section[23]. We order the regions according to the amount of unexplained variation (i.e. the difference between outturn and predicted expenditure).

2.27 Figure 11 below shows, for each region, the proportion of unexplained cost variance in 2021-22. A negative number means that the region spent less than expected (according to our statistical model) while a positive number means that the region spent more than expected (according to our statistical model).

Figure 11: Deviation between outturn and expected (modelled) maintenance expenditure, 2021-22- Regional comparisons[24]



[23] This allows the interpretation of these findings to be consistent with Network Rail's current organisational structure as reflected in the five regions. However, the routes comparisons are available in Annex A.

[24] Given the uncertainty associated with any statistical model, we consider any region that is within +/−10% of our modelled prediction (as shown by the x-axis at zero) is not an 'outlier'. These regions are marked grey. Regions that are marked blue are considered 'outliers'. The lines surrounding the central estimate of a given region'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 number representing the deviation between outturn and modelled cost.

2.28 The figure shows that maintenance expenditure at the regional level, was between -17% and +17% of that predicted by our model for 2021-22. Similar to last year, **Scotland** and **Eastern** are the largest outliers.

2.29 The **Eastern** region's actual maintenance expenditure was 17% above the model's prediction. Last year it was 12% above 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. We will work with Network Rail to better understand this issue.

2.30 Furthermore, it is not clear why **Scotland**'s maintenance expenditure continues to be below the model prediction compared to other regions (-17% in 2021-22 from -18% in 2020-21). Network Rail Scotland said the variance may be explained by improved co-ordination in the planning and delivery of maintenance and renewals, though it is unclear to what extent Network Rail Scotland did this better than other regions, to the point where it can justify this unexplained difference. We will continue to work with Network Rail to better understand this issue.

2.31 In last year's analysis, **Wales & Western** appeared to spend c.4% on maintenance more than our model's prediction. This year, the region appears to have spent 3% less than our model's prediction. The region stated that this is the outcome of the work they have undertaken to reduce costs. For example, the region said that it successfully delivered £26.2m opex efficiencies and continues to exercise robust cost control. The Wales & Western region also re-aligned the accounting classification of some minor maintenance works expenditure to be consistent with practice in other regions. According to the region, this also resulted in reduced maintenance expenditure.

2.32 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).

2.33 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

2.34 Maintenance Delivery Units (MDUs) are operating units within Network Rail's routes (each route is part of a region), responsible for the majority of the day-to-day upkeep of their designated part of the network. They ensure that the infrastructure (ranging from signals and power supplies to track and structures) is in good working order. MDUs are not responsible for renewals, so we only cover MDU maintenance expenditure.

2.35 Network Rail previously reduced the number of MDUs from 37 to 35. Woking closed in 2017-18 with activities previously undertaken by Woking moved to Clapham and Eastleigh, which then became Wessex Inner and Wessex Outer from 2018-19. Similarly, in 2019-20, Bristol, Plymouth, Reading and Swindon MDUs were restructured into Western Central, Western East and Western West.

2.36 To maintain comparability with historical data, we have previously analysed maintenance expenditure using the 37 MDU structure. However, we have always sought to analyse the MDUs in their actual structure, as far as the data can be accurately reported at that structure. This year we have undertaken the analysis for 36 MDUs as we have been able to re-allocate data from Woking, Eastleigh and Clapham to Wessex Inner and Wessex Outer, as explained below in paragraph 2.48. We have not been able to do the same for Western Central, Western East and Western West, so we continue to use the Bristol, Plymouth, Reading and Swindon MDU structure instead. Annex C maps the 36 MDUs to Network Rail's CP4 ten route structure (used in our route benchmarking analysis)[25] and to the five regions.

2.37 On average, MDUs accounted for around 67% of total network maintenance expenditure during the 8 years covered by this analysis. The remaining 33% is centrally-managed and it covers activities such as structure examination, major items of maintenance plants and other HQ managed activities.

2.38 This part of the chapter is organised as follows: we first compare the 36 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

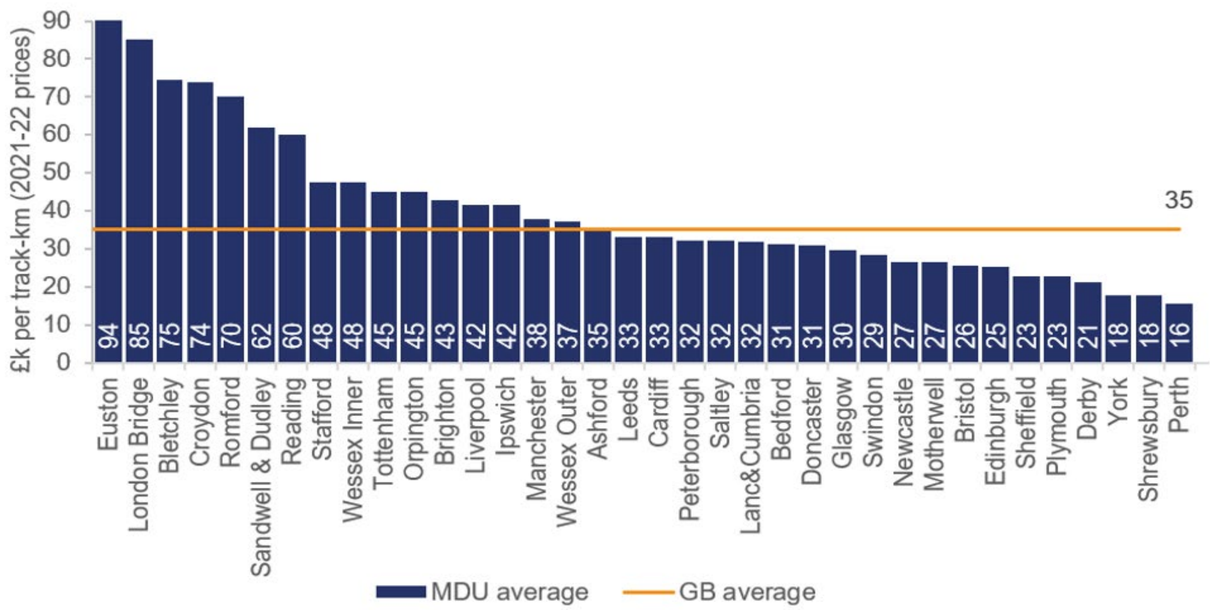
[25] Using the former geographical boundaries of the CP4 ten routes, we can localise each MDU within that structure.

findings with those from our regional level analysis (in the 'MDU Benchmarking results' section).

MDU context

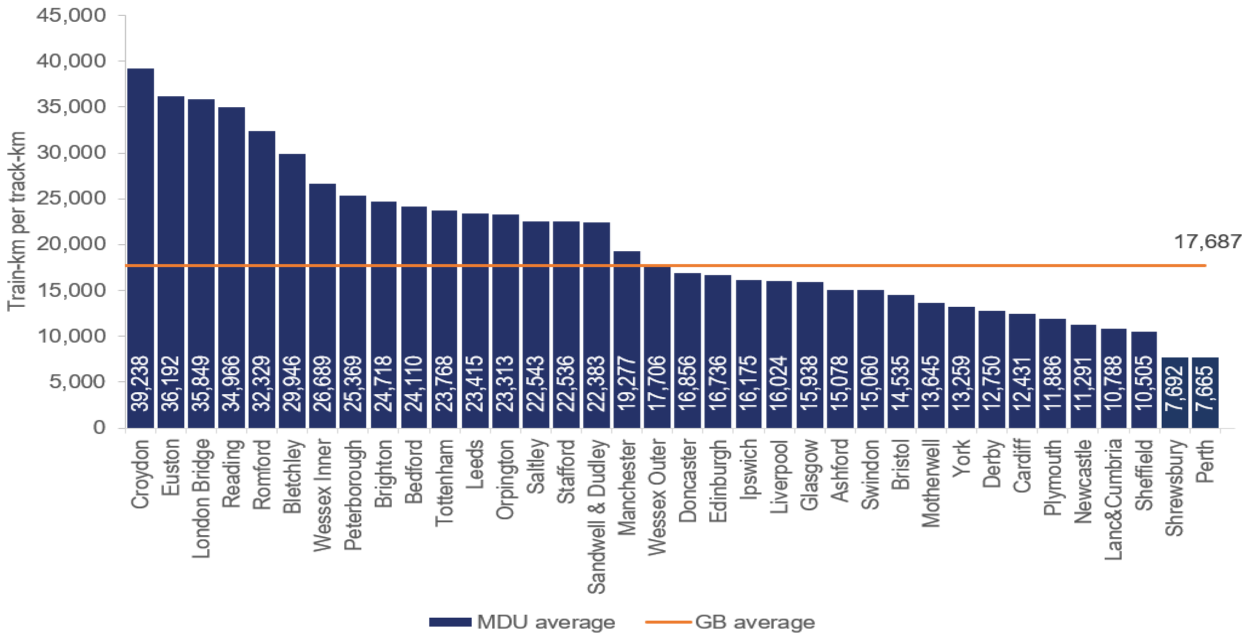
2.39 **Maintenance expenditure**: Figure 12 below shows that MDUs spent, on average, c. £35k per track-km each year. Euston spent the most, at £94k per track-km, whilst Perth spent the lowest amount, at £16k per track-km.

