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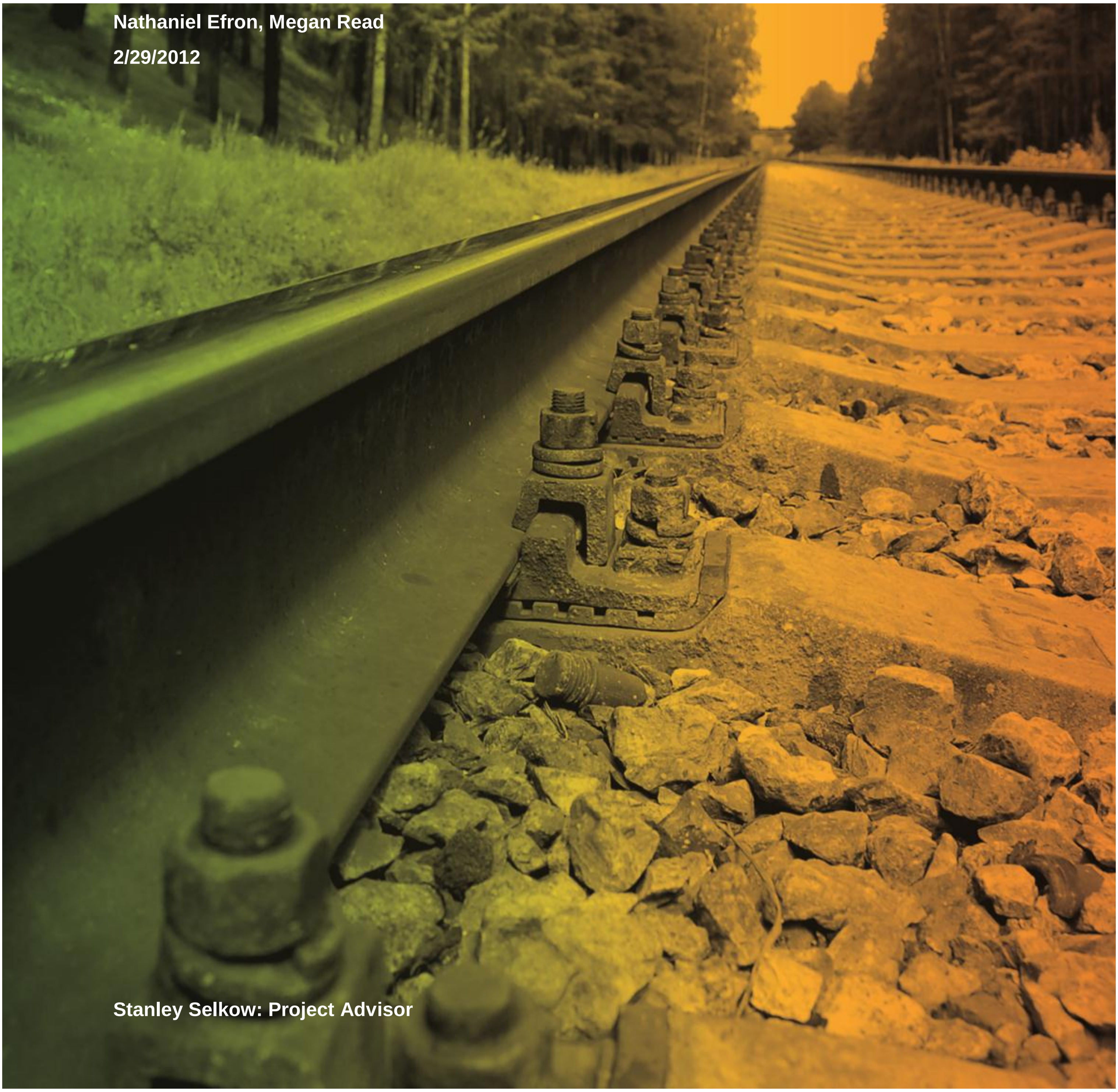
Analysing International Tunnel Costs

An Interactive Qualifying Project



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Abstract

Throughout the world, tunnels vary greatly in design, excavation, and completion resulting in a wide array of prices. The current sentiment in Australia and New Zealand (ANZ) suggests that tunnel delivery is more expensive there than in the rest of the world. Our goal was to identify key cost drivers, compare international tunnelling costs, and gauge ANZ's position for each driver. Through working with our sponsor, AECOM, we compiled findings from data analysis, interviews, surveys, and case studies to accomplish this goal. We discovered that tunnelling in ANZ is not statistically more expensive than in other nations, but that average tunnelling costs are greater, especially for road and rail construction. We provided recommendations for potential cost reduction in ANZ through investigation of several key cost drivers: geotechnical awareness, labour costs, standardisation, market structure, project delivery, and client knowledge.

