Infrastructure and Projects Authority

Case Study: Benchmarking tunnelling costs and production rates in the UK

Synopsis

As part of the Transforming Infrastructure Performance (TIP) programme, the Infrastructure and Projects Authority (IPA) is developing a new top-down benchmarking methodology, which will be used to encourage better and more consistent benchmarking across infrastructure projects among both government departments and client organisations. The exercise described in this document successfully explored and tested that methodology.

Benchmarking is the process by which the costs, schedule, benefits and performance of a project are evaluated by comparison against a common standard derived from similar projects. There is currently no UK government-approved top-down benchmarking methodology for infrastructure. Furthermore, there are often discrepancies within the data used for this purpose.

In September 2018, in collaboration with the British Tunnelling Society (BTS), a tunnelling forum was held as a pilot to help formulate the methodology. Tunnels were chosen as they have been successfully benchmarked in the past and allow effective testing of the IPA's methodology. Industry stakeholders from multiple sectors came together to share information on tunnelling costs, with additional data provided directly from a range of departments, sponsors and programmes which are involved in tunnelling activities.

The exercise demonstrated that, when done in an appropriate forum, there is considerable appetite for collaboration and data sharing in a non-commercial environment between public and private organisations for the purpose of robust benchmarking. The methodology was also well received, being accepted as a recognisable standard and best practice.

The IPA will look to continue to facilitate similar exercises and develop increasingly sophisticated benchmarks which extend beyond costs to include schedule, benefits and performance. Similar initiatives are being planned, for example to generate a benchmark for Project Management costs.

Following the exercise, participants have been able to enhance their own benchmarking and decision making capabilities by enriching the information and analysis provided with their own data.

While an analysis of the cost data was carried out and a number of key findings and recommendations were formulated, further data sets are required to produce a tunnel benchmark which can be used more widely. These are being sought from international projects.

Introduction

This paper describes a recent re-benchmarking exercise carried out in 2018. It sets out the methodology adopted, the results, and recommendations for their future use.

In December 2010 Infrastructure UK (IUK) published the Infrastructure Cost Review, which sought to investigate an apparent difference between the cost of infrastructure construction in the UK in relation to other countries. The Technical Report contained benchmarking information for energy, rail, road and flood defence schemes, while the Main Report set out the purpose and findings of the reports.

Owing to an expected upcoming pipeline of tunnelled projects at the time, one of the cost comparisons was of tunnel works. Appendix G of the Technical Report dealt with tunnels and included benchmarking figures. It was produced specifically by the BTS, who researched the cost of a number of recently completed tunnels.

Infrastructure and Projects Authority (IPA)

IPA is the government's centre of expertise for infrastructure and major projects, joint reporting to HM Treasury and the Cabinet Office. It supports the continuous improvement and successful delivery of all types of projects, working with government and industry to ensure projects are delivered efficiently and effectively. It was established in 2016 from the merger of the Major Projects Authority and IUK, who produced the 2010 Cost Review mentioned above.

Infrastructure is one of five foundations of productivity set out in the government's Industrial Strategy, along with Ideas, People, Business Environment and Places. The TIP report, which was published in December 2017, is the government's plan to increase the effectiveness of investment in infrastructure, with 'Benchmarking for better performance' constituting the first theme of the programme.

To address this theme, IPA has established a benchmarking function to provide support across government, with the aim of encouraging a better and more consistent approach to benchmarking in projects across infrastructure sectors. Within public sector infrastructure projects benchmarking is a valuable tool to improve decision making and projects evaluation. However it is currently used infrequently and inconsistently, being most often undertaken in house and on a project by project basis. Following the TIP programme, the team's ambition is to ensure all major projects and programmes are selected, prioritised and evaluated using benchmarked data on both cost and performance.

The IPA is in the process of establishing a benchmarking methodology, for intended publication in early 2019. The exercise described in this document was intended as a pilot to help formulate that methodology.

Benchmarking

The term "benchmarking" has several meanings and frequently refers to the act of comparing one organisation's performance or practices against others in that particular industry, with the intention of improving relevant metrics in one's own business. Benchmarking leverages data to challenge conservative or optimistic estimates, as well as set (and check) performance and cost targets. When used appropriately, benchmarking will drive competition and innovation, securing better outcomes for projects.