Figure 12: Average maintenance expenditure per track-km, 2014-15 to 2021-22 (2021-22 prices)



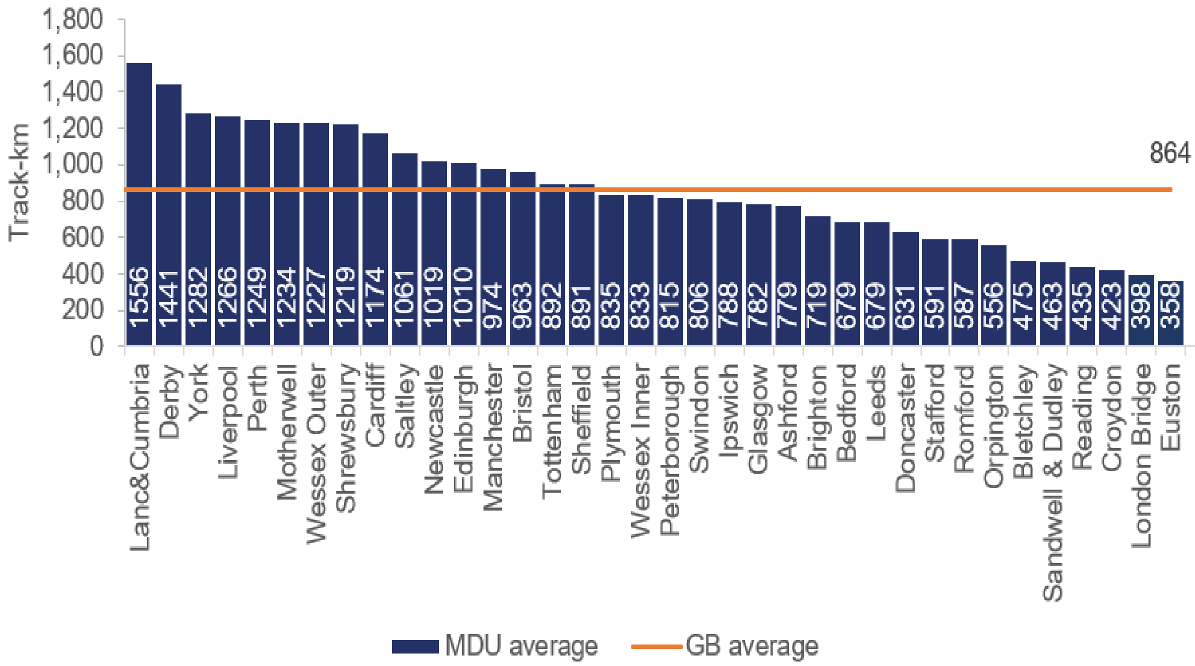
2.40 **Traffic Density:** Figure 13 below shows that traffic density (passenger and freight traffic per track-km) varied widely across MDUs. Croydon carried 39,238 train-km per track-km, on average, per year. On the other hand, Perth carried 7,665 train-km per track-km per year. The average GB-wide track density was 17,687 train-km per track-km.

Figure 13: Average traffic density (train-km/track-km), 2014-15 to 2021-22



2.41 **Network size (track-km):** as shown in Figure 14 below, Lancashire & Cumbria (Lancs & Cumbria) is responsible for the longest section of network with 1,556 track-km, whilst Euston maintains the shortest with 358 track-km. The average length of track covered by an MDU over the period 2014-15 to 2021-22 is 864 track-km.

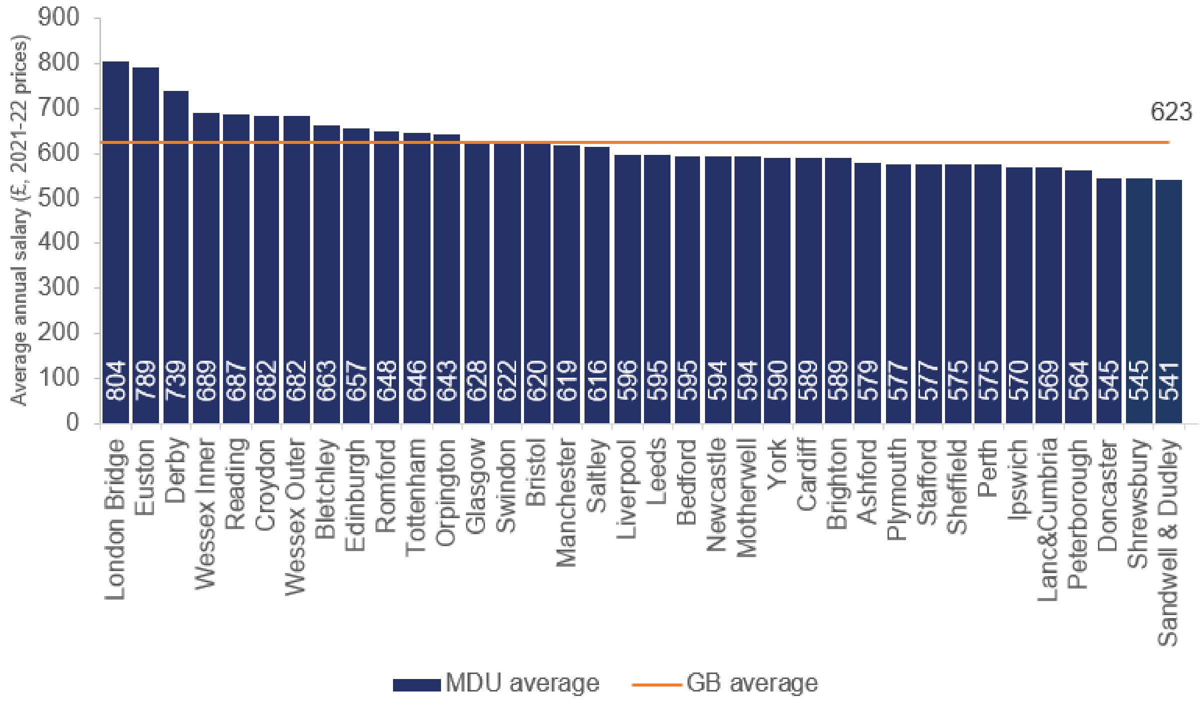
Figure 14: Average track-km, 2014-15 to 2021-22



2.42 **Wage levels:** As per last year's analysis, we have used median wages across the local authority areas covered by each MDU[26]. Figure 15 below compares this wage for each MDU. The average median weekly wage across all MDUs between 2014-15 and 2021-22 was £623 per week.

2.43 Average median weekly wages were highest in the local authority that covers London Bridge at £804. In contrast, Sandwell & Dudley had the lowest average median weekly wage at £541, followed closely by Shrewsbury at £545.

Figure 15: Average median weekly wages, 2014-15 to 2021-22 (2021-22 prices)



2.44 **Average length of possessions (number of possession hours/number of possessions):** As shown in Figure 16 below, Liverpool has the longest length of possessions at 14.1 hours per possession, whilst Reading has the shortest at 2.9 hours per possession. The average length of possessions for an MDU over the period 2014-15 to 2021-22 is 5.7 hours[27].

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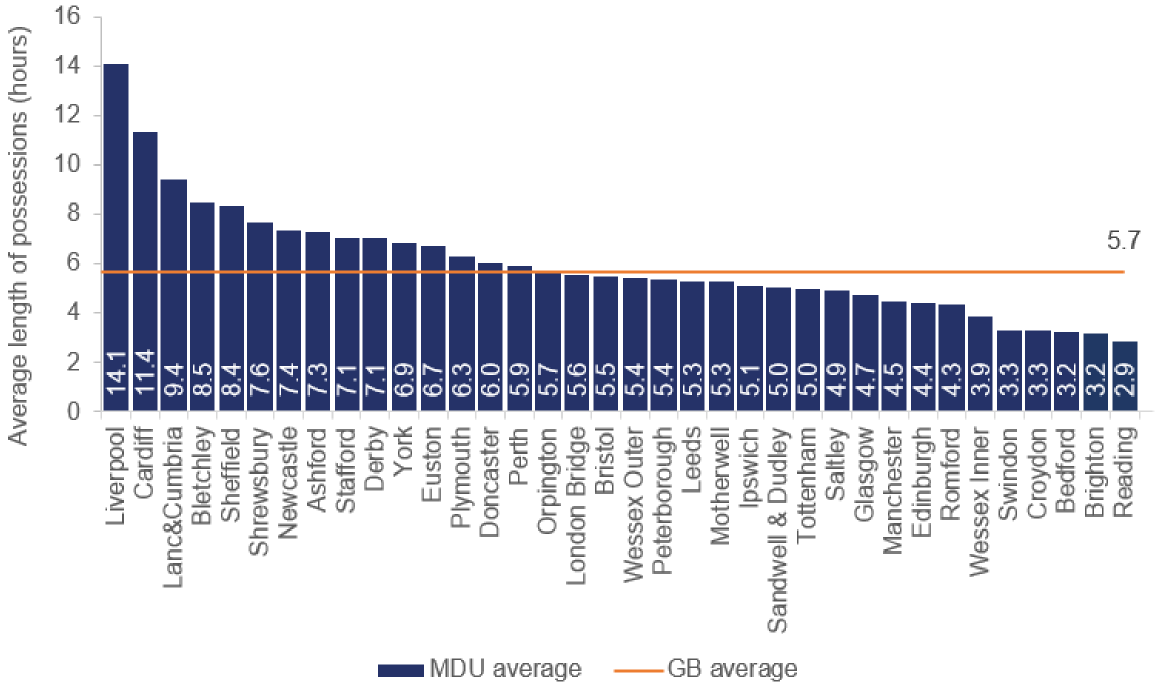
[26] Data is sourced from the Office for National statistics (ONS) on weekly earnings by local authority. We matched these local authorities with each of the 36 MDUs geographical area of operation. Note that this weekly wages data is not Network Rail specific. It simply reflects the level of wages in each geographical area covered by MDUs.

[27] In the analysis we used number of days/number of possessions, which is the same variable we use in the route analysis. However, to facilitate a better visual comparison of MDUs in this figure, we chose to show the

Figure 16: Average length of possessions hours, 2014-15 to 2021-22



2.45 **Average number of tracks (track-km/route-km)** across all MDUs in 2021-22 was 1.97. Bedford had the highest average number of tracks at 3.30, followed by Euston and Peterborough at 3.22 and 3.18, respectively. Perth MDU had the lowest average number of tracks at 1.34, followed by Glasgow at 1.49.

2.46 **Average electrification** across all MDUs was 43% between 2014-15 and 2021-22. Shrewsbury had no electrified sections, followed by Derby, Perth, Sheffield, Plymouth, Bristol, Cardiff, and Saltley, all with negligible proportions of electrified track (<10%). On the other hand, Croydon was almost fully electrified, followed by Euston, Orpington, London Bridge, Peterborough, and Romford, all with above 95% of track electrified.

2.47 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 2021-22 is Reading at 94%, followed by London Bridge at 93%. Shrewsbury, Perth, and Sheffield have none of their track length in criticality bands 1 & 2.

variable as the number of hours/ number of possessions, as it has larger numbers, whose representative bars are easier to compare in a figure like this one.