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Executive Summary

Throughout the world tunnels interconnect cities, cut through mountains, transport water, and dive deep into mines. These passageways help keep humanity interconnected and carry many resources we could not survive without. The continuous use of tunnels by the world's growing population necessitates both their upkeep and their expansion, resulting in costly expenditures. The public sector throughout the world helps to financially support these expansive projects and would greatly benefit from the quantification and reduction of costs. Every country constructs tunnels with slightly different methods and has various associated cost factors. In Australia and New Zealand (ANZ) a sentiment exists that constructing tunnels is significantly more expensive than in other parts of the world. Developing a method for comparing tunnels internationally and identifying and quantifying the numerous variables that influence tunnelling costs, could potentially result in reducing the cost of tunnel delivery and the fiscal burden on the public.

Tunnelling differs from the construction of other infrastructure in a plethora of ways. The main issues that distinguish tunnels from other infrastructure arise from the risk involved with excavation through unknown ground conditions and the numerous individual cost drivers that contribute to the overall cost. These cost drivers include, but are not limited to the following direct and indirect factors, all of which must be accounted for in our analysis.

- Geology
- Excavation Type
- Materials/Plant
- End-Use
- Length
- Face Area
- Depth
- Lining Type
- Locality
- Labour Cost
- Health and Safety Regulations
- Market Competition
- Client Knowledge
- Government and Public Support
- Contract Type
- Cost of Bidding

Geology can range from soft sands and gravel to extremely hard rock and often includes fault lines and water permeation issues. A site investigation (SI) is completed during the initial design stages of a project to account for and plan for various ground conditions. Varying geologies necessitate different methods of excavation, which include cut and cover, drill and blast, roadheaders, and tunnel boring machines (TBMs). There are also an array of end-uses for tunnels including road, rail, water, wastewater, cable, mining and scientific tunnels. Each end-use has its own specifications and requirements for operation and safety. Every tunnel also has its own length, face area, depth, and lining type and can pass through urban or rural locations. In addition to all of these variables, tunnelling is also affected by many indirect factors often related to the country of construction as each differs in its labour costs, health and safety regulations, environmental regulations, level of market competition, client knowledge, and amount of government and public support. Varying contract types such as design and construct (D&C); design, build, operate (DBO); build, own, operate (BOO); and public private partnerships (PPP) are also common in different countries and affect the cost of bidding and financing. As illustrated by the quantity of variables listed above, tunnelling is a very unique area of construction in which every excavation has its own challenges to surmount.

In addition to accounting for numerous cost drivers when evaluating tunnels domestically, international comparisons add increased difficulty. This results from the need to convert currencies and account for inflation in each individual country. Construction cost indices are not standardized globally and often comprise different costs and methods depending on the country of origin.

Previous research completed on this topic has been scarce and generally lacks supportive data. An in-depth study has been completed comparing tunnelling in the United Kingdom to other European countries. We used this study as a base-line and related it to ANZ in comparison with the rest of the world. The only past research on construction in ANZ was a paper comparing infrastructure costs in Australasia that did not focus on tunnelling. This paper had very limited data and stated in its recommendations that future research is needed to confirm any of its conclusions. We sought to build off of and expand upon this past research in order to accomplish our goals. The aim of this project was to provide insight regarding whether tunnel delivery is more expensive in ANZ than the rest of the world, identify the key cost drivers for tunnelling, and gauge ANZ's position for each. We accomplished this goal through the following objectives and deliverables.

1. Create an accurate method of comparing tunnel project cost-estimates using information derived from interviews with cost estimators.
2. Determine whether tunnelling in ANZ is statistically more expensive than the rest of the world.

3. Accurately define the key cost drivers (direct and indirect) that contribute to the overall cost of tunnel project delivery through interviews and data collection.
4. Gauge Australia and New Zealand's international position in terms of cost for each key driver.
5. Identify and establish any benefits associated with a higher cost rate in Australia.
6. Produce recommendations for the tunnelling industry in ANZ regarding cost reduction in constructing tunnels.

In order to accomplish the above objectives we completed a literature search focused on gathering information regarding the cost drivers of tunnelling. In addition we gathered extensive data on tender and outturn costs of tunnels completed globally within the past 15 years. As a result of this archival search we compiled a database including 158 tunnels from 35 different countries evenly distributed throughout ANZ, Asia, the Americas, and Europe. These tunnels were distributed through various categories including end-use, geology, size, location, and excavation type. To normalize this broad set of data, we divided each project by length and volume and applied construction specific indices to account for inflation and common exchange rates to make the data comparable in third quarter 2011 Australian dollars. The entire adjusted database was used for our preliminary cost comparison of tunnel costs in Australia to those in the rest of the world.

A combination of statistical tests, averages, standard deviations, and graphs were used to assess and illustrate our data. Tunnels were separated by tender and outturn costs and then compared by region, by end-use and region, and by locality and end-use. Information from 11 interviews with industry professionals and 54 survey responses were used to provide qualitative and quantitative information to supplement our data analysis and help support or negate our claims. These interviews and surveys also served to identify and qualify the various cost drivers in ANZ in contrast to the rest of the world. In addition, an individual project comparison was completed in which several tunnels were evaluated from Australia, New Zealand, Asia, and Europe. These tunnels were selected based on similar excavation types, end-uses, and locality in an attempt to assess the cost differences between very relatable tunnel projects.