In this paper we use “benchmarking”, or more accurately “cost benchmarking”, to mean the collation of actual costs from completed projects in order to predict likely outturn costs for another project. We recognise that benchmarking has more sophisticated potential application beyond cost estimates, however this broadly falls beyond scope of the exercise outlined in this paper.

The process requires obtaining cost figures for similar projects both in the home country and other, comparable, countries, which are then plotted on a graph against key factors that impact cost; for example, tunnelling costs are often plotted against tunnel diameter or length. Costs are usually expressed as all-in figures which are simple to use, e.g. cost per metre of tunnel, and frequently need to be adjusted for inflation to set a common date for comparison purposes.

Tunnelling cost & production rate benchmarking exercise

Appendix G of IUK's 2010 Cost Review (Technical Report) has been referenced on a number of tunnelling projects. With tunnelling projects comprising a significant part of the UK's current infrastructure plans, it was considered that an update of that appendix would be a helpful exercise for project sponsors and decision makers.

Under the impetus of the IPA's TIP programme, a number of organisations began compiling their own tunnel benchmarking data. The IPA benchmarking team, together with Highways England (HE), sought to bring this data together in a tunnelling forum where key delivery organisations and individuals could benefit from sharing information on tunnelling costs. In order for this to succeed, participants needed to agree on consistent and common metrics, as well as a methodology and protocols for the sharing of data.

It was agreed that IPA and HE would work with the BTS, as subject matter experts and the author of Appendix G, to help establish a template for the collation of new data and prepare an updated cost benchmark for tunnels.

Practical challenges of benchmarking tunnels

There are a number of difficulties in estimating the costs of major economic infrastructure (rail, road, energy, water projects). Firstly, there is often a limited number of similar projects or similar tasks to enable reliable unit costs to be established. Secondly there are a number of variables, including ground conditions, tunnelling method, length, diameter and access arrangements, which make any direct comparison difficult or impossible. Thirdly, owing to the long duration of infrastructure projects the costs available at completion are usually a number of years in the past. This is compounded by the fact that the project may have been tendered or contracted in very different economic conditions to those prevailing when the benchmarking exercise is carried out.

Most significantly, data is rarely readily available and for public sector projects there are no universally recognised metrics, notably for performance. The result is that any data used for benchmarking is often, sparse and not always suitable for robust comparison.

For example, when analysing the cost data received for completed projects it is often not possible to separate the costs related to tunnelling from other project costs. The contract sum may or may not have included items such as indirect costs (for example, overhead), spoil disposal, cross passages and portal construction.

The lesson is that benchmarking cannot be undertaken as a purely mechanical exercise. Subject matter expertise and direct project knowledge is required to enable sensible decisions about which projects can provide valid benchmark data, about how to adjust for inflation and economic factors, and how to allow for differences between the benchmark projects and the project in hand.

Logistics

The benchmarking initiative comprised a series of workshops with all interested parties. The first to agree the process and necessary protocols, followed by a second to share the tunnel cost data before a final meeting to review and discuss the results.

A bespoke template, based on the International Construction Measurement Standards (ICMS), was produced by the BTS and circulated by IPA to participants. The purpose of the template was to avoid discrepancies in the data provided and ensure that the tunnel cost could be accurately separated from the overall project costs and that the specific attributes of the tunnel, depth, and ground conditions, could be compared and understood. This was circulated to all participants for review prior to the first workshop. Appropriate steps to anonymise, encrypt and store data were discussed and agreed.

The method of data collection, the template and the level of detail requested required two iterations of data collection in order to arrive at a robust set of project returns.

Participants

The delivery organisation participants in the project comprised Crossrail; High Speed 2; Heathrow; Network Rail, Transport for London, Highways England; Thames Tideway Tunnel; National Grid and Scottish Water, in addition to IPA, the BTS and the Department for Transport's (DfT) Transport Infrastructure Efficiency Strategy (TIES) team.

IPA benchmarking methology

The IPA's benchmarking methodology, which is being developed with support from the private sector and is based on the approach developed on major projects since 2016, seeks to compare cost, schedule, benefit and performance. It intends to do so by breaking down the total project into common assets or components which might in themselves be comparable to similar assets from other projects.

For example, a major rail project is often made up of stations, viaducts, tracks, and tunnels etc. Each of these components can be benchmarked using agreed metrics which can, with the support of experienced individuals, produce a Benchmark Indicative Asset Cost (BIAC) for each specific asset. The total benchmark for a project can then be assembled with a series of BIACs drawn from a range of other projects.