MDU Analysis

Data

2.48 We have previously analysed maintenance expenditure using the 37 MDUs structure. From 2017-18, Network Rail reported Wessex MDUs as Wessex Inner and Wessex Outer in lieu of Woking, Eastleigh and Clapham. This reduced the MDUs from 37 to 36. This year, the analysis is based on data for Network Rail's 36 MDUs for financial years 2014-15 to 2021-22. To move from the 37 to the 36 MDUs structure, we re-allocated data from Woking, Eastleigh and Clapham to Wessex Inner and Wessex Outer. For 2017-18 to 2021-22, we calculated the expenditure for Wessex Inner and Wessex Outer separately as a proportion of the total expenditure for Wessex Inner and Wessex Outer, and then applied those proportions to the total for Woking, Eastleigh and Clapham for the years 2014-15 to 2016-2017[28].

2.49 This analysis builds on the model employed in our year 2 of CP6 report (2020-21), using mostly the same variables but with the addition of another year's worth of data, and two new variables: average possessions length and average rainfall. Note that average rainfall is calculated at route level and is assigned to MDUs within that route.

2.50 Last year, Network Rail was unable to supply passenger and freight traffic data at the MDU-level due to a data recording hiatus, whilst it transferred between systems. We 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 issue has been resolved and Network Rail was able to provide us with actual passenger and freight traffic data at the MDU-level for the year 2021-22[29]. This improved our results as our model has consistently shown that traffic is one of the main drivers of maintenance expenditure.

Dependent variable

2.51 The dependent variable is maintenance expenditure, allocated to the MDU level. This excludes centrally managed expenditure (covering activities such as

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[28] This probably introduced some errors in the analysis, but it was the only way forward as we try to report our analysis in a structure that matches Network Rail's current structure. Since the allocation is done for the years that are the 3 oldest in our analysis (out of the total of 8 years), this may not have a significant impact on our comparisons for the latest year.

[29] Network Rail was not able to provide us with the passenger and freight traffic data for 2020-21. This means that for 2020-21, we continued to use the same data we calculated for last year.

structures examination, major items of maintenance plant and other HQ managed activities).

2.52 In 2020-21, there was a significant drop in traffic due to the impact of the pandemic. This was accompanied by a 5% increase in maintenance expenditure at the MDU level from 2019-20, as social distancing, reduced staff availability and supply chain pressures, among other factors, made it more difficult and costly to carry out work on the infrastructure. In 2021-22, maintenance expenditure at the MDU level has returned to pre pandemic levels.

Independent variables

2.53 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	Time windows for maintenance activities may be wider on multiple track sections of the network, which means the teams can do the work more efficiently. In addition, there may be relatively 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.

Variable	Expected direction of relationship	Reason for relationship
Switches and crossings (S&C) density (number of S&C/track-km)	Positive	A network with more switches and crossings per track-km is more complex and therefore requires more costly maintenance.
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.
Wage levels (£ per week)[30]	Positive	Maintenance work in each MDU is carried out largely by a local labour force. It is expected that maintenance work 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.
Average days per Possession (Number of possession days/number of possessions)	Positive	More longer possessions of the network mean that Network Rail would be likely to spend more in terms of labour, materials costs, etc.
Average rainfall (mm per year)	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

[30] ONS seasonally adjusted median average weekly earnings (AWE) per local authority. We obtained the data by mapping local authorities to Network Rail's MDUs. We adjusted these weekly wages data for inflation and they represent real median earnings. 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 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 of relationship	Reason for relationship
		make it more difficult to undertake infrastructure work.
Year	N/A	The purpose of this term is to separate out the common annual trend in maintenance expenditure 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 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. Given the pandemic was an event that significantly affected Network Rail's operations, especially during the year 2020-21, we use a dummy for year 2020-21 to isolate its impact.
Year-specific dummy variable (applies to 2021-22)	N/A	The purpose of this term is to separate out the common change in expenditure across MDUs due to the 2021-22 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.

Descriptive statistics

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

Table 5: Summary of variables (all monetary variables in 2021/22 prices)

Variable	Mean	Std. Dev.	Min	Max
Maintenance expenditure (£m)	30	9	16	60
Track-km (km)	864	319	353	1623
Passenger train-km (million train-km)	14.1	4.3	5.9	25.2
Freight train-km (million train-km)	1.2	0.7	0.1	3.7
Average number of tracks	2.1	0.5	1.3	3.3
Proportion of electrified track (%)	51%	35%	0%	100%
Switches and crossings density (S&C per track-km)	0.7	0.3	0.3	1.5
Criticality 1 & 2 density (%)	33%	28%	0%	98%
Wage levels (£/week)	622	65	520	846
Average days per Possession (days)	0.3	0.2	0.0	1.7
Average Rainfall (mm per year)	87	28	41	150

Model specification

2.55 We have adopted the same functional form as in the route analysis: 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.

2.56 We have estimated a number of variants of the following model but settled on the following specification[31]:

[31] A bold font means the variable is new relative to our year 2 of CP6 report.

$$
\begin{aligned}
\ln(maintenance\ cost) \\
&= \beta_0 \\
&+ \beta_1 \ln(track\ km) \\
&+ \beta_2 \ln(passenger\ train\ km) \\
&+ \beta_3 \ln(freight\ train\ km) \\
&+ \beta_4 \ln(switches\ \&\ crossings\ density) \\
&+ \beta_5 (proportion\ of\ electrified\ track) \\
&+ \beta_6 (proportion\ of\ track\ criticality\ 1\&2) \\
&+ \beta_7 \ln(average\ number\ of\ tracks) \\
&+ \boldsymbol{\beta_8} \mathbf{\ln}(\boldsymbol{average\ days\ per\ possession}) \\
&+ \ \beta_9 \ln(wage\ levels) + \boldsymbol{\beta_{10}} \mathbf{\ln}(\boldsymbol{average\ rainfall}) + \ \beta_{11}(Year\ ) \\
&+ \beta_{12}(dummy_{2020-21}) + \ \beta_{13}(dummy_{2021-22}) + \ error\ term
\end{aligned}
$$

2.57 We have made changes to our model in previous reports to reflect feedback from Network Rail. These include controlling for rainfall and average days per possessions as additional cost drivers in the MDU model. This, alongside the increased size of the dataset, has improved the robustness of our results.

2.58 In its feedback last year, some of Network Rail's regions suggested that we use track category instead of track criticality, as they considered track category to be a better driver of maintenance expenditure than track criticality. We have tested this hypothesis in this model, however the coefficient for track category came up with a negative sign which is counterintuitive. We therefore decided to keep track criticality in our model as in previous reports.

2.59 In this part of the chapter, we have continued to use the weekly wage data from the ONS instead of Network Rail's average annual wage data that we used in the routes' analysis section. Although we received this data at MDU level and aggregated it at route level, the analysis showed that this data produces more meaningful results at route level than at MDU level. We consider that one possible reason for this is because the disaggregated data at MDU level does not account for hosting: when an MDU performs work on behalf of other MDUs (usually within the same route/region), the wage paid to the staff doing the work is paid by the hosting MDU. This has the implication of inflating the cost of wages for the hosting MDU whilst reducing it for the MDUs where the work is located. Therefore, given that hosting is a widespread practice within Network Rail, this could explain why using Network Rail's average annual wage data at MDU level leads to counterintuitive estimates. As we aggregate the data to route /region level, the impact of hosting is smoothed out. On the other hand, the ONS data is used here as a proxy for the level of wages in each MDUs' geographical area rather than Network Rail's actual wage levels. This is not affected by hosting or any other issues in data recording by Network Rail.

Estimation approach

2.60 Similar to last year's analysis, 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.

2.61 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 MDUs' performance relative to the average of the peer group, after controlling for differences in relevant cost drivers.

Model estimates

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

Table 6: OLS estimated results

Variable	Coefficient
Track-km	0.28***
Passenger train-km	0.36***
Freight train-km	0.15***
Average number of tracks	−0.48***
Proportion of electrified track	0.46***
Switches and crossings density	0.25***
Criticality 1 & 2 density	0.10
Wage levels (median weekly wage)	0.51***
Average days per possession	0.08***
Average rainfall	0.11***

Variable	Coefficient
Year	0.02***
Dummy for 2020-21	0.18***
Dummy for 2021-22	0.09*
Constant	−10.04***
Number of observations	285
R^2	0.67

***statistically significant at the 99% confidence level
** statistically significant at the 95% confidence level
* statistically significant at the 90% confidence level

2.63 The results show a statistically significant relationship between the amount that an MDU spends on maintenance and: the level of traffic (both passenger and freight), network complexity (measured by the average number of tracks, electrification and S&C density), the level of wages in the local authority covered by that particular MDU, the size of the network (track-km), the average rainfall and the average length of possessions. 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.

2.64 Similar to last year, the analysis also shows that there has been an average annual increase in maintenance expenditure of 2.0%[32] per year (in real terms) over the period covered by our sample, which cannot be explained by changes in network size, traffic or other observable factors. Also, after accounting for observable differences between MDUs, maintenance expenditure in 2021-22 appears to be 9.0%[33] above this historical/background trend. This may be due to inefficiency, headwinds (cost increases outside of Network Rail's control), or some other factors.

2.65 The model's R^2 is 0.67. R^2 is a measure of goodness-of-fit. It represents the proportion of the variance in maintenance expenditure that can be statistically explained by the independent variables in the model. This means that our model can explain 67% of the variance in maintenance expenditure across MDUs and over time. This is an improvement as compared to our model last year which had an R^2 of 0.61. This improvement comes from the use of a bigger dataset, the

[32] Calculated as $(e^{0.02} - 1)$.

[33] Calculated as$(e^{0.09} - 1)$.

inclusion of the new explanatory variables as well as the better measurement of traffic data as discussed above.

2.66 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 expenditure by 0.28%. 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 expenditure by 0.36%. The same independent 1% increase in freight traffic would increase costs by 0.15%[34]. These results show economies of density – costs increase less than proportionally with traffic;

(c) increasing the proportion of electrified track by 1% would increase maintenance expenditure by 0.46%. That is, if an MDU went from 50% to full electrification, our model indicates that its maintenance expenditure would be 38% higher[35];

(d) increasing the density of switches and crossings by 1% increases maintenance expenditure by 0.25%;

(e) a 1% difference in local wages is associated with a 0.51% difference in maintenance expenditure;

(f) maintaining a given length of track as a single-track route is expected to cost 39% more than maintaining the same length of track as a double-track route[36];

(g) 10% longer network possessions are associated with 0.8% higher maintenance expenditure; and

(h) 10% higher rainfall is associated with 1.1% higher maintenance expenditure.

