Geobear Transport Study

Geobear

A report by Volterra Partners, June 2018

Volterra

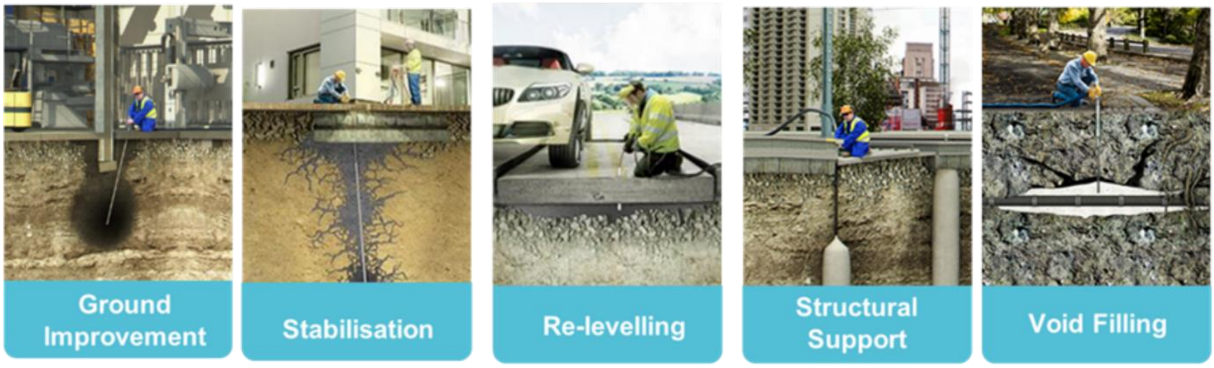
Contents

1 Executive Summary

- Geobear is an engineering company that supplies an **innovative approach** to resolving subsidence through the application of an expanding geopolymer injection technology. Geobear has been **applying this approach for over 30 years.**

- The main advantage of Geobear is the speed with which the work can be undertaken - between **two and ten times faster than traditional maintenance methods**.

Geobear Solutions:



- Volterra has **assessed the total costs of transport infrastructure maintenance** - financial and socio-economic - in three key transport infrastructure markets; **road, rail and aviation.**

- The value that can be derived from faster infrastructure maintenance was then estimated by drawing on data from a variety of sources, such as the Office of Road and Rail (ORR), Network Rail (NR) and the Department for Transport (DfT), as well as making some assumptions where necessary.

- Our results assume constant contractor maintenance costs. Therefore, savings from faster maintenance methods are the result of **reductions in socio-economic costs to users and also in the financial penalties** incurred by either infrastructure owners or transport operators.

- The **savings are dependent on the speed** with which Geobear can deliver infrastructure maintenance, the **timing of infrastructure closures** and the **proportion of maintenance works** that Geobear can deliver.

The three transport modes studied in this report (road, rail and aviation) may be in competition with each other but they have very different structures, incentives and regulations.

Road

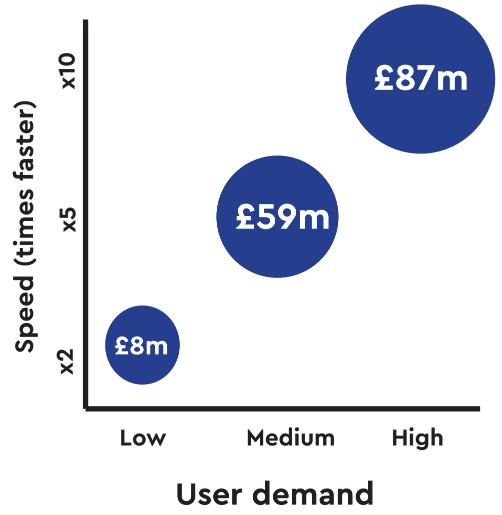
Financial cost

- Borne by infrastructure owner
- Highway authorities often bear additional costs of night time maintenance to reduce disruption to users.

Socio-economic cost

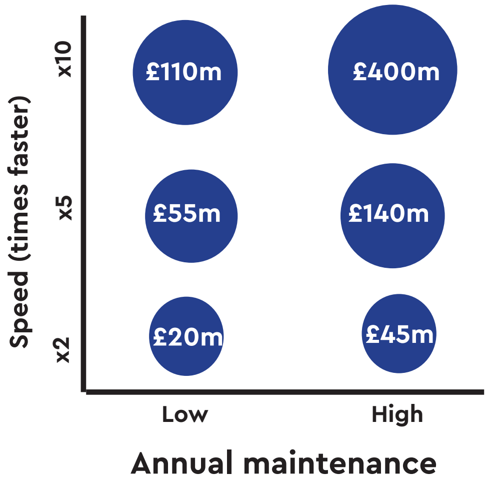
- Delays, noise, emissions, unreliability
- Borne by road users and genrally not valued in the process of maintenance tendering

Potential yearly benefits from faster road maintenance



Rail

Potential yearly benefits from faster rail maintenance



"Faster rail maintenance becomes more valuable in situations with high demand"

There are clear financial penalties for poor performance of both network infrastructure owners and train operating companies.

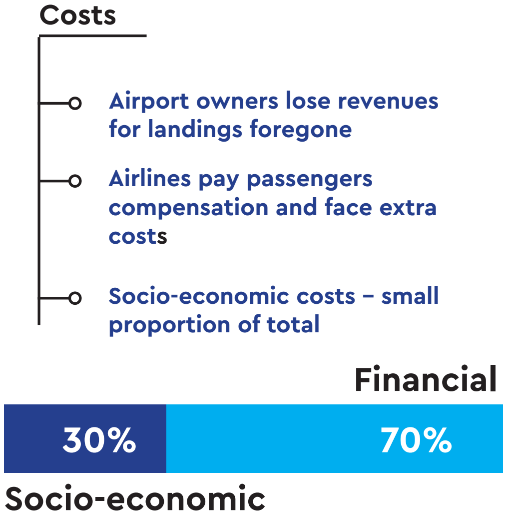
But...

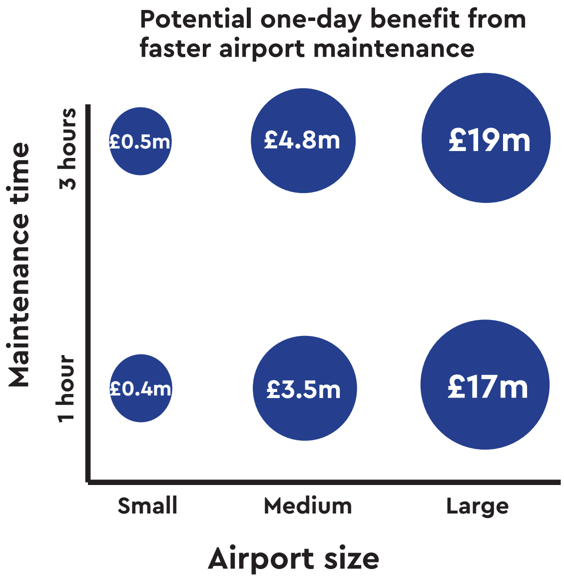
Financial penalties only account for 35% of the costs arising from maintenance works with user costs accounting for the majority

Cost Split

Air

The air sector monetises a much higher proportion of total maintenance costs





UK -> G7

UK results were extrapolated to give an indication of potential yearly savings from faster maintenance methods across the G7.

No extrapolation for the aviation industry – maintenance occurs sporadically.

Yearly G7 Savings in Road and Rail

Speed of Maintenance	Combined Yearly Savings (£bn)	
	Lower	*Upper*
2x faster	0.3	0.7
5x faster	0.9	2.2
10x faster	1.4	4.3

Transport Infrastructure Maintenance: Current Problems and Innovative Solutions

- When infrastructure maintenance is put out to tender, the **award of the contract is largely judged on the contractor cost of delivering the maintenance**. Volterra analysis suggests that the **delays and other costs imposed on transport infrastructure users can often be much larger than the pure financial costs** of maintenance.

- It would make **better sense, economically, to have a system of infrastructure maintenance tendering which considered** both the **financial costs borne by the infrastructure owners** - including financial penalties incurred as well as contractor cost - **and the socio-economic costs imposed on users**.

- It is surprising that the Department for Transport does not apply a valuation to the delays caused by maintenance works. **Investments in transport are justified through the valuation of user benefits, so why are maintenance works not valued in user costs?** It may be that the costs involved in valuing the user disbenefits are disproportionate to the scale of the impacts, but it must be possible to produce some simple rule of thumb guidance.