Projects in other Western European countries tend not to include costs of supervision or land purchase, for example. This makes projects appear relatively cheap when compared with UK projects, where those costs are usually included in the overall figures. When properly applied, the BIAC approach removes those costs and therefore allows for better comparisons.

Data management

Data was collected directly from a wide range of departments, sponsors, programmes and other controlled sources involved in tunnelling activities. The data collected was historical cost, schedule, performance and attributes data. Data was initially gathered both locally and internationally.

For estimating cost benchmarks:

- the total cost for each tunnel was rebased to 2016/2017 base year using HMT GDP deflators;
- foreign currencies were converted to GBP using applicable historical exchange rates and then rebased in the cases of international tunnels;
- the cost per kilometre (£million/km) was obtained by dividing the total cost by total length for each tunnel;

- the volume of the tunnel was also calculated for further analysis (fig. 3);
- sample statistics were obtained and analysed to assess the quality of the sample and the validity of the inference made from the sample.

Initially a set of 169 projects was collected, based on the total available data set. However the quality of this data was very mixed. The data quality was scored with a large proportion of the data being classified as poor to low quality based on a number of factors which would undermine the analysis, this included a lack of key data asset attribute information (i.e. length, depth, tunnelling method, project age), differences in technology and labour, or the inability to extract the tunnel asset cost from the total project cost (which may include non-tunnelling assets such as bridges, viaducts, or other direct and indirect cost).

A second round of data collection was carried out to ensure that a consistent set of high quality data, based on a BTS revised template, was captured for analysis. This excluded projects prior to 2004 to limit the variability of long term cost inflation.

Data was obtained for sixteen UK tunnels from both the transport and utilities sectors, in ground conditions ranging from soft rock to cohesive and non-cohesive soils. Construction methods included Tunnel Boring Machine (TBM), backhoe shield and excavator, with precast concrete or shotcrete linings. A reduced number of projects resulted in higher quality and more reliable analysis.

A small number of international tunnel data points were received, however it was not possible to assure the data quality to the same standard as the UK projects, as the quality of the technical information (i.e. undefined ground conditions, or the inclusion of other project costs) was not sufficient to ensure a consistent set of comparators. Improving the quality of technical information from international projects is a focus of the IPA benchmarking team going forward.

Results and Analysis

The analysis has been carried out in five groups:

1. Cost vs Diameter for Transport projects.
2. Cost vs Diameter for Utility projects
3. Comparison of transport projects against utility projects using total tunnel volume
4. Comparison of transport projects against utility projects using cost per unit volume against tunnel length
5. Assessment of tunnel performance or production rates.

It was apparent that the data separated distinctly into transport tunnels and utility tunnels. The former were larger, in the range of 5.5m to 11.5m diameter but most fell between 6.8m and 8.1m, while utility tunnels were in the range of 2.m to 8.8m but most fell between 3.4m and 5.2m.

For each project the total tunnel cost was normalised for length and plotted against the external diameter of the tunnel. The results are shown on figure 1 for transport tunnels and figure 2 for utility tunnels.

Factors that were investigated but considered not to be principal drivers of cost for these tunnels were ground conditions, tunnelling method and lining type. The principal drivers of cost across both groups are, perhaps unsurprisingly, length and diameter with some useful correlation of data points to trend lines being presented.