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[34] 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.

[35] The percentage increase is calculated as $[(1^{0.46}/0.5^{0.46})-1]=0.38$

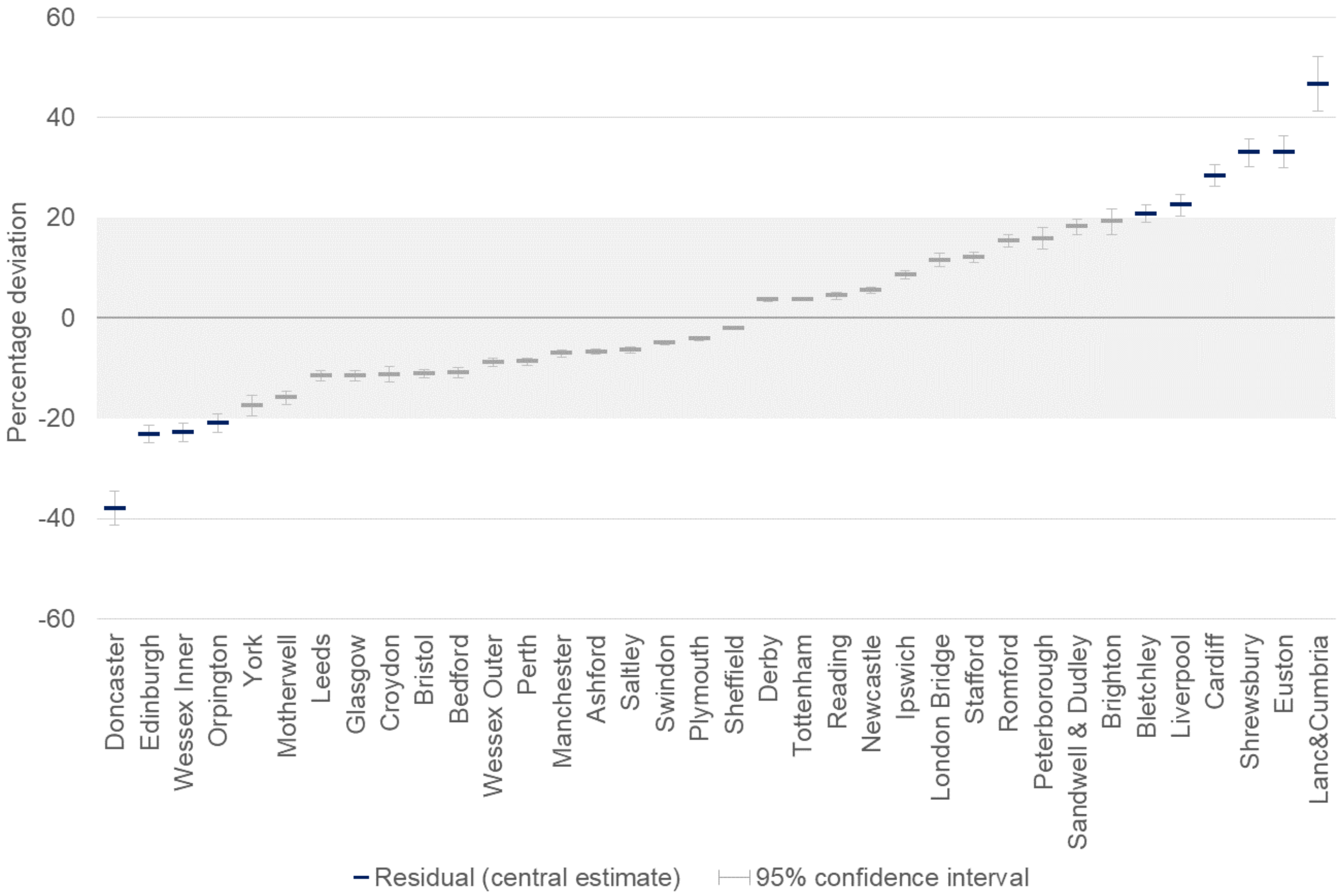
[36] The percentage difference is calculated as $[(1/0.72)-1]=0.39$. Note that one km of double-tracked route counts as two track-km. The cost of maintaining a one km line as single-track is therefore $1^{0.28}\times 1^{-0.48}=1$, whereas the cost of maintaining a one km line as double-track is $1^{0.28}\times 2^{-0.48}=0.72$. This indicates that it is cheaper to run the same length of line as a double-tracked network.

MDU benchmarking results

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

2.68 Figure 17 below shows the proportion of unexplained cost variance for each MDU in 2021-22. 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.

Figure 17: Deviation between outturn and expected (modelled) maintenance expenditure, 2021-22[37]



[37] 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) is not an 'outlier'. These MDUs are marked grey. MDUs that are marked blue are therefore considered 'outliers'. The lines surrounding the central estimate of a given MDU'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 number representing the deviation between outturn and modelled cost.

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

(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.

2.70 The analysis shows that, in 2021-22, the **Doncaster, Edinburgh, Wessex Inner and Orpington** MDUs are in the first category (<-20%). **Lancashire & Cumbria**, **Euston**, **Shrewsbury**, **Cardiff**, **Liverpool** and **Bletchley** are in the second category (>+20%). At the extremes, **Doncaster** spent 38% less than predicted by our model whereas **Lancashire & Cumbria** spent 47% above our model's prediction. The ordering of MDUs is broadly similar to that generated from last year's analysis. However, the range of unexplained differences in 2021-22 (i.e. -38% to +47%) is narrower than that implied in last year's analysis (-55% to +39%). This is an indication of an improvement in our model due to a larger dataset and the inclusion of the new explanatory variables.

2.71 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. One general explanation that the regions provided was "hosting". This involves one MDU undertaking maintenance activities on some infrastructure (e.g. overhead line) on behalf of other MDU(s) but the costs continue to be paid by the hosting MDU and are not charged to the MDU where the asset is located. The regions stated that this type of hosting arrangement is common and may therefore help to explain some of the outliers.

2.72 Similar to last year, **Shrewsbury** and **Cardiff** (both in the Wales route and Wales & Western region) are both towards the more costly end of the distribution. The Wales & Western region explained that such a big positive difference between outturn and predicted expenditure could be due to the geographical spread of the MDUs and the age of their infrastructure relative to other MDUs.

2.73 Out of the six most costly MDUs as compared to our model's prediction, four (i.e. **Lancashire & Cumbria, Euston, Liverpool and Bletchley**) are in the North West & Central region. The region has pointed out that the Lancashire & Cumbria and Liverpool MDUs are some of the most geographically dispersed MDUs, with a number of satellite units delivering work in more remote areas. In particular, according to the region, Lancashire & Cumbria covers some difficult to access rural areas and includes older infrastructure alongside a section of the West Coast Main Line (WCML). The region 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.

2.74 In addition, the North West & Central region has explained that some of these MDUs cover a network with increased maintenance requirements due to additional traffic carrying HS2 materials. For Euston, the region mentioned that the unexplained difference may be a result of increased line blockage working, due to track worker safety requirements (leading to an increase in non-time on tools) this is particularly significant for WCML access.

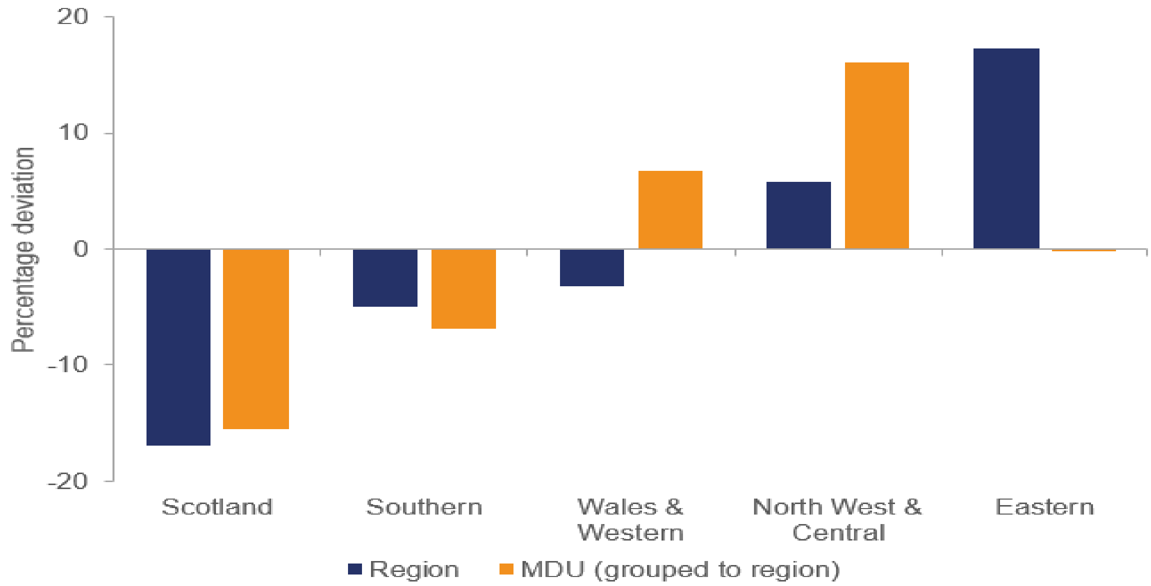
2.75 All the MDUs in Scotland seem to spend less than our model's prediction, which is in line with the regional results.

Consistency between regional and MDU results

2.76 In Figure 18 below, we compare the regional level results to those implied by the MDU analysis. To do this, we map MDUs to regions, and then sum outturn and expected (modelled) cost from the MDU data/model up to region level.