- The financial costs of maintenance are already large, but the costs imposed on transport infrastructure users in terms of delays, vehicle operating costs, safety, emissions and unreliability can also be very substantial. A system which judges maintenance bids on a **combination of capital cost and user costs would lead to better maintenance procurement, resulting in a better overall outcome and lower societal cost**.

- There are **some existing contracting mechanisms which are more successful in including socio-economic costs** to users in their valuation:

  - In the USA, some states include a monetary value of user costs from road closures in the bidding process, by applying a **simple daily charge reflecting the disruption caused by the road (or lane) being out of operation**. The contract award is therefore then **based on a combination of the financial costs and the user costs of the road closure**.

  - Similar **"Lane Rental" charges** have been applied for maintenance requiring a lane or road being out of operation; for example lane rental charges are sometimes used on design, finance, build and operate (DBFO) maintenance contracts for major roads like the M40.

  - Maintenance contracts could include **simple incentives or disincentives**, through the form of a bonus payment awarded for early completion and deductions in the case of not meeting target performance.

- **This kind of approach would encourage innovative new techniques for delivering maintenance works** which produce significant economic benefits. In the aviation sector change would be relatively small, but **in the road and rail sectors there could be sizable changes and significant economic gains.**

2 Introduction

2.1 Volterra was commissioned by Geobear to assess the financial and socio-economic impacts that faster maintenance could have in the transport infrastructure sector, in comparison to more traditional methods. The report highlights the scale of benefits and how these benefits would vary according to transport mode, level of demand and other factors.

2.2 The study focuses on the road, rail and aviation industries. There are financial costs to infrastructure owners and socio-economic costs imposed on others. The three transport modes may be in competition with each other but they have very different structures, incentives and regulations.

2.3 Roads in the UK are generally free to use, but users do not receive any compensation when they are delayed. Due to the lack of financial charges, roads are judged on their socio-economic rather than financial performance. The socio-economic costs for roads include:

- Congestion;
- Vehicle Operating Costs;
- Emissions and Pollution;
- Safety;
- Noise.

2.4 The rail industry has a different structure, with competitive bidding to secure operating franchises and an infrastructure owner – NR in the UK – charged with maintaining the infrastructure. The contracts between train operating companies (TOCs), the infrastructure owner and regulators create a complex and litigious system with clear financial penalties for poor performance of both the network infrastructure and the services.

2.5 The aviation industry is the most self-reliant sector financially and the sector requiring the least amount of subsidy. Regulation in this industry is required to prevent abuse of monopoly power, minimise environmental impacts and to maintain competition between both airports and airlines.

2.6 The analysis in this paper is based on the underlying assumption that the Geobear product delivers a similar outcome in terms of price and maintenance quality, but with timescale reduced by between 50-90%. This speed advantage assumption is supported by examples that have been obtained by stakeholders who have been involved in projects with Geobear in different markets. These examples are provided by Geobear themselves; Volterra does not have the technical skills to validate these examples.

2.7 The approach to valuing the benefits from faster infrastructure maintenance recognises the uncertainty associated with each sector. All three are complex, regulated markets with different incentives and outcomes.

2.8 There is uncertainty over the degree to which Geobear outcomes compare with traditional maintenance methods in terms of:

- Speed of delivery;
- The price of the project;
- The quality and duration of the maintenance.

2.9 For each sector, this report applies a bottom-up approach using examples of individual maintenance works on a section of road, rail and aviation, considering two types of impact:

- **Financial:** Effects of infrastructure closure on the owner's costs and revenues (rail, road and airport owners) and the operators (airlines and TOCs);
- **Socio-economic:** Valuing the broader societal costs from the closure of infrastructure and the benefits of faster infrastructure maintenance.

2.10 In this paper, financial costs incurred by infrastructure owners and operators refer to penalties and fines that may arise as a result of infrastructure maintenance, rather than changes in the contractor maintenance cost itself.

2.11 The results of the bottom-up approach are used to extrapolate the financial and socio-economic returns to an annual UK and G7 valuation in the industries in which this is appropriate, namely road and rail. The same extrapolation method is used to estimate the savings that faster infrastructure maintenance methods could bring in some of Geobear's other key markets – Finland, Sweden and Poland.

2.12 This report draws on a range of publicly available information. Where information is unavailable, transparent assumptions are applied. Where judgement is required, a range of outcomes is produced. Chapter 2 provides an overview of Geobear, whilst Chapters 3-5 describe the overall approach to quantification and valuation, and how that is applied across the three infrastructure sectors. Finally, Chapter 6 presents this paper's findings for all three industries and Chapter 7 draws on these findings to present our conclusions.

3 Geobear: The Company

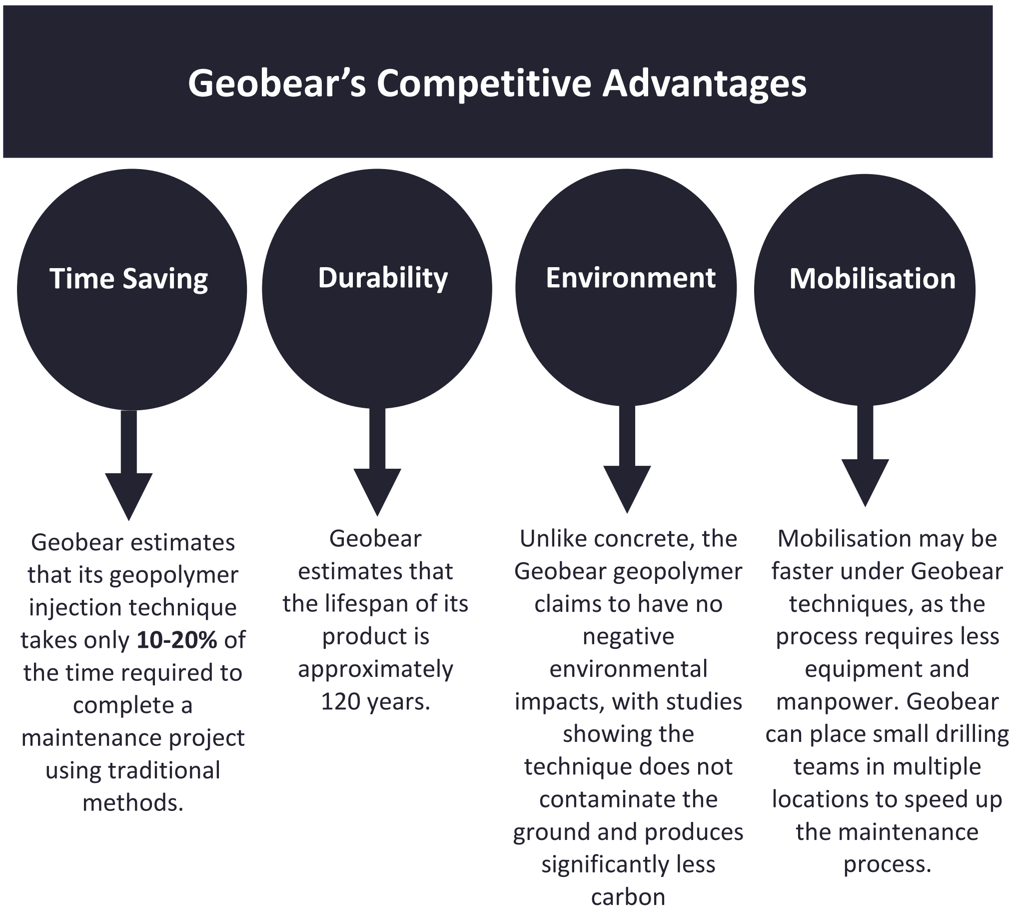
History and background

3.1 Geobear, formerly known as Uretek, was founded in Finland during the 1970s. The company established their UK business in 1989, with Geobear's headquarters now situated in London.

3.2 In the 1990s, it discovered an innovative ground engineering solution to resolving subsidence through the application of an expanding geopolymer injection technology, which forms the core of its business today. To date, Geobear has treated over 10,000 sites in the UK and has completed more than 200,000 projects worldwide.

3.3 The advantages Geobear claims to hold over traditional techniques include:

Figure 1: Geobear's claimed competitive advantages



Geobear Solutions

3.4 Geobear uses its core product to remediate issues via the injection of expansive geopolymer resins. Examples of the kind of problems that the Geobear product can be used to deal with are shown in Figure 2.