1. Cost vs Diameter for Transport projects.

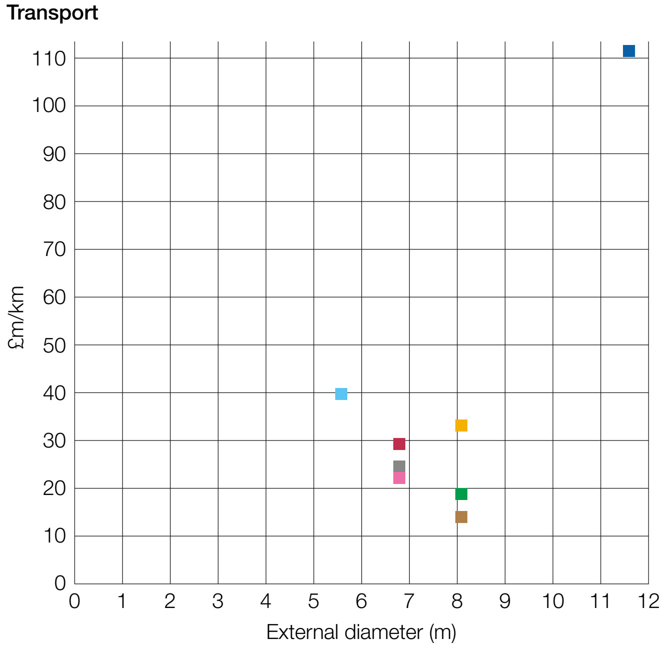

Figure 1: Transport Tunnels

Figure 1 plots the eight transport tunnels (as coloured squares). It is clear that given the small sample size of projects with variable tunnel length and tunnelling methodology the graph should be viewed with some caution, if using this graph to benchmark transport tunnels. Additional observations (rows of data) are required to produce a robust analysis. For a better representation, which takes account of a larger range of influencers, see Figure 4.

2. Cost vs Diameter for Utility projects

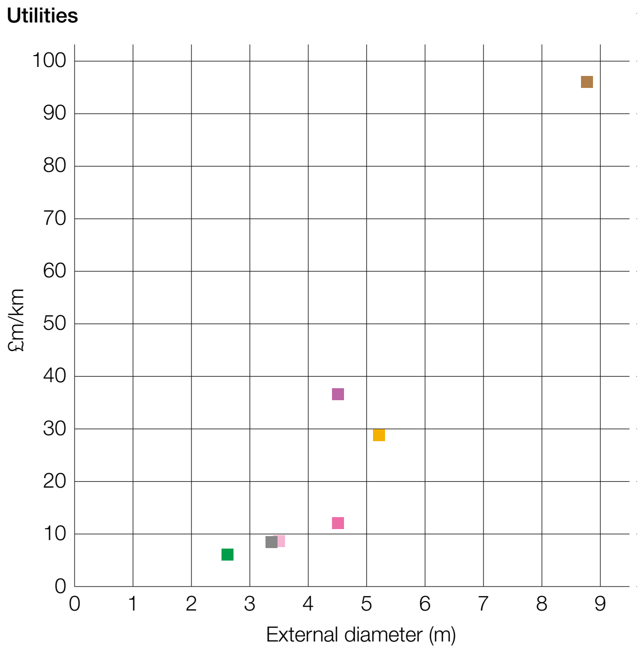

Figure 2: Utility Tunnels

Figure 2 plots the seven utility tunnels (as coloured squares). Again, while it is possible to interpret a clearer progression on utility tunnels than transport tunnels, given the small sample size of projects the graph should be viewed with some caution if using this graph to benchmark transport tunnels. Additional observations (rows of data) are required to produce a robust analysis. For a better representation, which takes account of a larger range of influencers, see Figure 4.