2.77 Note that we do expect some differences in the regional and MDU level results as the two models are different in terms of the costs modelled and the cost drivers controlled for. As described earlier, all MDUs accounted for around 67% of regional maintenance expenditure during the period covered by our analysis, with the remaining 33% centrally managed and covering activities such as structures examination, major items of maintenance plant and other HQ managed activities. However, this comparison helps us to draw out some insights regarding the robustness of the two analyses, by looking at whether the results for individual business units point in the same direction and by comparing the scale of unexplained differences.

Figure 18: Comparison of region and MDU deviations from expected (modelled) maintenance expenditure, 2021-22



2.78 Figure 18 shows that the results at both MDU and regional level for Scotland, Southern and North West & Central point in the same direction, with a relatively small difference in the scale.

2.79 Although results for Wales & Western also point to opposite directions with a relatively sizeable difference in scale, the MDU results are comparable with route level results whereby the Wales route (and all its MDUs) appears to have spent more than our model's prediction whilst the Western route (and all its MDUs) spent less than our model's prediction. The results for Eastern have the largest difference in scale.

3. Renewals

Introduction

3.0 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.

3.1 In PR08, PR13 and PR18, we modelled maintenance and renewals expenditure together. The potential advantages of this 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.

3.2 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.

3.3 Therefore, in our year 1 of CP6 report, we estimated separate models for maintenance and renewals. Whilst this change greatly improved our modelling of maintenance expenditure, it also highlighted that our approach to the modelling of renewals needed further improvement. Notably, the 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.

3.4 In last year’s analysis (year 2 of CP6), we addressed those shortcomings by comparing renewals unit costs (in simple terms, expenditure divided by work volume) and did this separately by main asset class and for different types of renewals activity.

3.5 We have followed the same approach for this year’s analysis as it allows for 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.

3.6 We have analysed the average unit costs (expenditure divided by work volume) separately by main asset classes (Track, Signalling, Civils and Buildings) and for different types of renewals activity. Whilst part of this analysis is discussed in the

"Context" section of this chapter, we are only publishing our detailed analysis on conventional track renewals as this compares better with last year's analysis.

3.7 This chapter describes the statistical model we have estimated to explain conventional track renewals unit costs at a route level as a function of key cost drivers. These results are then aggregated at regional level. Unlike in our maintenance expenditure analysis, where Network Rail provided us with data only at regional level, Network Rail was able to supply us with renewals data at the level of the existing 14 routes. To adjust this data to the level of the ten CP4 routes, we aggregated the East Coast and North & Eastern routes into the LNE route and we aggregated the Central, North West and West Coast Mainline South into the LNW route. All other routes stayed the same.

3.8 Although we conducted our analysis at the level of the CP4 ten routes, we present only the regional comparisons in the main report, with the routes comparisons made available in Annex A. This allows us to be consistent with Network Rail's current organisational structure, as Network Rail is currently regulated at a regional level.

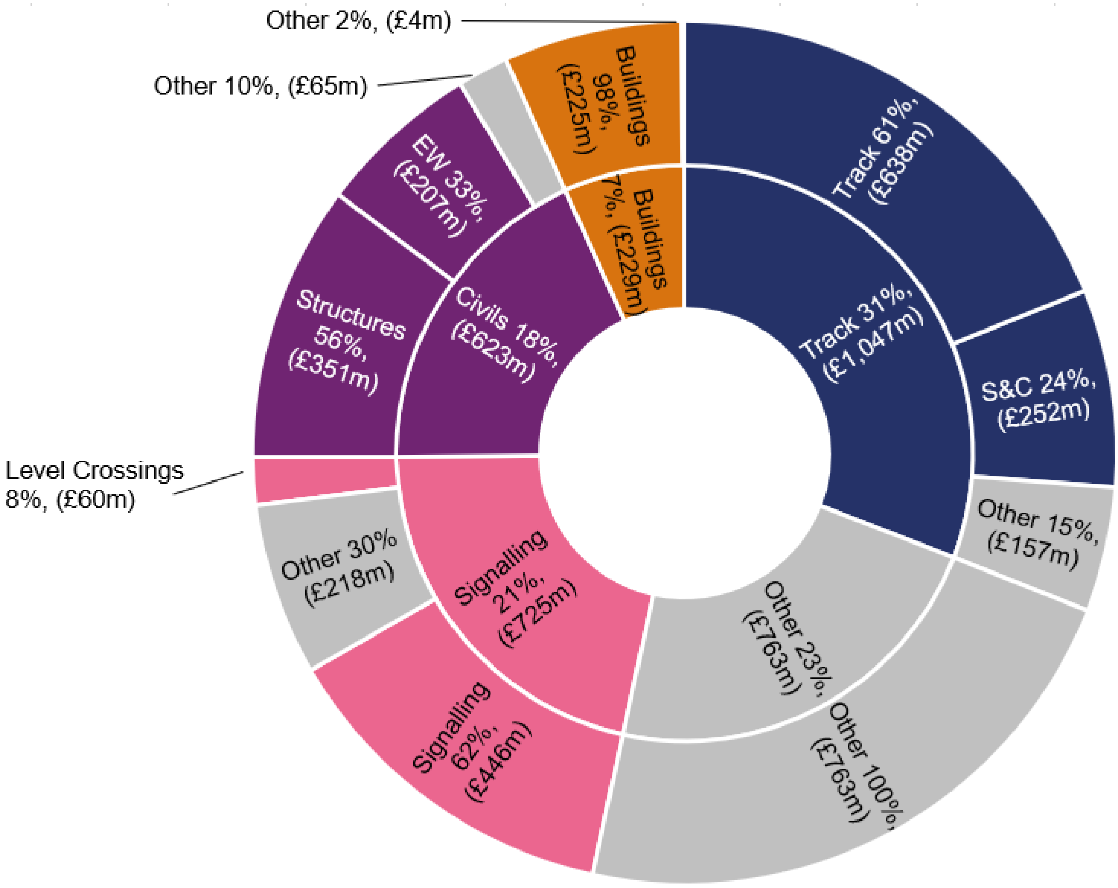
3.9 This chapter is organised as follows: the next section ('Context') provides a description of the make-up of Network Rail renewals activity and how regions compare in terms of their overall expenditure and volume of work, asset characteristics and network usage. The following section ('Analysis')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

Context

Renewals across asset classes

3.10 **Breakdown of Network Rail's renewals expenditure by asset class:** Figure 19 shows the breakdown of average total renewals expenditure by asset class between 2014-15 and 2021-22.

Figure 19: Breakdown of average total renewals expenditure by asset class, 2014-15 to 2021-22 (2021-22 prices)[38]

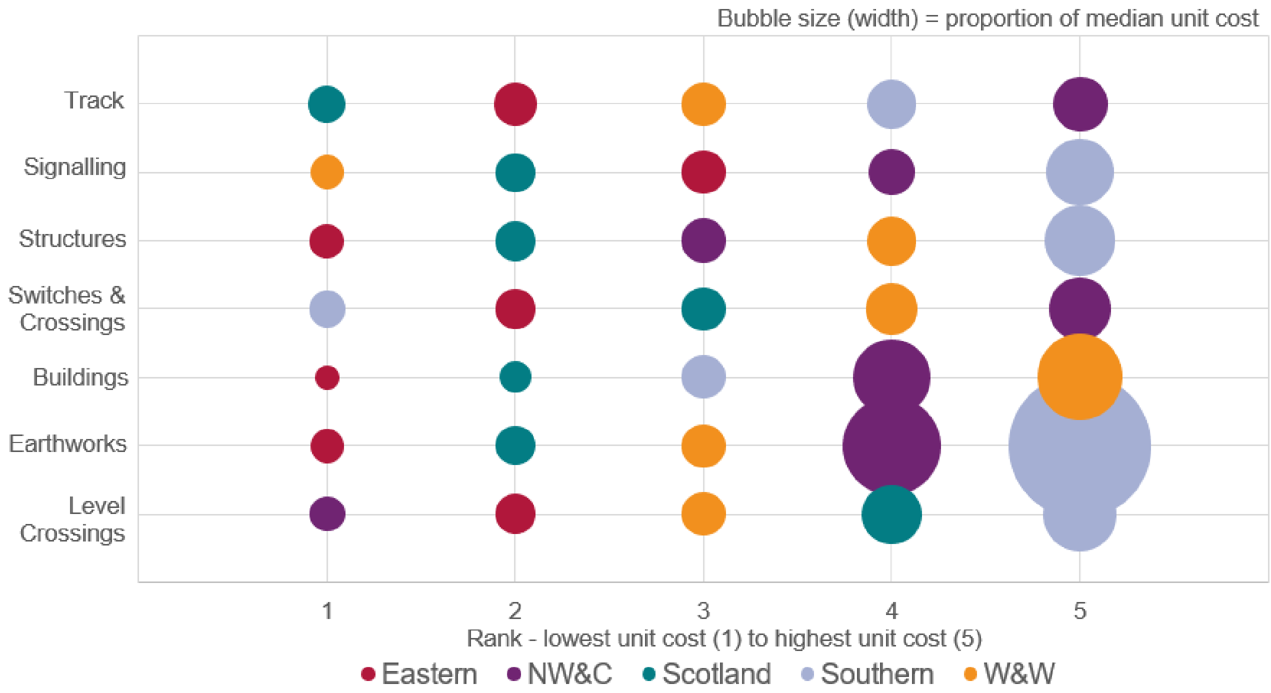


3.11 As indicated by the inner ring, expenditure on Track, Signalling, Civils and Buildings accounted for 77% of the total. Asset classes are further split into sub-asset class or work type in the outer ring of the figure. For instance, the Track and Switches & Crossings sub-asset classes accounted for 85% of average total Track renewals expenditure.

38 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 20 shows the 8-year average renewals unit costs, by asset and sub-asset class, and by region, with regions ranked for each asset according to their average unit cost. A rank of 1 represents the region with the lowest unit cost for a given asset class and a rank of 5 represents the region with the highest. The size (width) of the bubbles shows how large each region's average unit cost is relative to the median region in each asset and sub-asset class. **Southern** and **North West & Central** have some of the highest average unit costs across the majority of asset classes. In comparison, **Eastern** and **Scotland** have some of the lowest average unit costs across the asset classes.