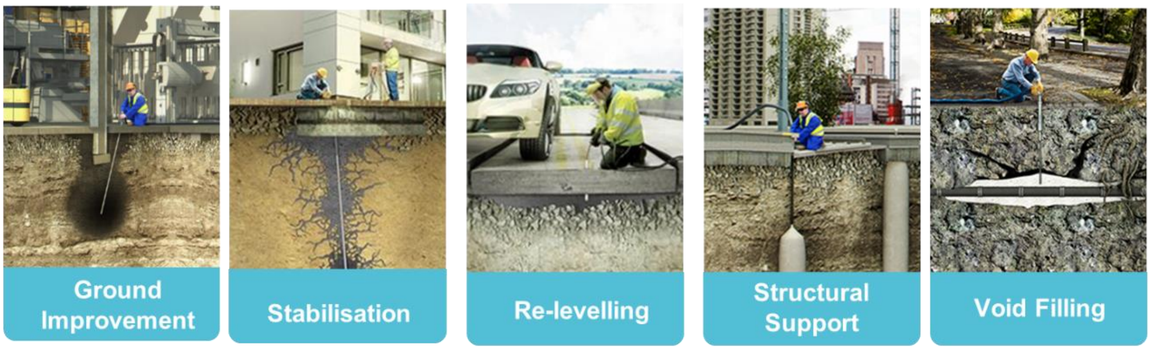
Figure 2: Examples of problems that Geobear solve

Source: Geobear

3.5 Illustrative images of the solutions that Geobear provide are shown in Figure 3. A basic overview of the application of each solution is as follows:

- Ground improvement: improves the bearing capacity of treated soils resulting in long-term support;
- Stabilisation and Re-levelling: the highly expansive geopolymer is used to lift or stabilise sunken concrete slabs;
- Structural support: solution is used in very weak soils, where geopolymer "columns" are inserted at close centres providing significant compression of surrounding soils; and
- Void filling: highly expansive geopolymer material with a lengthy liquid phase used for bulk void filling.

Figure 3: Geobear solutions



Source: Geobear

Verifications

3.6 Volterra has been provided with a range of quotes from various stakeholders in some of Geobear's key industries that go some way towards verifying the Geobear product.

Technical Expertise:

3.7 Colin M Eddie is an expert in the design and construction of tunnels and underground space, with over 35 years' experience in the tunnelling industry. In 2005, he was invited to become a Fellow of the Royal Academy of Engineering and in 2015 he was further honoured with the appointment of Royal Academy Visiting Professor of Innovation and Tunnelling at the University of Warwick. Colin has managed the design and construction of many prestigious projects including the UK's largest tunnel, the North Downs Tunnel for the Channel Tunnel Rail Link. He has also acted as a member of the expert panel to the CrossRail Projects; the Thames Tideway Projects and most recently the Silvertown Road Crossing at Greenwich. Having worked in collaboration with Geobear, Colin had the following to say about Geobear's solutions:

"*"For many years I was the Engineering Director of one of the UK's largest design and build tunnelling contractors, but I now run my own independent consultancy business (CECL). I am also the Royal Academy of Engineering's Visiting Professor (Innovation and Tunnelling) at the University of Warwick lecturing on tunnelling and Advanced Geotechnics on both their MSc and Undergraduate courses.*

I first became involved with Geobear (then Uretek) in 2016 when they came to present to myself and a few members of my team. Whilst I was previously aware of their system, I had not considered it to be relevant to my work which was exclusively on major infrastructure projects. It soon became apparent however that their technology is extremely scalable and ideally suited to many problems which require ground strengthening, groundwater control or displacement control.

My initial interest was focused on displacement control and in particular the possibility of using their processes in real-time to protect the existing built environment from potentially damaging movements associated with the construction of tunnels and underground space. I had many years of experience using conventional compensation grouting solutions and was acutely aware of the high cost and scale of these traditional settlement mitigation measures. Working with Geobear I then set about defining a Real-Time Displacement Control system and we filed for Patent Protection in 2017. The process was later to be given the name GroundShield™.

All the Geobear applications use the incredible power of two component expansive Geopolymers to strengthen the ground; to control groundwater or to create displacement of the soil. Geobear can tailor the resin selection process which means that different products are used for different applications. If we want to permeate and strengthen a fine granular soil for instance, a slow reacting and low viscosity product will be selected. This will permeate the pore space and result in negligible movement. If however we want to fracture a stiff clay at depth to remediate or *prevent settlement damage, then a fast reacting product can be selected which will create an instantaneous lifting pressure.*

The process is highly predictable, and the principal control is the comparatively small volume of product that needs to be injected each time. Furthermore, the process has recently been improved with the development of downhole mixing techniques using packer technology which means that multiple injections can be made at the same point, thereby eliminating the need to re-drill. Unlike conventional forms of grouting, small-scale plant and equipment (often hand held) is used and the fracturing energy comes entirely from the expansion force (up to 10MPa) of the chemical reaction and not the injection pressure normally crated by large scale mechanical pumping equipment. Relationships between lifting pressure and expansion are well understood for each product and have been used as the basis of design for many years.

The technology has been in use around the world for over 30 years. The products and processes have been rigorously tested and offer sustainable and long-term (>120 years) solutions which are safe to use in even the most sensitive of environments. In addition to the obvious cost, time and environmental benefits, the process substantially reduces or even eliminates disruption to stakeholders and the public.

Whilst my particular area of interest relates to tunnelling and underground space, I have been working with Geobear across their full range of applications. The technology is extremely versatile and Geobear can offer a total engineered solution. I have been pleased to work with their in-house engineering teams to develop a one-stop design solution for all applications. This service can include concept design, site characterisation, detailed design (including advanced numerical modelling where required), execution (and associated verification) and after sales support."

Professor Colin M Eddie, Managing Director, Colin Eddie Consulting Ltd.

Rail:

3.8 Since expanding its business to the UK, Geobear has undertaken multiple projects for Network Rail (NR), the UK's rail infrastructure owner. Often these have been employed in projects where conventional maintenance techniques are problematic. An example was at Oxford station, where an underpass needed to be structurally filled and supported to ensure passenger safety. Geobear offered a void filling solution, compared to the alternative of having to break through the passenger ticketing office and platform to allow for traditional grouting methods. An employee at Network Rail who was involved with the project had the following to say about Geobear:

"Geobear's injection method was successfully delivered in four shifts to complete a targeted structural void fill at Oxford station. The traditional alternative would have taken five times more shifts and was technically not the solution, the alternative to Geobear would have caused our facilities passengers a huge amount of inconvenience and disruption. The work carried out by Geobear was undertaken across 4 consecutive night shifts. We have very sensitive neighbours so the lack of disruption was paramount to successful delivery. The treated asset enables 6.6 million passengers to travel through the station each year. The Geobear solution enabled the customer flow

kept intact during the repair works, and prepared the station for future expansion by increasing structural strength. Network Rail was pleased with how the solution worked in terms of speed of installation and overall performance, we couldn't commend the team high enough for the professionalism shown throughout the delivery."

Bill Smalley, Construction Manager, Network Rail

3.9 This comment emphasises both the speed advantage and extra flexibility obtained by using Geobear methods. Not only was Geobear's solution up to five times faster in this case, but the work was also undertaken during the night in order to minimise disruption to rail services and passengers.

Road:

3.10 Geobear has undertaken multiple road projects within the remit of Reading Borough Council, such as their ground stabilisation project on Northumberland Avenue[1]. The following quote has been provided by an employee of the council, who emphasises his satisfaction with Geobear's solutions:

"*If you look at the economics, we're accruing long term savings by investing in the future of road. We've worked with Geobear on a number of schemes and their methods always deliver for us."*

Sam Shean, Reading Borough Council

Residential:

3.11 Geobear has previously undertaken work with the construction company known as Kier Group:

"*Resin injection took just a week, which meant a substantial time saving compared to 'remove & replace' and enabled residents to maintain access during the work".*

Simon Gardner, Project Manager, Kier

3.12 Simon's comments support Geobear's arguments that they are able to minimise disruption (to residents in this case) during a project. His reference to Geobear's shorter timeframe illustrates the potential savings that can be made from faster maintenance methods.

[1] www.geobear.co.uk/geobear-complete-road-stabilisation-reading/

4 Road

Background

4.1 In the UK road industry, whilst highway authorities (infrastructure owners) have targets to achieve in terms of congestion and reliability, road maintenance generally has no direct financial penalties to the infrastructure owners and no compensation for road users.

4.2 The benefits of faster highway maintenance are therefore related to user benefits: time savings, reliability, vehicle operating costs and safety. When valued in monetary terms, these socio-economic benefits will vary depending on the level of demand for the given road and the scale of the closure required.

Analysis

4.3 The analysis uses a range of data provided by the Department for Transport (DfT), the Office for Road and Rail (ORR) and highway authorities across the country.