3. Comparison of transport projects against utility projects using total tunnel volume

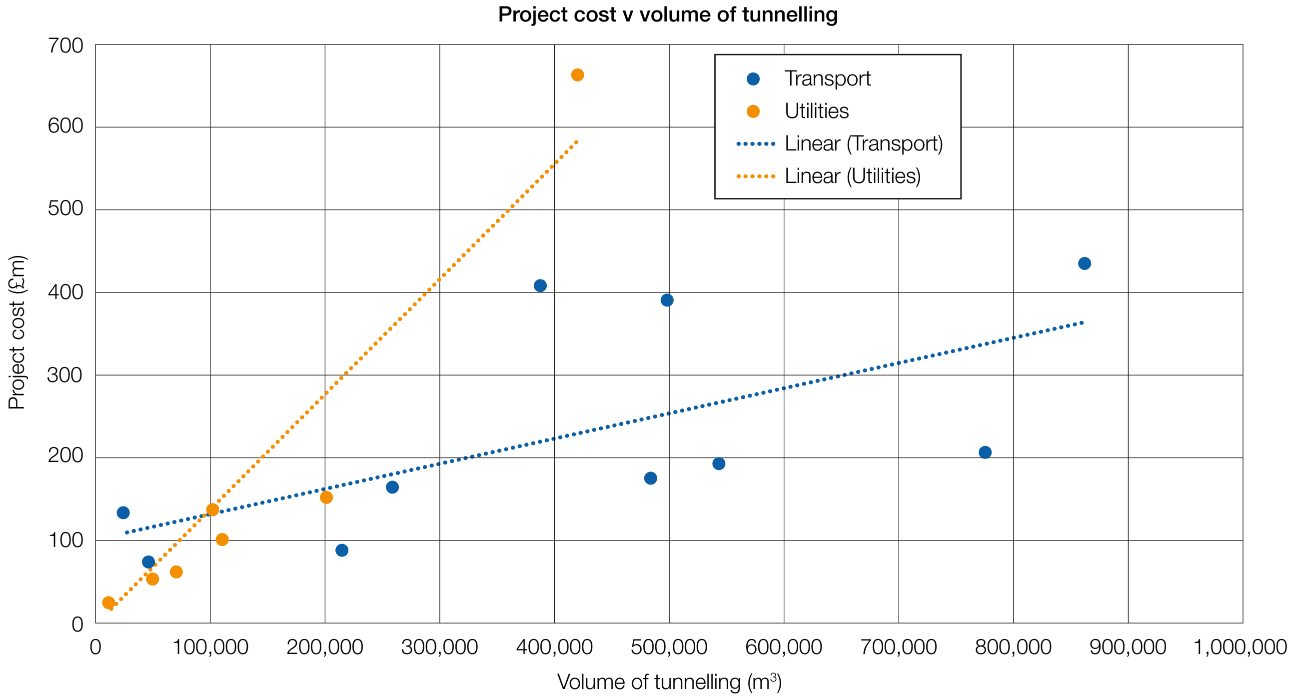

Figure 3: Comparison of transport projects against utility projects using total tunnel volume

Figure 3 shows the total project cost plotted against the volume of tunnelling. The (linear) trendlines highlight the key difference between transport and utility tunnels, utility tunnels having comparatively lower tunnelling volumes and therefore a lower contract value resulting in proportionally higher fixed costs such as TBM purchase and site establishment.

Factors that were investigated but not considered to be principal drivers of cost for these tunnels were ground conditions, tunnelling method and lining type. The principal drivers of cost are considered to be length and diameter.