Figure 20: 8-year average unit cost rankings per asset class, 2014-15 to 2021-22



Conventional track renewals

3.13 There are three main types of track renewals:

(a) conventional track renewals (work intended to fully replace the existing track asset utilising conventional track renewal methodologies);

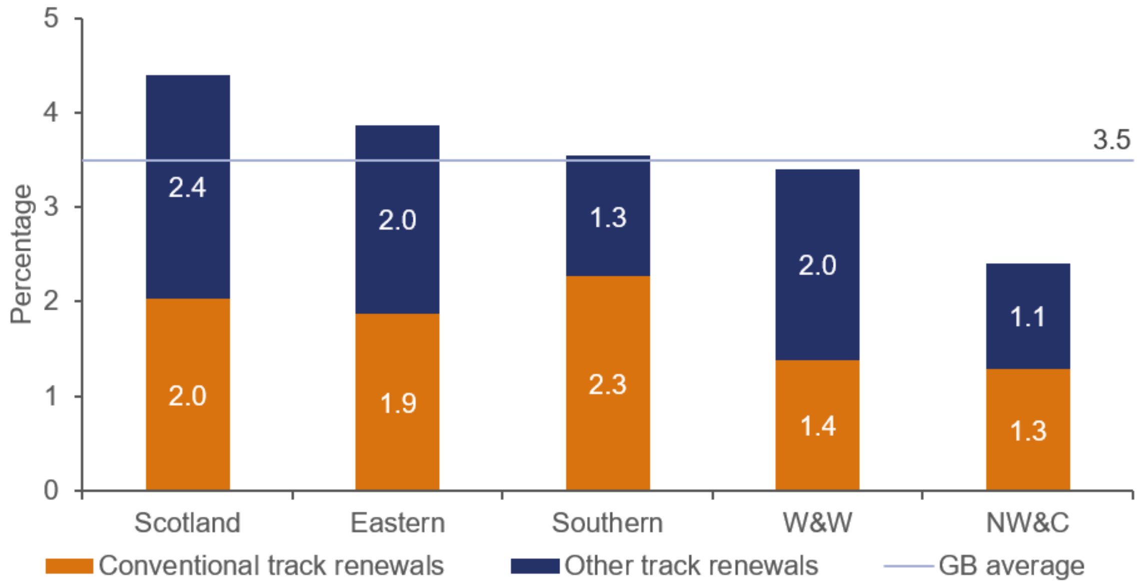
(b) track refurbishment (work intended to extend the life of the existing track asset rather than fully renew it); and

(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.

The following paragraphs discuss conventional track renewals, which is the main focus of this chapter.

3.14 **Proportion of track renewed:** Figure 21 shows the volume of track renewed as a proportion of total region track-kms. On average, Network Rail renewed 3.5% of its track each year between 2014-15 and 2021-22. The Scotland region renewed its track at the highest rate (4.4%, 2.0% of conventional track renewals and 2.4% of other types of track renewal), whilst North West & Central renewed at the lowest rate (2.4%, 1.3% of conventional track renewals and 1.1% of other types of track renewal).

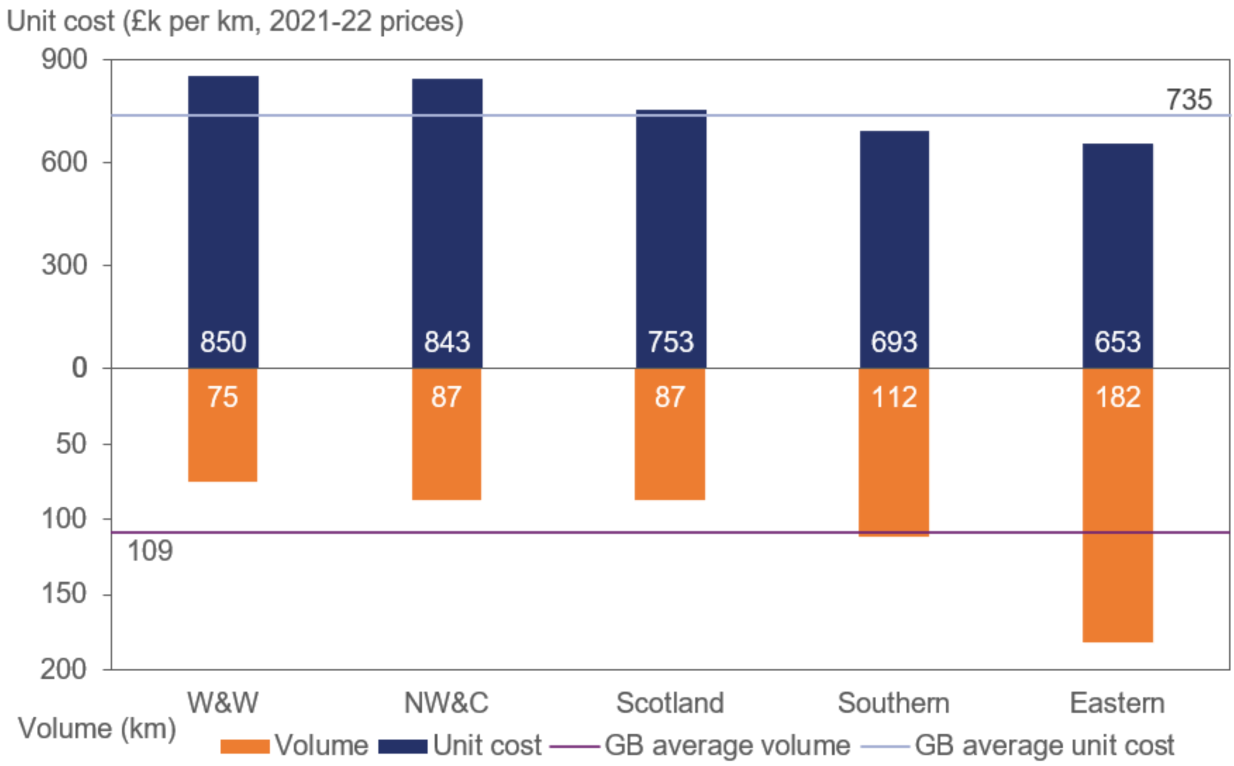
Figure 21: Average proportion of track renewed each year, 2014-15 to 2021-22[39]



3.15 **Conventional track renewal average unit cost and volumes:** Figure 22 shows the 8-year average unit cost and volumes for conventional track renewals by region. The average across all regions is £735k per track-km for unit costs and 109km for volume renewed. On average, Wales & Western has the highest average unit cost (£850k per track-km) and lowest volume renewed (75km), whilst Eastern has the lowest average unit cost (£653k per track-km) and the highest volume renewed (182km). The figure suggests that there are economies of scale, i.e. the greater the number of conventional track-km renewed, the lower the unit cost becomes.

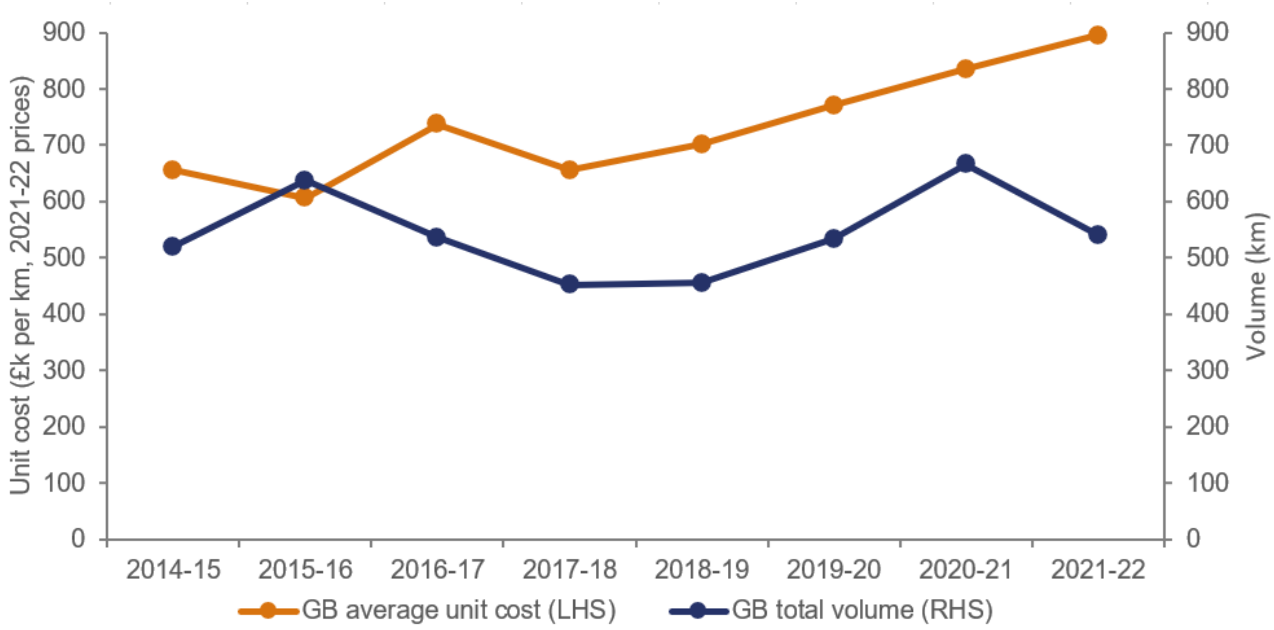
[39] Proportion of conventional track renewed per route is calculated as conventional track renewals costs divided by track-km. Proportion of other track renewals per route is calculated as the sum of high-output renewals and track refurbished, divided by track-km.

Figure 22: Conventional track renewal – 8-year average unit cost and volumes, 2014-15 to 2021-22 (2021-22 prices)



3.16 **Trends in conventional track renewal unit costs and volumes (Network Rail):** Figure 23 shows the trend in the 8-year average unit cost and volumes for conventional track renewal for Network Rail as a whole. Real terms unit costs have been on an upward trend since 2017-18. This could be due to inefficiency, changes in work mix or other factors. Volumes have also risen every year since 2017-18, apart from in 2021-22 where they fell by 19% as compared to 2020-21. Trends in unit costs and volumes are less clear prior to 2017-18.