4.4 Where possible calculations are based on data obtained from these sources. Assumptions made in the model will be transparent and clearly outlined. The core assumptions that underpin the road analysis are:

- Level of traffic: The number of vehicles wishing to use a given stretch of road that is closed for road works will determine the costs of delays and hence the benefits of faster completion;
- Proportion of works that could be undertaken by Geobear: there are many different types of road maintenance work, ranging from measures to improve the skid resistance of the surface to undertaking deep inlay work. Geobear's engineering techniques will provide a quicker alternative to some, but not all, maintenance work undertaken;
- Geobear's speed advantage: Volterra does not have the skills to verify the Geobear approach; instead, we illustrate a range of scenarios whereby Geobear is between two and ten times faster than traditional road maintenance techniques. These scenarios are based on case studies provided by Geobear and quotes from external individuals who have been involved in projects with the company.

4.5 The starting point for the demand scenarios is to use published data from Highways England on the level of traffic on the M62. That is used as a 'high' scenario for road works on the Strategic Road Network. That level of demand is then scaled down to account for low and medium scenarios on the Strategic Road Network (SRN) and scenarios on other road types that are not on the SRN.

Financial Impacts

4.6 Apart from the direct financial ('contractor') cost of the works there are generally no financial implications for most roadworks (other than vehicle operating costs, which are covered below under 'socio-economic impacts'). Unlike the rail industry, which has a defined framework for compensating passengers and TOCs when rail lines are shut, road users are expected to either bear a higher level of congestion on their existing route, or use a longer alternative route, with no financial compensation.

Socio-Economic Impacts

4.7 The socio-economic costs imposed on road users from roadworks include:

- Increased journey time: either through higher levels of congestion on a route that has one lane shut, or a longer route if the existing one is closed altogether;
- Additional vehicle operating costs (fuel, vehicle maintenance etc.) from having to drive further;
- Other marginal external costs, such as infrastructure wear and tear; increases in the risk of accidents; effects on local noise levels and air quality; and higher greenhouse gas emissions.

4.8 These costs are valued using DfT's WebTAG guidance, which provides values of time, vehicle operating costs and marginal external costs that can be used to express the impacts summarised above in monetary terms.

4.9 For further information on the methodology, see Chapter 1 in the Technical Chapter document for an example calculation.

Scaling up our findings

4.10 Scaling up the findings to obtain an annual UK-wide savings figure involves a high degree of uncertainty, but depends on:

- The total number of roadworks across the UK in a given year;
- The proportion of those roadworks that could be undertaken by Geobear;
- The proportion of these works that occur on low, medium and high demand roads.

4.11 In order to ascertain the total number of roadworks across the year, a combination of data is used:

- For the SRN, the ORR publishes data on the level of 'lane unavailability' arising from roadworks each year;
- For other roads in England under the responsibility of local authorities, data from the 'Highways Maintenance Appraisal Tool' (HMAT), produced by the Transport Research Laboratory, is used to derive the number of kilometres of roadworks undertaken in each category per year;
- The HMAT does not cover London, Scotland or Wales, so data from the DfT showing the length of roads in London, Scotland and Wales relative to England is used to scale the rest of the results up to a total across Great Britain.

4.12 As noted above, the proportion of roadworks that could be undertaken by Geobear is an important consideration in determining the overall answer. Table 1 shows the different categories of maintenance work used in HMAT, along with our assumptions about the proportion that could be undertaken by Geobear.

Table 1: Highway maintenance categories

Type of highway maintenance work	% of annual maintenance budget	% assumed to be within scope of Geobear
Surface dressing	10%	0%
Micro asphalt	10%	0%
Moderate overlay	20%	0%
Moderate inlay	20%	20%
Deep inlay	20%	50%
Reconstruction	20%	0%
Overall		**8.9%**

/ Volterra assumptions

Innovative Road Maintenance Contracts: Rewarding more efficient maintenance

4.13 There are no direct charges for using the roads in the UK, unlike tolled motorways in France, for instance. The "owners" of highway infrastructure - Highways England for the Strategic Road Network, local authorities for most of the rest, and a few city authorities such as Transport for London who control the Transport for London Road Network (TLRN) - therefore receive no income from their customers. All income to those authorities comes through government grant. When income is not determined by performance then it is always difficult to set the right incentives.

4.14 In place of charges/fees as a measure of performance, the roads sector needs an alternative and the normal alternative is "user benefits" or time savings, with elements of other costs such as environmental, safety and reliability. An investment appraisal assessing the economic case for new infrastructure will compare the costs of implementation against the benefits of operating; if the value of user benefits exceeds the value of the costs, then there is a net societal gain. Generally the DfT suggests that if the Benefit:Cost Ratio (BCR) exceeds 2:1 then the project is considered "high value for money" and is likely to be built, subject to finance availability.

4.15 There appears however to be a significant area of spending where that process of socio-economic appraisal is not applied, and that is highway maintenance. Highway maintenance spending in the UK does not generally take account of the user costs caused by maintenance; instead there tends to be a "we need to do this" justification in which the infrastructure owner will often choose the contractor that can deliver the maintenance at the lowest financial cost.

4.16 If the focus is only on the financial cost of maintenance then contractors have little incentive to develop techniques that might deliver faster maintenance. A push towards more performance-based contracts that include a monetary value for the time spent delivering the maintenance might incentivise contractors and increase the efficiency with which maintenance is delivered, thereby reducing the overall societal cost. There are some examples of this occurring both internationally and in the UK, which are outlined below.

Cost plus Time ('A + B' Bidding)

4.17 For the past two decades[2] the Federal Highway Administration (FHWA) in the US has been encouraging the use of innovative contracting methods in highway construction and maintenance to better consider the needs of road users in the procurement process. One procurement method that has been rolled out across multiple US states is the 'A + B' bidding method, which rewards the contractor for completing a project as quickly as possible. An example of an 'A+B' contract being used was for the Iowa Bridge in 2007, where the state department needed the bridge to be delivered in half the initial quoted time, so resorted to A+B bidding. This drew in contractors with innovative maintenance techniques and helped shorten delivery time.

4.18 A+B bidding is a cost-plus-time bidding procedure that captures[3]:

- **A:** The cost to perform the work, i.e. the traditional contract unit price
- **B:** The cost of the impact to the public, i.e. the user costs of the road maintenance are assigned a daily monetary value. The daily **B** value will be multiplied by the number of days maintenance required to complete the project.

4.19 The contractor that will win the bidding process is the firm with the lowest combined cost, meaning that the highways authority is willing to pay a premium in order to significantly reduce the overall public impact.

4.20 A+B bidding contracts encourage contractors to be innovative and deliver more efficient outcomes aimed at minimising total financial and socio-economic cost, rather than simply minimising financial cost. These contracts are likely to minimise delivery time and reduce road user impacts on congested roads.

---

[2] https://ops.fhwa.dot.gov/wz/contracting/

[3] http://www.wsdot.wa.gov/Projects/delivery/alternative/ABBidding

Lane Rental

4.21 Some maintenance contracts have some form of a 'lane rental charge', whereby a fee is assessed for occupying lanes (and hence denying access to road users) during the maintenance process. The rental fee can be dependent on both the number of and time that lanes are closed. In the case of one-off maintenance, contractors may be required to submit their proposed lane rental times with their bids. Then, the amount of total lane-rental charges a contractor proposes can be combined with the cost for the maintenance to determine the successful bidder.

4.22 Lane rental charges are also prevalent in long term maintenance contracts in the UK, such as in the M40 Design, Finance, Build and Operate contract, where the private firm is rewarded through yearly 'availability' payments depending on the availability and quality of the infrastructure (road). If the concessionaire fails to meet the availability requirement, the payment for the given year is reduced by a pre-determined formula taking into account the duration, time-of-day, and severity of the incident[4].

4.23 Firms who are either aware that lane availability will have a financial value placed on it in the bidding process, or know they will face financial penalties if the road under their management experiences unavailability, are more likely to employ faster and more efficient methods of road maintenance. These firms will be willing to pay higher maintenance costs in return for faster maintenance.

Incentives & Disincentives

4.24 This form of maintenance contract simply provides incentives for the early completion of maintenance, such as provision for a reward that is based upon a fixed amount per day for completing the maintenance ahead of schedule. Conversely, a penalty would be applied for each day that the project is delayed.

4.25 These types of maintenance contracts are prevalent in multiple countries, such as Germany – where bonuses are sometimes awarded for early completion – and Western Australia, where performance indicators are often included in the maintenance contract, allowing for the possibility of bonus payments if exceeding target performance and deductions in the case of not meeting target performance.