4. Comparison of transport projects against utility projects using cost per unit volume against tunnel length

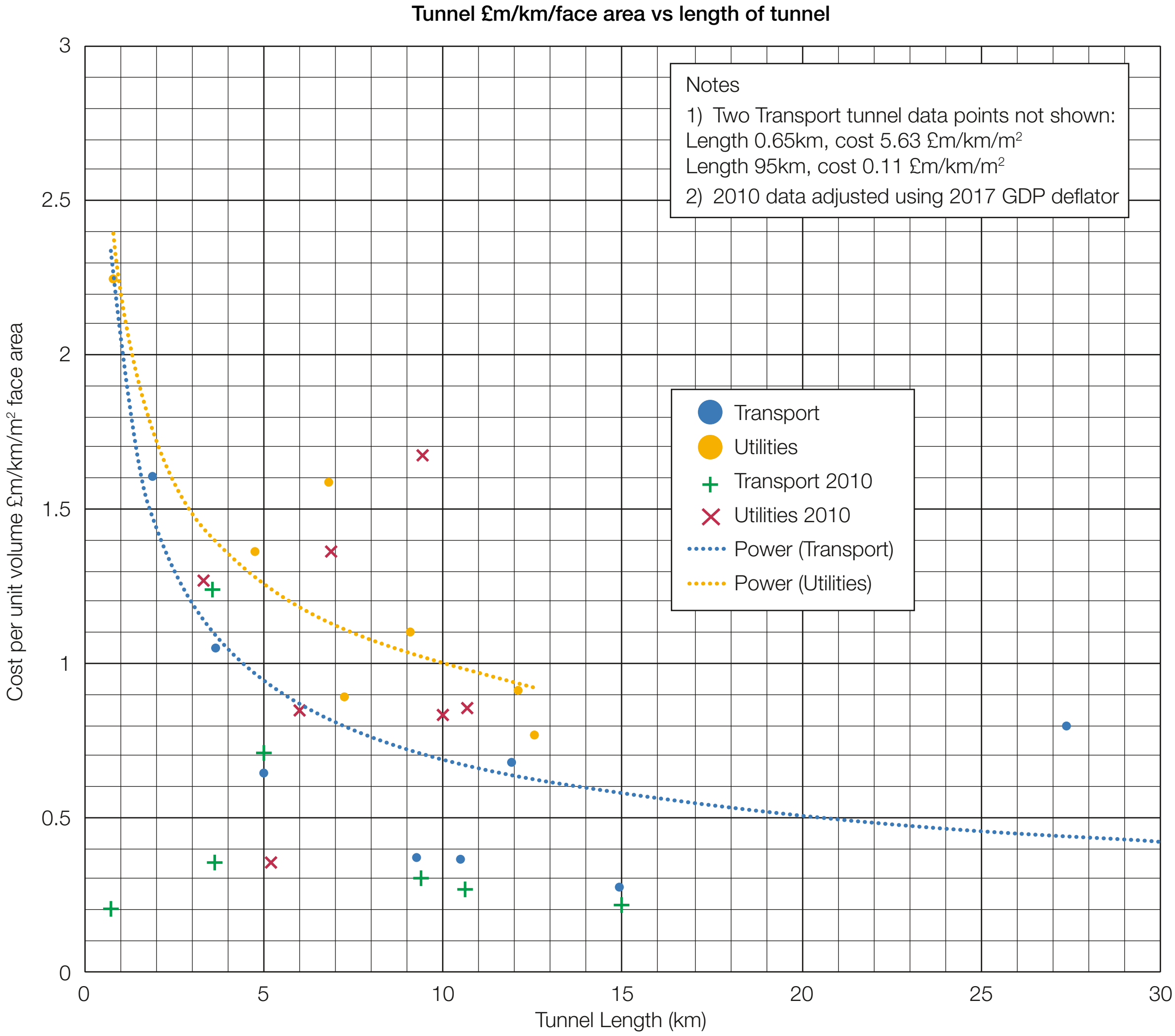

Figure 4: Comparison of transport projects against utility projects using cost per unit volume against tunnel length

Figure 4 shows data points of cost per unit volume (£m/km/m^2 of face area) plotted against tunnel length. The graph shows two sets of data, for transport tunnels and utility tunnels (plotted as the solid point markers), together with a trendline established using a power function. Two transport tunnel data points (the smallest and the longest) are omitted from the figure for clarity but are included in the trendline.

It can be seen that the trendlines are a reasonable fit through the data, certainly for utility tunnels between 2.6m and 8.8m diameter and up to 13km long and transport tunnels between 5.6 and 11.6m diameter and up to 30km long.

Both transport tunnels and utility tunnels greater than 5km in length approach a linear trendline, suggesting that at this length they become **more cost effective**.