Figure 23: Trends in Conventional track renewals – average unit cost and volumes, 2014-15 to 2021-22 (2021-22 prices)



Analysis

Data

3.17 The analysis is based on data for financial years 2014-15 to 2021-22, recorded at the level of the ten routes that were introduced by Network Rail in CP4. For the year 2021-22, Network Rail supplied us with data at the level of the 14 routes. To adjust this data to the level of the ten CP4 routes, we aggregated the East Coast and North & Eastern routes into the LNE route and we aggregated the Central, North West and West Coast Mainline South into the LNW route. All other routes stayed the same.

Dependent variable

3.18 The dependent variable is annual average unit costs at the route-level for conventional track renewals. We obtain this variable by dividing total annual expenditure on conventional track renewals by the amount 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 onwards, 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 2021-22 prices, using the Consumer Price Index (CPI).

Independent variables

3.19 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.

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

(a) conventional track renewals;
(a) track refurbishment;
(b) high-output track renewals;
(c) switches and crossings; and
(d) other.

3.21 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 unit cost of conventional track 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.

3.22 We also tested whether the intensity[40] of maintenance and enhancements expenditure has a bearing on conventional track renewals unit costs, e.g. through increased pressure on the supply chain. Model estimates came up with counterintuitive relationships and we therefore excluded these variables from the final model. This was also the case for average wage levels.

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

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

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	A greater number of track-km renewed should lead to a lower average unit cost as we expect there to be economies of scale.
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)[41]	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.
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 costly renewals work. Higher rainfall may also make it more difficult to undertake infrastructure work.
Proportion of track category 1A, 1 & 2[42] (category 1A, 1 & 2 km/track-km)	Positive	A network with a higher proportion of track in category 1A, 1 and 2 is likely to require more frequent and more costly renewals and may need to be kept in a

[41] 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 the two traffic variables) improves on degrees of freedom. This in turn improves the robustness of our model.

[42] See footnote 8 for the definition.

Variable	Expected direction of relationship	Reason for relationship
		better general condition than other parts of the network. It may also be more difficult to undertake engineering work on such sections of the network (for example, due to higher train speeds and usage) and their access time window may be narrower. 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.
Switches and crossings (S&C) density (number of S&C/track-km)	Positive	A network with more switches and crossings per track-km is more complex and therefore requires more costly renewals.
Average days per Possession (Number of possession days/number of possessions)	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, 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 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. Given the pandemic was an event that significantly affected Network Rail's operations, especially during the year 2020-21, we use a

Variable	Expected direction of relationship	Reason for relationship
		dummy for the year 2020-21 to isolate its impact.
Year-specific dummy variable (applies to 2021-22)	N/A	The purpose of this term is to separate out the common change in unit costs across routes due to the 2021-22 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.

Descriptive statistics

3.24 Table 8 below presents some summary statistics that describe the variables in our conventional track renewals unit costs model.

Table 8: Summary of variables

Variable	Mean	Std. Dev.	Min	Max
Conventional track renewals average unit cost (£k per track-km renewed)	761	202	437	1,397
Conventional track-km	54	30	9	133
Refurbished track-km	34	29	0	130
High-output track-km	20	26	0	122
Train-km (million train-km)	55	31	17	143
Average rainfall (mm)	84	29	41	150
Proportion of track category 1A, 1 & 2 (%)	36%	12%	8%	54%
Proportion of electrified track (%)	48%	31%	0%	96%
Possessions duration (days per track-km)	0.3	0.2	0.0	0.8
Switches and crossings density (number of S&C/track-km)	0.6	0.1	0.4	0.9

Model specification

3.25 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.

3.26 We have estimated a number of variants of the following model but settled on the following specification[43]:

$$\begin{aligned}\ln(\mathit{conventional\ track\ renewals\ average\ unit\ cost}) \\ = \beta_0 \\ + \beta_1 \ln(\mathit{conventional\ track\ km}) \\ + \beta_2 \ln(\mathit{refurbished\ track\ km}) \\ + \beta_3 \ln(\mathit{high\text{-}output\ track\ km}) + \beta_4 \ln(\mathit{train\ km}) \\ + \beta_5 \ln(\mathit{average\ rainfall}) \\ + \beta_6(\mathit{proportion\ of\ electrified\ track}) \\ + \boldsymbol{\beta_7(proportion\ of\ track\ category\ 1A, 1\ \&\ 2\ )} \\ + \boldsymbol{\beta_8 \ln\ (switches\&crossings\ density)} \\ + \beta_9 \ln(\mathit{possessions\ duration}) + \beta_{10}(\mathit{dummy}_{2020-21}) \\ + \beta_{11}(\mathit{dummy}_{2021-22}) + \beta_{12}(\mathit{year}) + \mathit{error\ term}\end{aligned}$$

3.27 We have made changes to last year's model to reflect feedback from Network Rail following publication of last year's report. These include controlling for the proportion of track category (i.e. (track category 1A + category 1 + category 2)/track-km) instead of track criticality as well as measuring average possession duration as the number of possession days/number of possessions instead of number of possession days/ track-km. We have also included switches & crossings density as an additional variable in the model.

Estimation approach

3.28 Similar to last year's analysis, 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.

3.29 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

[43] A bold font means the variable is new relative to our year 2 of CP6 report

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[44].

Model estimates

3.30 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	Coefficient
Conventional track-km	-0.34***
Refurbished track-km	-0.01
High-output track-km	0.01**
Train-km	0.19***
Average rainfall	0.41***
Proportion of track category 1A, 1 & 2	0.51**
Proportion of electrified track	0.04
Possessions duration	0.06***
Switches and crossings density	0.16
Year (average annual unexplained growth rate in renewals average unit costs)	0.02
Dummy for 2020-21 (deviation from the annual growth rate above due to Covid-19)	0.25***
Dummy for 2021-22 (deviation from the annual growth rate above)	0.29***
Constant	2.54**
Number of observations	80
R^2	0.62

[44] See illustration in paragraph 2.18 above.

Variable	Coefficient
*** Statistically significant at the 99% confidence level ** Statistically significant at the 95% confidence level	

3.31 Table 9 above shows that there is a statistically significant relationship between conventional track renewals average unit costs and: the volume of conventional track renewals; the volume of high-output renewals; train-kms; average rainfall; proportion of track category 1A, 1 & 2; and the length of possessions undertaken.

3.32 After normalising for factors such as traffic and network complexity, the analysis shows (based on the coefficient of the year term) that there has been an average annual increase in the average unit costs for conventional track renewals of 2.0% per year (in real terms) during the period from 2014-15 to 2021-22 (same as for the period 2014-15 to 2020-21, in the year 2 of CP6 report).

3.33 In 2021-22, the rate of growth in the average unit costs for conventional track renewals increased to 2.7% compared to the long-term trend of 2.0%. According to last year's report, this rate of increase (from the long-term trend) was 2.6% in 2020-21, which means the increase in conventional track renewals unit costs was well above the trend in each of the last two years. We consider that this may be due to inefficiency, headwinds or some other factors including some project-specific factors (e.g. project location), which cannot be taken account of in a top-down analysis of this sort. For example, some of this increase may be due to rising input price inflation (i.e. changes in prices above the Consumer Price Index (CPI)) as discussed in our 2021-22 Annual Efficiency and Finance Assessment report.

3.34 Our results suggest no clear relationship between the conventional track renewals average unit cost and the volume of track refurbished, the proportion of electrified track or the number of switches and crossings per track-km.

3.35 The model's R^2 is 0.62. 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 62% of the variance in conventional track renewals average unit costs across regions and over time. Although this is an improvement as compared to our model last year which had an R^2 of 0.59, this relatively low R^2 suggests that there are still some 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[45]. The R^2 is considerably lower

[45] Network Rail has worked 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

than in our regional maintenance expenditure model, which can explain over 96% 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 0.34% in conventional track renewals unit costs. 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 0.19%; conversely, a 1% decrease in traffic would reduce costs by the same proportion;

(d) 10% higher rainfall is associated with 4.1% higher conventional track renewals unit costs;

(e) going from 50% to 100% proportion of track category 1A, 1 & 2 would be expected to result in 42% higher conventional track unit costs[46]; and

(f) 10% longer network possessions are associated with 0.6% higher conventional track renewals unit costs.

Benchmarking results

3.37 This section compares outturn conventional track renewals unit costs against expected spend as predicted by our model, given each region's characteristics. As mentioned earlier, whilst the underlying analysis was conducted using route level data, we have aggregated our route level results to the regional level and that is

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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 is expected to be used as a benchmark in the preparation of Network Rail's strategic business plans for PR23.

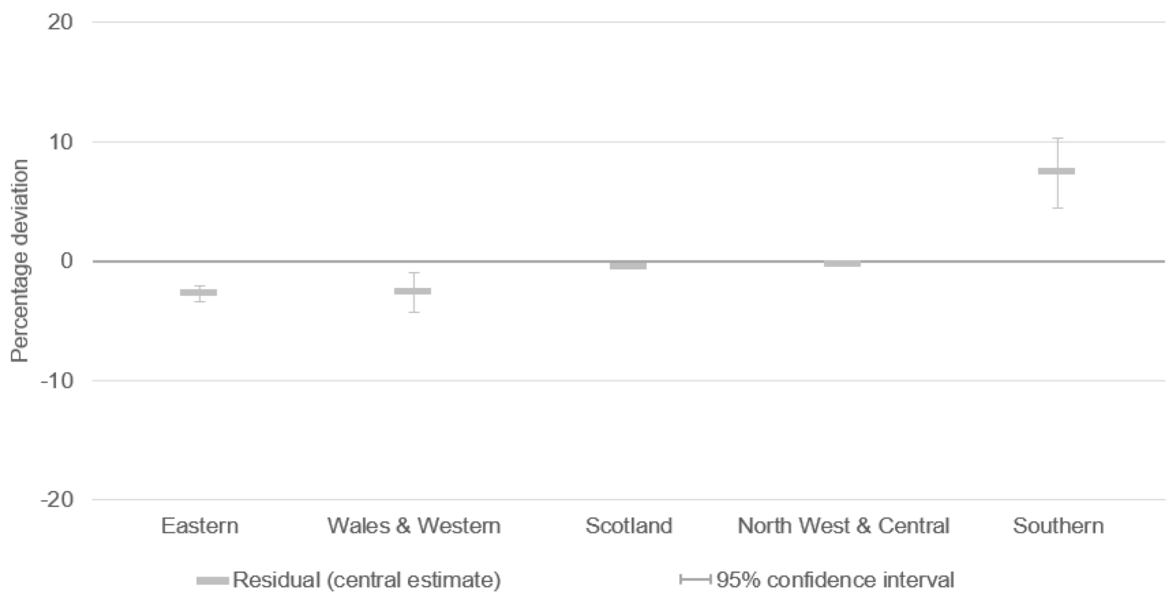
[46] This is calculated as $[(1^{0.51}/ 0.5^{0.51}) -1]$.

what we present in this section[47]. We order the regions according to the amount of unexplained variation (i.e. the difference between outturn and predicted unit costs).