[4] Jeffrey A. Parker & Associates, Inc. (2009): Introduction to Public-Private Partnerships with Availability Payments

5 Rail

Background

5.1 The UK rail industry is highly regulated and structured. NR is responsible for maintaining the tracks and rail infrastructure, whilst the TOCs are responsible for running the majority of trains on the network. Rolling stock leasing companies are not relevant to the analysis in this report.

5.2 In the event of a track possession due to maintenance, structures exist to determine the compensation that is paid by NR to the TOC. As there are established mechanisms and parameters determining the penalties NR face when a railway undergoes maintenance, there are clear financial incentives for NR to minimise delays to operators caused by maintenance.

5.3 Maintenance on the rail network can be split into two categories, planned and unplanned, which will each result in different financial penalties to NR. The financial penalties and losses of income NR will face are as follows:

- **Schedule 4 (S4) Possession Regime:** In the event of planned service disruption, restricting a TOC's access to the network, NR must compensate train operators through the form of a S4 payment. The amount of compensation is calculated through a liquidated sums formulae and reflects the impact of possessions on fare revenue; the costs incurred from running replacement buses; and the costs of a change in train mileage[5]. In return for this insurance, TOCs pay a pre-determined access charge supplement (ACS) that covers the estimated efficient cost of S4 payments.
- **Schedule 8 (S8) Possession Regime:** The regime determines the level of compensation NR must pay a TOC for the long term financial impact of unplanned service disruption. It is a benchmarked regime, meaning that if NR performance deteriorates below pre-defined baseline levels, they will have to make S8 payments to TOCs. The S8 payment rates tend to be higher than S4 rates and are unique to each TOC. The rates are based on the Passenger Demand Forecasting Handbook[6].
- **Variable Usage Charge (VUC):** In the event of any kind of disruption, NR will experience a loss of income through the variable usage charge mechanism. The VUC is payable by a TOC for any journey on the rail network, and is calculated by multiplying the vehicle-specific rate by the distance travelled. Therefore if no journeys are made on the rail network due to maintenance, no income will be earnt through the VUC.

5.4 Whilst the financial penalties NR faces due to maintenance are well-defined, the extent to which they take into account delays to users is less clear. Yet when valued in monetary terms, the socio-economic costs of delays to users will be significant. The value of user delays depends on the level of demand on the rail line that requires maintenance.

[5] Rail Delivery Group (2014): Charges and Incentives User Guide
[6] Rail Delivery Group (2014): Charges and Incentives User Guide

Analysis

5.5 The rail analysis uses a range of data from NR, the Office for Road and Rail and the TOCs.

5.6 Where possible calculations are based on data from these sources. Assumptions made in the model are clearly described. The three core assumptions that underpin the rail analysis are:

- **Planned or Unplanned maintenance:** Unplanned maintenance costs more than planned maintenance, as the effect on fare revenues takes into account that passengers will be more 'forgiving' in their purchasing decisions when rail maintenance is planned and they are given sufficient time to make alternative plans. Costs of planned maintenance can be further moderated by maximising night time work, when financial and socio-economic costs are at their lowest.
- **Passenger demand:** Demand and service frequencies are the main determinant in the amount of compensation and they also determine the extent of socio-economic costs.
- **Geobear's speed advantage:** The speed advantage of Geobear on specific maintenance interventions. Volterra does not have the skills to verify the Geobear approach. Instead, the report applies a range of scenarios whereby Geobear is between twice and ten times as fast as traditional techniques of rail maintenance, based on case studies provided by Geobear and quotes from external individuals who have been involved in projects with the company.

5.7 Results are presented in a 3x3 matrix, in which scenarios for three levels of passenger demand and three different speed advantages are tested, for both planned and unplanned maintenance situations.

5.8 In producing low, medium and high passenger demand scenarios, data from the following actual train routes is used initially:

Table 2: Bottom-up rail scenarios

Information:	Low Demand	Medium Demand	High Demand
Route	Treherbert Central (Welsh Valleys) to Cardiff Central	Derby to Manchester	Clapham Junction to London Waterloo
Trains per Day	15-70	40-90	700-1500
Passengers per Day	400-2,000	1,900-4,200	222,000-489,000

Financial Impacts

5.9 The financial impacts of rail maintenance in each of these scenarios are then calculated using the data sources highlighted in Table 3.

Table 3: Financial impacts data sources and uses

Data Source	Use
ORR:	
GB Rail Industry Information[7]	Estimation of the number of passengers per train for different levels of demand.
Infrastructure Asset Failure Performance[8]	Calculation of the total yearly disruption on the rail network caused by works that Geobear would have been able to deliver through selecting sub-categories in the data that are applicable to Geobear methods.
NR:	
Possession indicator report	Estimation of the total amount of planned maintenance carried out on the rail network in a given year.
Train cancellations	Estimation of the total amount of unplanned maintenance carried out on the rail network in a given year.[9]
Yearly S4 and S8 payments to individual TOCs	Combining the amount of maintenance with GB rail information on yearly passenger km travelled, allows for an estimation of financial penalty costs per passenger km under different demand scenarios.
Track usage price lists	Estimation of the average VUC for a given journey.

Socio-Economic Impacts

5.10 Finally, the socio-economic cost imposed on passengers from the non-running of rail services for each demand scenario are calculated. This covers:

- Time delays to passengers whose train services are not running;
- Additional costs borne by passengers and other travellers from higher road congestion, greater vehicle operating costs, higher carbon emissions, and greater risks of accidents as passengers switch to alternative modes of transport.

[7] Outlines the total yearly passenger km and train km travelled by for each TOC.

[8] Dataset that gives the number of incidents and total delay minutes for each type of infrastructure asset failure.

[9] An assumption has to be made in this case as not all cancellations will be due to unplanned maintenance. Analysis in this report is based on the assumption that 30% of cancellations are due to unplanned maintenance.

5.11 Socio-economic costs are estimated using the average number of passengers per train in each demand scenario. Once the total number of passengers affected has been established, the Transport Analysis Guidance (WebTAG)[10] dataset gives parameters that allow for the valuation of the user impacts in monetary terms.

5.12 For further information on the methodology, refer to Chapter 2 in the Technical Chapter for an example calculation.

Scaling up our findings

5.13 Scaling up these bottom-up findings to obtain an annual UK-wide savings figure involves a high degree of uncertainty, but generally depends on:

- The total number of days' worth of engineering works that occur across the UK in a given year;
- The proportion of these engineering works that are the type of projects Geobear could feasibly deliver.

5.14 Data released by the ORR outlining the yearly number of infrastructure asset failure incidents[11] and total delay minutes of these incidents are used to scale up our one day findings to an annual national savings figure.

5.15 The three categories of incidents applicable to Geobear are:

Table 4: Yearly maintenance time delays

Type of Infrastructure Failure	Average Delay	Total Delays	
	Hours	*Hours*	*Days[12]*
Civil engineering structures, earthworks and buildings	6	3,284	219
Other infrastructure	1	5,401	360
Mishap: Infrastructure costs	2	3,809	254
Total	**-**	**12,494**	**833**

13/14 Key Statistics, ORR Table 2.112 – latest data.

5.16 It is uncertain how many of these incidents Geobear could feasibly deliver. We therefore provide a minimum figure – based on number of days maintenance required in the first category only – and a maximum figure, based on half the total maintenance required on all three categories.

[10] https://www.gov.uk/guidance/transport-analysis-guidance-webtag
[11] http://dataportal.orr.gov.uk/displayreport/html/html/1f9452f9-a101-46cb-bd05-2cc03c172cab
[12] The number of days maintenance required annually is calculated by dividing total delay hours in the given category by fifteen, representing the average daily rail timetable length.

5.17 Finally, in order to give a weighted yearly savings figure, an assumption is required as to the proportion of these maintenance works that occur on low, medium and high passenger demand rail lines.

6 Aviation

Background

6.1 The global air industry is highly regulated. There are three main stakeholders:

- **Airports:** provide airside and terminal facilities to airlines and passengers;
- **Airlines:** sell a transportation service to passengers;
- **Passengers:** use the facilities provided by the airport and the service offered by airlines.

6.2 In the event of a runway shutdown – for example due to a maintenance issue – there is severe disruption caused for these three groups of stakeholders. Figure 4 describes the disruption to different stakeholders as a result of airport maintenance. These events are not frequent, and whilst there are clear regulations on compensation that airlines have to offer passengers when unable to operate a flight, such rules on the compensation that airlines are entitled to from the airport are much less clear.

Figure 4: Description of the airport maintenance costs to different stakeholders

Costs to the airline:
Delays, diversions and cancellations imply airlines have to pay compensation to customers. They also face higher staff, maintenance and parking costs. Finally, there will be severe knock on effects across the entire network for most airlines.