5. Assessment of tunnel performance or production rates

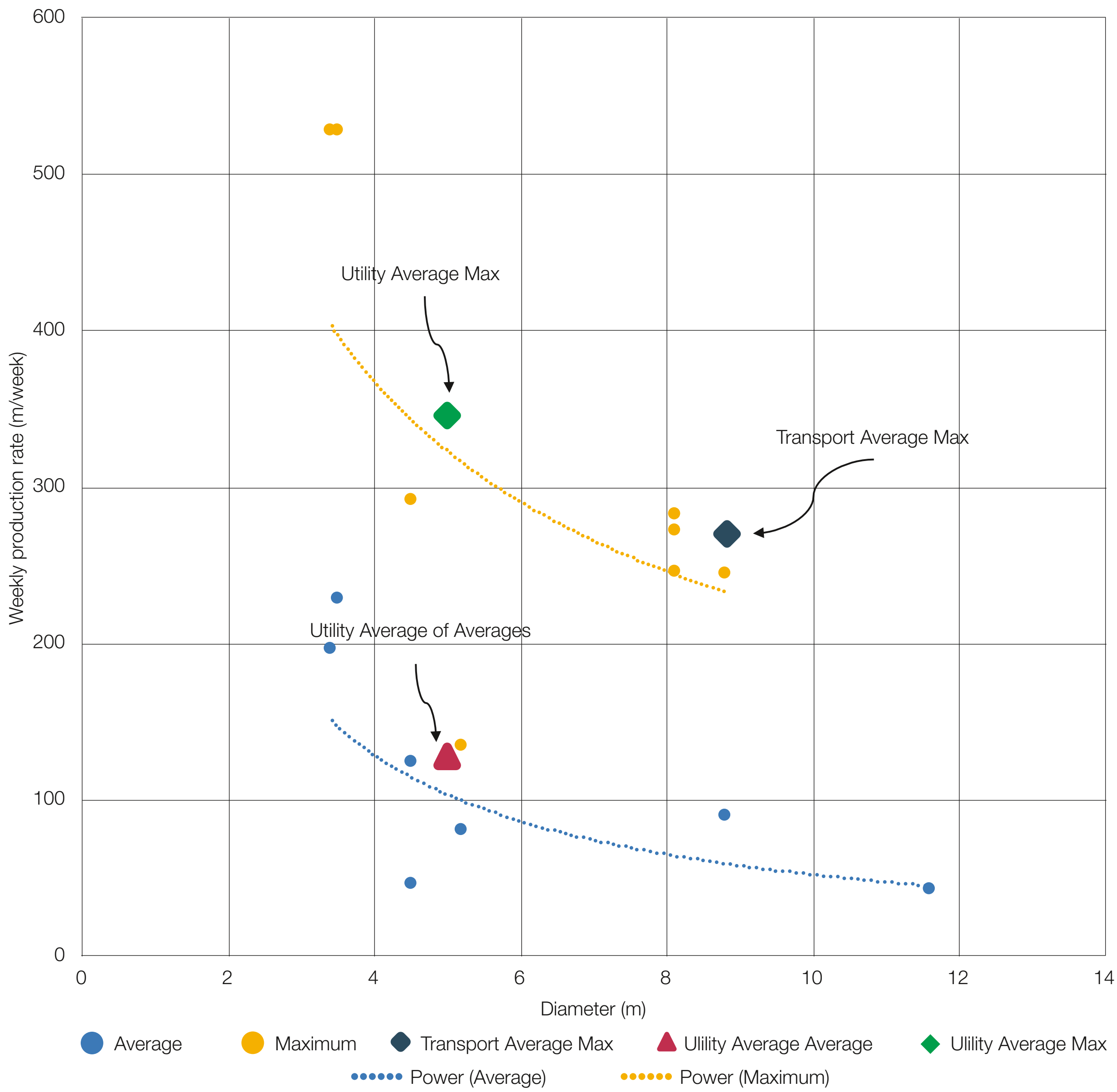

Figure 5: Weekly production rates

This data was included in order to widen the scope of the exercise and explore the potential for considering the performance of tunnelling projects. Production rate information was available for six utility tunnels and five transport tunnels.

Figure 5 shows the weekly average production rates and the weekly maximum production rates for all tunnels. There is a considerable scatter of the results, but there is a trend for the production rate to fall with increasing diameter (and hence excavated volume), which is as expected. The arithmetic averages of the rates lie slightly above the trendline and these are shown on the figure.

Tunnelling traditionally has a low production rate on commencement as the tunnelling activity is commissioned, the production cycle is established and the operating gangs become familiar with the process and site setup and work to optimise the productivity. The difference in productivity can be large, as can be seen in figure 5 in the range of 150m and 200m per week depending on the tunnel diameter. Caution is therefore required when making early stage assessments of programme durations of tunnelling projects and subject matter experts should be consulted.

International benchmarking

The above data does not currently include any international data. There was significant variance in the value of the only two international data points gathered and without understanding further the attributes of these projects, it would not be helpful to provide these points.

One of the key benchmarking objectives outlined within the Transforming Infrastructure Performance (TIP) publication was 'to build support for greater international collaboration, for example through the G20 Global Infrastructure Hub and the OECD'. The benchmarking team is supporting this objective by presenting and sharing the outputs, outcomes and lessons learned from the tunnelling benchmarking work with our international partners through the OECD and the Global Infrastructure Hub.

Summary

At the forum, participant organisations built productive relationships and used their expertise to enrich a shared data set, which was of ultimate benefit to the whole group. It demonstrated that there is a strong appetite and further opportunity for industry, clients and other stakeholders, both public and private, to collaborate and engage in a non-commercial environment for the purpose of sharing data and improving benchmarking capabilities.

Furthermore, the IPA top-down BIAC benchmarking methodology was tested and proven as a concept. As a result of its successful application and reception by infrastructure organisations, DfT are incorporating the methodology as part of the TIES benchmarking initiative.

Tunnelling is a complex activity and no two tunnels are the same. Consequently, there is a considerable scatter in the available data and it is recommended, when these graphs are consulted for benchmarking future tunnel projects, that they be used intelligently and by subject matter experts.

Although the number of data points was relatively low, good statistical correlation supports the methodology deployed, which uses a bespoke data capture process, focuses on more recent projects, and ensures as much technical information can be captured as possible to allow informed analysis.

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References

1 Infrastructure Cost Review, HM Treasury, December 2010

2 Transforming Infrastructure Performance, Infrastructure and Projects Authority, December 2017

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