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 costs should be in each case.

3.39 Figure 24 below shows, for each region, the proportion of unexplained cost variance in 2021-22[48]. A negative number means that the region spent less than expected (according to our statistical model) whilst a positive number means that the region spent more than expected (according to our statistical model).

Figure 24: Deviation between outturn and expected (modelled) unit costs for conventional track renewals by Network Rail region, 2021-22[49]



[47] This allows the interpretation of these findings to be consistent with Network Rail's current organisational structure as reflected in the five regions. However, the route comparisons are available in Annex A.

[48] This is obtained as an average of the average unit costs for the relevant routes, weighted by renewals volume.

[49] Given the uncertainty associated with any statistical model, we consider any region that is within +/−10% of our modelled prediction (as shown by the x-axis at zero) is not an 'outlier'. These regions are marked grey. The lines surrounding the central estimate of a given region'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 number representing the deviation between outturn and modelled cost.

3.40 The figure shows that conventional track renewals' average unit costs at the regional level are between -3% and +7% of what our model would expect. This range is smaller than in last year's analysis (-10% to +10%). Network Rail told us that following last year's report as well as Deloitte's work, the regions have been undertaking internal benchmarking and analysing outlier projects to understand the reasons for cost variance from the benchmark and to identify any mitigating actions to apply to current and future projects.

3.41 Compared to last year, **Eastern** is still at the lower end (least costly) of the range (-3%), whilst **Southern** has replaced **Wales & Western** at the top end (most costly) of the range (+7%). While in our analysis last year, Wales & Western's average conventional track renewals unit costs appeared to be 10% more than our model predictions, this has reduced to 3% less than our model's prediction. The region explained that since last year they have managed to deliver £33 million worth of efficiencies on its track renewal portfolio. To achieve this, the region said it implemented internal benchmarking which compares track renewal costs and project level costs against other regions to understand reasons for cost variances and any mitigating action that can be learned. The region is embedding this in its assessment of current and future projects to keep the costs down. The region is also using this, combined with Deloitte's recommendations, to benchmark the rates they are planning to use in its CP7 strategic business plan.

3.42 It is important to note that the unit costs of renewals are 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 regions.

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

Annex A: Route model's results comparison

Figure 25: Deviation between outturn and expected (modelled) maintenance expenditure by Network Rail route, 2021-22

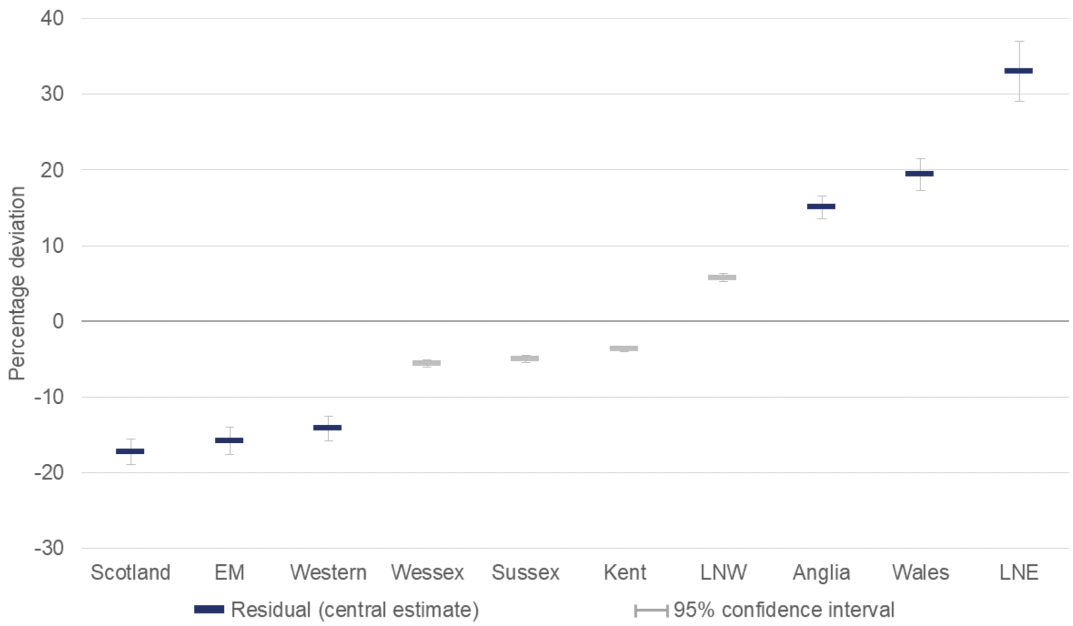
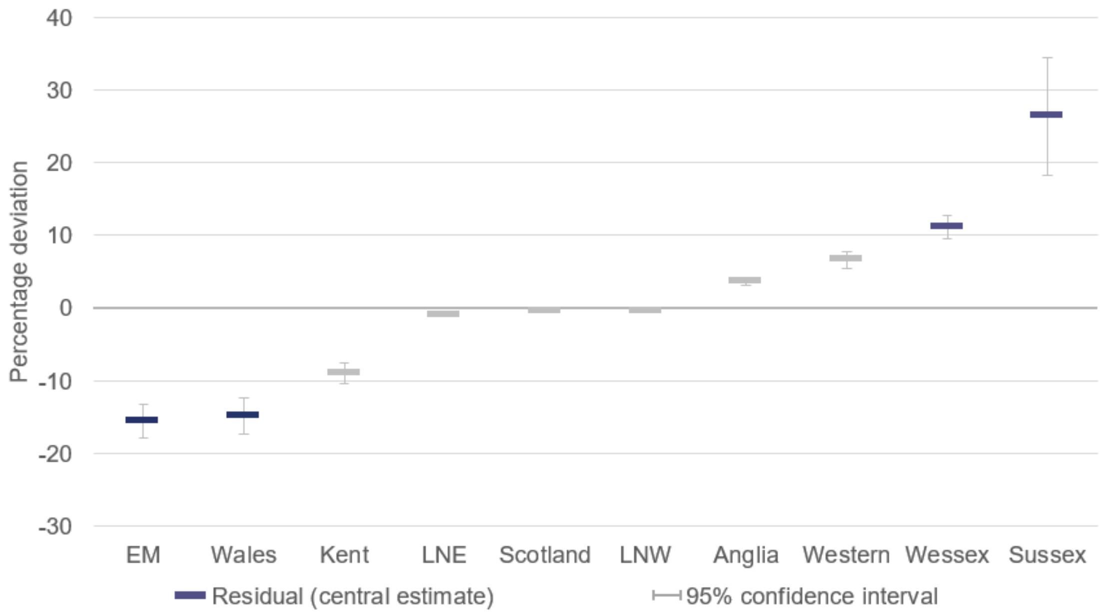
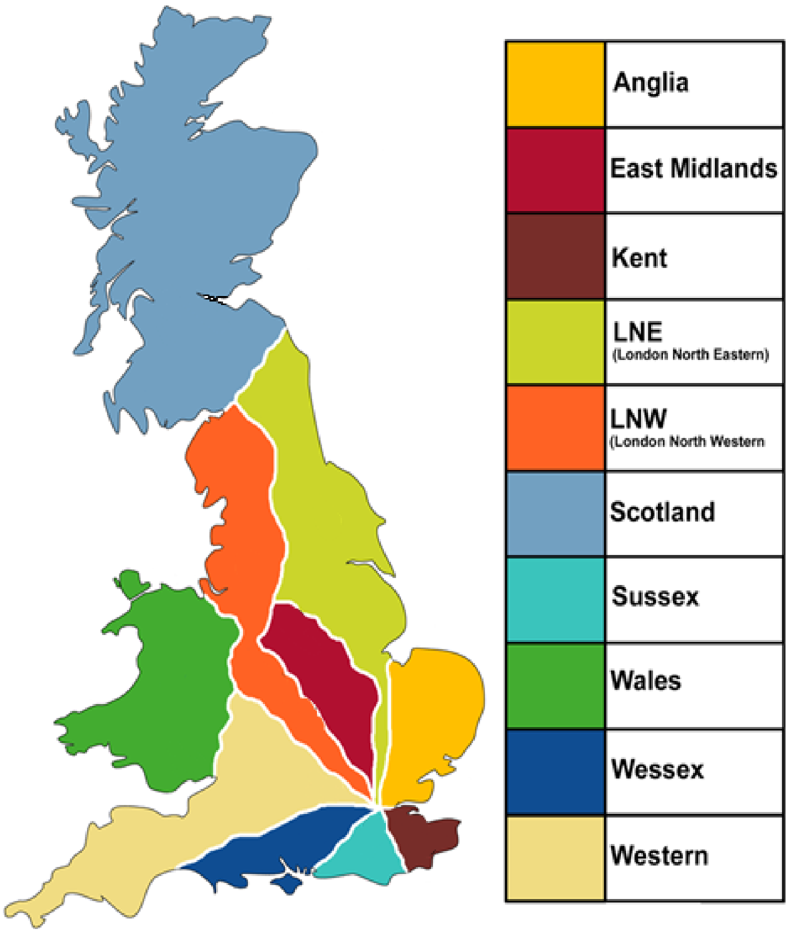


Figure 26: Deviation between outturn and expected (modelled) unit costs for conventional track renewals by Network Rail route, 2021-22



Annex B: Network Rail's geographic routes and regions

CP4 ten routes covered in this analysis



CP6 structure with 14 routes

Annex C: 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)	Bedford, 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	Wessex Inner, Wessex Outer
	Sussex	Brighton, Croydon
	Kent	Ashford, London Bridge, Orpington
Wales & Western	Wales	Cardiff, Shrewsbury
	Western	Bristol, Plymouth, Reading, Swindon

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