Costs to the airport:
In the event of a runway shutdown, flights have to be diverted to alternative airports and some arriving flights will suffer cancellations. The airport will lose on the potential income arising from landing/parking fees associated with these flights.

Costs to passengers:
Passengers will see their journeys disrupted and this in most cases will imply taking considerably more time to reach their destination. Business travellers value their time more than leisure travellers, hence the impact of a shutdown will be higher on business passengers.

Externalities:
Additional CO_2 emitted as a result of flight diversions and aircraft holding airborne as they await a landing slot.

6.3 The total cost of a runway shutdown will be largely dependent on the overall level of demand. An inoperative runway at Cardiff will have a much lower impact than one at Heathrow. Similarly, a runway shutdown during peak summer would result in higher costs than during the off-peak season.

Analysis

6.4 The model used for the air sector is based on a study which simulates the complete shutdown of Heathrow airport during an hour[13] (Pejovic, 2009). This model uses updated values from Eurocontrol's Standard Inputs for Cost Benefit Analysis[14] as well as a study on the cost of delays by the University of Westminster[15].

6.5 Similar to Pejovic's paper, the rescheduling of affected flights is based upon the following assumptions:

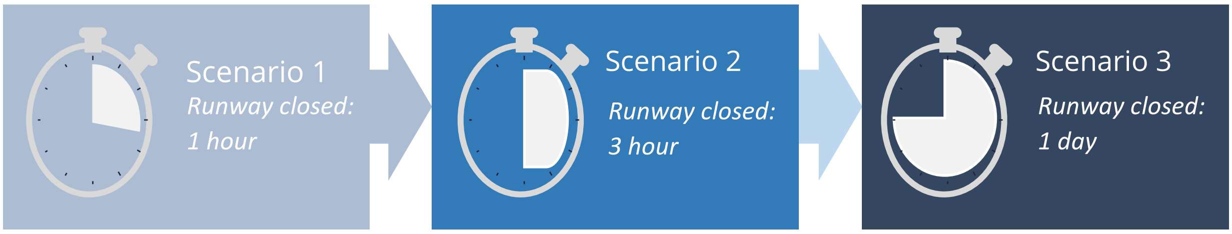
- Airborne flights are assumed to divert to alternative airports unless they are scheduled to land 20 minutes or less before re-opening time – in which case they hold airborne.
- Departing flights are delayed and allocated new slots once the runway re-opens. Non-delayed flights have priority over those delayed, but once these have departed delayed flights depart in their scheduled order.
- Flights are cancelled if they are delayed > 3 hours.

6.6 In producing low, medium and high demand scenarios we simulate a shutdown at the following airports[16] during their busiest hour:

- Low demand: Cardiff (CWL) – busiest hour 09:00 am
- Medium demand: Luton (LTN) – busiest hour 07:00 am
- High demand: Heathrow – busiest hour 09:00 am.

6.7 First, a scenario where the runway is closed for a single hour is tested – to allow comparability with Pejovic's Heathrow Case Study and simulate a scenario where Geobear's methods may be up to 15 times faster. Then, the impact of a three-hour shutdown is tested. This allows for another evaluation of the costs when using Geobear's method, which in this case is approximately 5 times faster. Finally, the runway is assumed to be closed for a whole day to allow for traditional maintenance methods.

Figure 5: Runway shutdown scenarios



6.8 It is worth noting that whilst a shutdown at Cardiff and Luton completely interrupts operations, Heathrow can continue to operate at 50% of its capacity and thus handle approximately half of its scheduled air traffic movements.

[13] A tentative analysis of the impacts of an airport closure, Pejovic, Noland, Toumi, Williams, 2009.

[14] Standard Inputs for Cost-Benefit Analyses, Eurocontrol, 2018

[15] European airline delay cost reference values, University of Westminster, 2015

[16] The flight schedule for Luton and Cardiff airports was extracted from Flightradar24 on the 3d of April.

Financial Impacts

6.9 Airlines will bear most of the losses associated with a runway shutdown, for they face:

- Costs of delays – in the form of higher staff, airport, handling costs as well as passenger compensation. These are estimated using Eurocontrol recommended values.
- Cost of diversions – as a result of additional landing fees, repositioning of aircraft and staff as well as passenger compensation. These are estimated using Eurocontrol recommended values.
- Cost of cancellations – as a result of passenger compensation and network effects, such as staff and aircraft being located at the wrong airport.
- Environmental cost – the airline faces the cost of extra pollution, through aircraft either being held airborne or facing a diversion, as well as the cost of repositioning the plane back to the original airport.

6.10 In the event of a runway shutdown, airports will face a decrease in the level of aeronautical revenue they collect – as landing fees are only collected if the runway is operative. The revenues foregone as a result of fewer aircraft landing at the airport are calculated from the landing fees and the number of flights during the different scenarios.

6.11 Landing costs at Heathrow are calculated according to the noise category of the aircraft. As a consequence we are unable to add this cost to our model. Nevertheless, this makes our estimate directly comparable to Pejovic's study[17] which also ignores this cost.

Socio-Economic Impacts

6.12 The socio-economic costs as a result of air travel disruption cover time delays to passengers – either due to a delay, a diversion or a cancellation – and additional CO_2 emitted.

6.13 Socio-economic costs are estimated using the average load factor for a commercial flight[18] and the proportion of business and leisure travellers for the airport[19]. After the total number of passengers affected by type is estimated, data on passenger value of time from Eurocontrol is used to value the impact of delays in monetary terms.

6.14 It is hard to estimate the amount of time lost as a consequence of a cancellation or diversion – since each passenger will take a different time to arrive at their destination. Balvanyos and Lave (2005) estimate that cancellations and diversions

[17] A tentative analysis of the impacts of an airport closure, Pejovic, Noland, Toumi, Williams, 2009.

[18] Eurocontrol, 2018

[19] CAA Annual Passenger Survey, 2015 (Cardiff), 2016 (Luton)

cost a minimum of $60 and $100 per passenger respectively. The lack of official recommended values implies these costs can only be used as an indication.

6.15 Using the fuel burnt values given by Pejovic and Noland in their Heathrow study as a proxy, we estimate fuel burn per minute of flight in order to calculate the additional CO_2 emitted from aircraft holding airborne. Again, based on this study the extra CO_2 per diverted flight is calculated and applied to each of our case studies. Overall, the environmental cost represents a small proportion of the total cost of a shutdown.

6.16 For further information on the methodology behind the calculation of each of these examples, see Chapter 3 in the Technical Chapter.

7 Results

7.1 Many of the outcomes found in the three models will be highly variable. This is a reflection of variations in demand by transport mode, location and time. To account for this, the results are shown in the form of a wide range of outcomes.

7.2 A range is more appropriate than a specific number, particularly as the process of scaling up delays and costs at individual sites to yearly totals is a difficult process.

Road

7.3 A number of different scenarios are shown, depending on the road type, level of demand and how much quicker Geobear is than traditional engineering techniques. Another important factor is the number of lanes on the road affected; a four lane motorway reduced to three lanes may be able to cope reasonably well, whereas a two lane road cut to one lane will probably suffer from higher congestion. Most roads across the country are single lane, and lane closure leads to traffic being diverted.

7.4 Tables 5 and 6 below show the total socio-economic benefit for every one kilometre[20] of road treated by Geobear instead of traditional methods.

7.5 The first table shows the costs involved from going from two lanes to one on an A road, whilst the second one shows the cost of closing a single lane A road and therefore having to divert traffic. This shows how much more beneficial it is to save time on roadworks that lead to a road being completely closed in a particular direction.

Table 5: Saving per 1 km of roadwork: 2-lane A road, with one lane shut

	Total savings per km (£)		
	Geobear Time Saving		
Passenger Demand	*2x*	*5x*	*10x*
Low	150	610	680
Medium	340	1,200	1,300
High	410	1,400	1,600

Table 6: Saving per 1 km of roadwork: 1-lane A road on SRN, shut

	Total savings per km (£)		
	Geobear Time Saving		
Passenger Demand	*2x*	*5x*	*10x*
Low	640	2,500	3,400
Medium	1,100	4,300	5,800
High	1,400	5,400	7,400

[20] The figures given are based on a weighted average of roadworks costs at three different times: during a weekday (30%), during a weekend (10%) and during the night (60%). Proportions are based on HMAT statistics reporting when roadworks occurred on different types of road, with proportions given for 24-hour (approx. weekday), off peak (approx. weekend) and night.

Rail

7.6 Initial findings are calculated using bottom-up approaches for low, medium and high passenger demand scenarios. In this section we outline the results of nine scenarios for a day of both planned and unplanned maintenance, where different levels of demand and varying speed differentials are considered.

7.7 Table 7 shows the potential overall savings to NR and their users by using Geobear methods for the equivalent of one day's unplanned traditional maintenance work. One day's maintenance means that the rail line is possessed for the entire 15-16 hour timetable period in which trains tend to operate each day, if traditional methods of maintenance are used. The sums are large, over £5m for a day on one of the busiest lines.

Table 7: Savings for one day unplanned rail maintenance

	Total Savings (£000)				
	Geobear Time Saving				
Passenger Demand	*2x*	*5x*	*10x*	% Financial Penalties	% Socio-Economic Costs
Low	10	25	50	34	66
Medium	40	100	200	41	59
High	1,100	2,600	5,300	21	79

7.8 Table 8 gives the potential savings to NR and their users by using Geobear for the equivalent of one day's planned traditional maintenance work. The savings made in planned maintenance costs are roughly half those of the unplanned scenario for two reasons. Firstly, the financial penalties are lower as passengers are given notice to make alternative travel plans, and secondly in the one day of planned maintenance scenario we assume that the works would occur on a weekend, when passenger demand and the number of trains running tends to be lower.

Table 8: Savings for one day planned rail maintenance

	Total Savings (£000)				
	Geobear Time Saving				
Passenger Demand	*2x*	*5x*	*10x*	% Financial Penalties	% Socio-Economic Costs
Low	1	3	6	29	71
Medium	20	50	100	38	62
High	510	1,300	2,600	18	82

Aviation

7.9 Table 9 outlines the potential cost savings from Geobear's method if traditional maintenance required that the airport be shut for a day. The scenarios considered here are that Geobear could perform the maintenance either five or fifteen[21] times faster (taking 3 hours or 1 hour respectively).

Table 9: Savings made from a one day airport closure

Airport Type	Savings (£m)			
	5x faster	*15x faster*	% Financial Penalties	% Socio-Economic Costs
Small	0.44	0.54	81%	19%
Medium	3.45	4.82	67%	33%
Large	16.8	19.3	74%	26%

7.10 This result is in line with previous estimates in the literature. For example, Pejovic[22] estimated the cost of a full (two) runway shutdown at Heathrow during one hour to be c. 1.2 million euros and our model estimates a cost of €0.67 million (or £0.58m) for a one runway shutdown at Heathrow – approximately half.

7.11 For a more detailed breakdown of the costs of maintenance for each airport, refer to Chapter 4 in the Technical Chapter.

Scaling up

7.12 A large amount of road and rail maintenance occurs in the UK every year. It is therefore necessary to scale up the Geobear method's cost savings to an annual figure, based on the total amount of road and rail maintenance we believe Geobear would be able to feasibly deliver annually.

7.13 In the case of aviation, maintenance is far more periodic in nature and does not happen consistently. It is therefore not appropriate to scale up aviation to an annual figure, as the periods between aviation maintenance are often much longer than a year. Aviation maintenance cost savings are viewed as 'one-off' scenarios that occur sporadically.

Road

7.14 Table 10 shows the results scaled up from the single scenarios described above, to an annual figure showing the benefit that Geobear could bring about across the whole of Great Britain in the highways sector.

[21] Fifteen times faster is used for comparability with Pejovic's (2009) Heathrow model.
[22] A tentative analysis of the impacts of an airport closure, Pejovic, Noland, Williams, Toumi, 2009, Journal of Air Transport Management.

7.15 There is uncertainty around these results, because:

- The proportion of works that can be done by Geobear may be higher: using our assumptions, only 9% of total roadworks are within scope;
- It is conservatively assumed that for every 1km of road closed by roadworks, the length of the diverted route is 2km. For some trips, this figure is likely to be much higher;
- The SRN high demand scenario is populated using actual data, but the level of demand for other scenarios relative to that is based on assumptions rather than actual traffic flows.

Table 10: Estimate of annual savings achieved through Geobear - highways

	Yearly Savings (£m)		
Passenger Demand	*2x*	*5x*	*10x*
Low	8.4	33.0	39.5
Medium	16.6	59.0	70.1
High	20.5	72.7	87.5

Rail

7.16 In the minimum scenario, Geobear would be feasibly be able to deliver on 219 days' worth of traditional maintenance work. In the maximum scenario defined, Geobear would deliver 416 days' worth of rail maintenance in a year. In terms of total delay minutes caused by infrastructure asset failure, these scenarios assign 4-8% of maintenance as the type of project that Geobear could feasibly deliver.

7.17 The minimum and maximum savings figures can be found in Chapter 5 of the Technical Chapter. The potential savings will vary depending on whether the maintenance is planned or unplanned.

7.18 Now if we make the following assumption about the proportion of rail maintenance that occurs on rail lines of each level of demand:

- Low – 30%
- Medium – 50%
- High[23] – 10%

[23] The proportion assumed for high is based on the proportion of GB passenger km that are accounted for by passengers arriving and departing at main London stations, as the bottom-up example used to underpin this scenario is a 'very-high' scenario based on one of the busiest rail lines in the UK.

7.19 Finally, we assume that 42%[24] of maintenance is planned and the remaining 58% of maintenance is unplanned, arriving at an overall yearly range of savings as shown in Table 11.

Table 11: Overall yearly rail maintenance savings by using Geobear

	Yearly Savings (£m)		
All Unplanned Maintenance	*2x*	*5x*	*10x*
219 Days	30	70	140
416 Days	60	200	690
All Planned Maintenance			
219 Days	15	35	70
416 Days	25	65	130
Overall			
219 Days	20	55	110
416 Days	45	140	400

Road and Rail[25] in the G7

7.20 The G7 consists of 7 countries – the UK, USA, France, Germany, Italy, Japan & Canada.

7.21 A basic extrapolation of the UK results is performed to arrive at an annual G7 yearly savings range for both the road and rail sector, using a factor for UK to G7 of approximately 15 for road and 7 for rail. Results for the G7 are shown in Table 12.

7.22 The road sector is scaled up by a factor that takes into account the total road passenger kilometres[26] travelled in comparison to the UK, and then also weights passenger kilometres by a traffic index score[27] as the road market focuses on socio-economic costs to users.

7.23 The G7 savings for the rail sector is calculated by using the total yearly passenger km[28] travelled in each country relative to the UK.

7.24 Whilst rail continues to have the potential to make larger savings, the savings that could be made across the G7 are substantial in both sectors, particularly if the Geobear method proves to be significantly faster than the alternatives. In fact, road savings will be significantly larger than rail in G7 countries where rail is utilised significantly less than in the UK, such as the USA and Canada.

[24] Assumption based on the total amount of S4 and S8 payments paid by NR in 2016/17. Bottom up scenarios suggest S4 is 40% lower than S8 unit cost per passenger km. Taking this into account during comparison of total S4 and S8 costs suggests 42% of maintenance is planned.
[25] No extrapolation was performed for the aviation industry due to irregular occurrence of aviation maintenance, but one-off closures of airport across the G7 can expect to incur similar savings to UK airports when employing faster maintenance methods.
[26] https://data.oecd.org/transport/passenger-transport.htm - OECD data for 2015 was used for all countries, except for Japan and Canada where only 2009 data on road passenger km was available.

[27] https://www.numbeo.com/traffic/rankings_by_country.jsp
[28] https://uic.org/IMG/pdf/synopsis_2016.pdf

Table 12: Yearly road and rail savings in the G7

	Yearly Savings (£bn)		
G7 Road	*2x Faster*	*5x Faster*	*10x Faster*
Low	0.1	0.5	0.6
High	0.3	1.1	1.4
G7 Rail			
Low	0.2	0.4	0.8
High	0.3	1.1	2.9
G7 Total			
Low	0.3	0.9	1.4
High	0.7*	2.2	4.3

** Some figures may not add up due to rounding.*

7.25 Robustness checks were carried out by scaling up the UK results to a G7 figure based on GDP and population. These results are found in Tables 33 and 34 in Chapter 6 of the Technical Chapter. The road savings made in the G7 based on GDP are almost identical to the amount stated in Table 12, whilst road savings calculated on the basis of population were found to be approximately 30-40% lower. This suggests that although road savings may be slightly overestimated, the results appear to be reasonably robust. When based on GDP and population, rail savings are approximately 60-80% higher than the amount stated in Table 12, suggesting that the method used to obtain the stated G7 rail figures was conservative.

Road and Rail in Finland, Sweden & Poland

7.26 Volterra was asked to perform a similar basic extrapolation for Finland, Sweden & Poland, as these countries' markets are of strategic interest to Geobear. The UK results are therefore extrapolated again pro rata to passenger distance travelled in these countries to give an initial indication of the potential yearly savings that faster maintenance methods could bring to the road and rail industries in these countries.

7.27 The only difference in methodology from the G7 extrapolation is that the rail results for these countries were scaled down by a factor of 0.65, as all rail industries in these countries are nationalised. Therefore we can expect there to be no financial penalties and hence only the value of the socio-economic cost (a 65% average of total costs in the UK) savings is estimated.[29] The results are given in euros.[30]

7.28 Finland's passenger kilometres travelled are significantly smaller than the UK; rail passenger kilometres are equivalent to just 6% of the UK's total passenger distance, whilst in the road sector it is slightly higher at 8% of the UK. Potential yearly savings of up to £7m in the road sector and £15m in the rail sector could be made through faster maintenance methods in Finland (Table 13).

[29] Note that the same scaling down was not performed at G7 level because G7 countries rail industries are far more varied, with a definite private sector presence in at least some countries.
[30] Exchange rate assumed to be £1 = €1.15.

Table 13: Yearly road and rail savings in Finland

Finland:	Yearly Savings (€m)		
Road	*2x Faster*	*5x Faster*	*10x Faster*
Low	0.8	3.1	3.7
High	1.9	6.8	8.1
Rail			
Low	1.0	2.4	4.8
High	1.9	6.3	17.2

7.29 Sweden's yearly passenger kilometres are also small relative to the UK; the UK results were extrapolated by a factor of 0.13 in the road industry and 0.10 in the rail industry. Potential yearly savings of up to £11m in the road sector and £25m in the rail industry could be made through faster infrastructure maintenance methods in Sweden (Table 14).

Table 14: Yearly road and rail savings in Sweden

Sweden:	Yearly Savings (€m)		
Road	*2x Faster*	*5x Faster*	*10x Faster*
Low	1.2	4.9	5.8
High	3.0	10.7	12.9
Rail			
Low	1.6	3.9	7.9
High	3.2	10.3	28.1

7.30 The largest yearly savings that could be made out of the three European countries discussed in this section would be in Poland, due to the fact that the country has yearly rail passenger kilometres equivalent to 14% of the UK and total road passenger distance equivalent to 30% of the UK. Table 15 shows that savings of up to £26m could be made in the road industry through faster maintenance, whilst yearly savings of up to £36m could be made in the rail industry in Poland.

Table 15: Yearly road and rail savings in Poland

Poland:	Yearly Savings (€m)		
Road	*2x Faster*	*5x Faster*	*10x Faster*
Low	2.9	11.2	13.4
High	7.0	24.7	29.8
Rail			
Low	2.3	5.7	11.5
High	4.6	14.9	40.8

7.31 Robustness checks were carried out for all countries by extrapolating the UK results based on the countries' GDP and population figures; results are outlined in Tables 35-40 in Chapter 7 of the Technical Chapter. For all countries, results based on GDP and population figures were at least identical if not significantly larger, suggesting that the method used to extrapolate the UK results for these countries was conservative.

8 Conclusions

8.1 The speed with which Geobear can deliver infrastructure maintenance compared to more traditional techniques is paramount in determining the total level of savings that using Geobear can deliver. Quotes that were received from stakeholders in different industries go some way towards suggesting that Geobear solutions often have a verifiable speed advantage in delivering maintenance.

8.2 The timing of infrastructure closures is also important; the time advantage of Geobear is likely to produce much larger savings in scenarios where works must occur during peak transport hours – such as unplanned maintenance on a busy rail line – or in scenarios where Geobear is able to work through the night and cause no disruption to users, unlike with traditional methods.

Road

8.3 If decisions on highway maintenance works were taken purely on the financial cost they would miss most of the economic costs associated with them. The financial incentive is all about cost reduction and not about delivering socio-economic gains to users. Unlike the rail industry, the roads have no system that penalises authorities for delays associated with roadworks.

8.4 This report does not in any way suggest that the UK authorities should reduce road maintenance spending; indeed the current state of local roads suggests a significant increase in spending is probably required. However it seems possible that the UK is missing an opportunity by not taking account of the user costs caused by maintenance and, more importantly, by not incentivising contractors to introduce new techniques/approaches which might be able to deliver the same outcomes faster.

8.5 The financial costs of roadworks are already large, but the costs imposed on road users in terms of delays, vehicle operating costs, safety, emissions, and unreliability can also be very substantial. A system which judges maintenance bids on a combination of capital cost and user costs would lead to better maintenance procurement and the development of new innovative maintenance techniques resulting in a better overall outcome.

8.6 This report suggests that the benefit brought about by using faster methods for highway maintenance could be considerable, although the scale of that benefit depends on the assumptions applied. The benefit per kilometre of roadwork can vary considerably depending on the level of traffic that uses it.

Rail

8.7 Stakeholders in the rail industry (such as Network Rail) face real financial penalties as a result of maintenance works and hence are much more likely to utilise maintenance methods that will save them time and reduce financial penalties.

8.8 Faster maintenance methods become much more attractive once socio-economic costs are taken into account. Financial penalties typically account for only 20-40% of total costs, with socio-economic costs accounting for the remaining 60-80% of total costs.

8.9 Faster maintenance methods are significantly more important on rail lines that have higher levels of passenger demand, as this is where the differential in costs between the two methods is at its highest. Dependent on actual maintenance costs, faster maintenance solutions may not be a profitable method to use at low levels of passenger demand, as financial penalties will be lower on less utilised rail lines and the user costs will be much less due to a lower number of passengers affected.

8.10 The time advantage of Geobear is key to determining the extent of the total benefits they can bring to an economy; the faster it is compared to traditional methods of maintenance, the larger the savings to the infrastructure owners and passengers.

Aviation

8.11 The large financial costs associated with runway maintenance works make the case for fast repair methods strong. Unlike the rail and road industries, socio-economic costs represent a smaller proportion than financial costs of runway maintenance work - financial costs typically account for 65% - 85% of total costs.

8.12 Socio-economic costs are still significant and must be considered, given the large volume of passengers affected by a runway shutdown. These are harder to estimate given the lack of consistent recommended values in the literature. Some though are offset by compensation payments from the airport owners and the airlines. Our estimate provides an indication of how large socio-economic costs could be as a result of runway maintenance works.

8.13 In a high demand scenario, the importance of faster maintenance increases. Airports like Heathrow handle a very large volume of flights each day, and the knock-on effects of severe delays, diversions and cancellations, lasts for days. Nevertheless, under a low demand scenario Geobear is likely to be more expensive than the savings that accrue from faster maintenance.

8.14 This report suggests that using faster solutions for runway maintenance would be highly beneficial; with the medium and high demand scenarios, benefits increase faster than demand.

Summary: a requirement for change

8.15 Some transport modes and locations are more likely to be amenable to paying for faster infrastructure repairs than others, mainly because in some industries infrastructure owners face tangible financial penalties, whereas in the road industry the economic costs of maintenance fall predominantly on users rather than the infrastructure owners.

8.16 It would make better sense, economically, to have a system of infrastructure maintenance tendering which considered both the financial costs borne by the infrastructure owners – including financial penalties incurred as well as contractor cost – and the socio-economic costs imposed on users.

8.17 It is surprising that the Department for Transport does not apply a valuation to the delays caused by maintenance works. Investments in transport are justified through the valuation of user benefits, so why are maintenance works not valued in user costs? It may be that the costs involved in valuing the user disbenefits are disproportionate to the scale of the impacts, but it must be possible to produce some simple rule of thumb guidance.

8.18 There are some existing contracting mechanisms which are more successful in including socio-economic costs to users in their valuation. In the USA, some states include a monetary value of user costs from road closures in the bidding process, by applying a simple daily charge reflecting the disruption by the road being out of operation. There are also examples of "lane rental" charges being applied for maintenance requiring the takeover of a road, and incentives installed in maintenance contracts through the form of bonus payments for early completion.

8.19 These kind of approaches would encourage innovative techniques for delivering maintenance works which produce significant economic benefits. In the aviation sector change would be relatively small, but in the road and rail industries there could be sizeable changes and significant economic gains.

Disclaimer

LIMITATION: This report has been prepared on behalf of and for the exclusive use of Volterra Partners LLP's Client, and is subject to and issued in connection with the provisions of the agreement between Volterra Partners LLP and its Client.

Volterra Partners LLP accepts no liability or responsibility whatsoever for or in respect of any use of or reliance upon this report by any third party.

105 Euston House
24 Eversholt Street
London NW1 1AD

info@geobear.com
www.geobear.co.uk