Conclusions and Recommendations

Data Collection and Analysis

Our research concluded that tunnel construction in Australia and New Zealand is not statistically more expensive than the rest of the world when compared by region or end type due to a large variance in the sample means. It was found that Australia does average higher than the rest of the world for construction of transportation tunnels, but not for utility tunnels. The higher average cost found for transportation tunnels is significant since rail and road projects are typically more publicized. This finding helps explain the opinion that tunnelling in Australia is more expensive than in the rest of the world while the large range in costs in our database exemplifies the numerous cost drivers that contribute to overall costs and the potential for cost reductions in ANZ.

Individual tunnel comparisons of six recent urban, TBM bored, rail projects supported the conclusion that tunnelling is not more expensive in Australia. It was found that the costs per cubic meter of these tunnels were very similar and differed by $70/m3. Since the excavation type and end-use were kept constant in this analysis and similar global costs resulted, it is possible that these are key cost drivers for tunnelling. Although inferences about regions as a whole should not be made from the results of this analysis, it still aids in understanding and illustrating the effects of several cost factors on unit cost as well as the sensitivity in analysis with such a small dataset.

For future analysis, it is recommended that tunnel projects be divided into groups by end-use, then analysed with location being the independent variable. The key to such a complex analysis is a large quantity of data and the careful elimination of conflicting variables. Further separation by excavation types would be ideal with a larger data set. It is also important to integrate findings from a variety of sources in order to counteract the lower reliability of some data. Findings can then be qualified with multiple sources of information agree upon the same conclusion.

We recommend that AECOM continue to add projects and costs to the database to overcome the lack of statistical significance related to not having enough data points and we feel that all future studies should exclude Australia and New Zealand from co-analysis as a result of their contrasting cost drivers. We would also suggest consulting various geotechnical engineers to produce a quantifiable geological difficulty rating scale which can be applied to each tunnel. The analysis would further benefit from quantifying the cost of bidding versus the location and contract type.

This is a key factor that has come up in our qualitative analysis, but currently lacks quantitative information. These factors could then be utilized for quantitative analysis of the database. We also recommend continuing to investigate why a wide range of tunnelling costs exists within a country, specifically Australia, which could help lead to major cost reductions.

Interviews and Surveys

Interviews and survey responses often agreed that tunnelling in Australia seems very expensive and provided explanations for this feeling. The key cost drivers mentioned in these interactions were geology, labour, materials/plant, safety and environmental regulations, government and public support, market structure, the cost of composing bids, contract type, and client knowledge. Interviewees unanimously agreed with our conclusion that Australia and New Zealand should be analysed separately. As a result we focused on Australian cost drivers in our interviews and reported on potential for cost reductions that were focused on Australia.

In general, interviewees strongly felt that there were no tangible benefits to higher tunnelling costs in Australia. Conversely, the majority of survey respondents had a wide range of possible benefits such as, higher worker productivity, better construction safety records, greater adherence to environmental standards, reduced operation and maintenance costs, better post-commissioning safety, and longer service life. The interviews suggested that these benefits did not outweigh increased costs, but future investigation could further research these statements.

In order to supplement these data, it is important to continue qualitative research. We recommend compiling and sending a lengthier, globalised survey which focuses in depth on the key areas of cost savings. In addition, this survey should seek out cases of significant cost reduction in the global market that can be further studied and possibly implemented in Australia.

Cost Drivers and Potential for Cost Reduction in Australia

The following list of key cost drivers were researched and are discussed below. Recommendations for these cost drivers were also provided when relevant. Although this advice is aimed at the Australian market, some changes may be applicable elsewhere in the world.

- Geology
- Labour
- Materials/Plant
- Safety and Environmental Regulations
- Market Structure
- Government/Public Support
- Client Knowledge
- Project Delivery

It was discovered that the design stage has a large potential for cost reductions in these categories, as at this point in a project the scope of the project is not completely set. In addition large decisions such as choosing the alignment, dimensions, and lining type during this stage can result in significant cost variance during construction.

Geology

Geology is the cited cause for the majority of cost overruns in tunnel construction. Ground conditions vary throughout the world, with major problems being caused by water permeation, fault lines, very soft materials that will not support themselves, and the variation of materials from soft sand or gravel to extremely hard rock. The conditions in Australia are not overly difficult to excavate through in comparison with the rest of the world.

We advocate that during the early feasibility stage, clients significantly increase the amount of SI undertaken. We recognise the issues with convincing clients to spend more money in the early stages of a project, when the overall viability, constructability and financing is still unknown, but all of our research subjects described a direct correlation between the amount of SI and cost savings. To accomplish this, we recommend providing more comprehensive education to clients who are considering constructing any type of subsurface works. Although this issue is not inherent to only Australia, it is an area that has marked as possessing a large potential for decreased risk and cost reduction.

Labour

Labour costs typically account for 30-40% of the overall budget for a tunnelling project as described by our interviewees. Variances in these costs between countries may account for a range in tunnelling costs. Labour prices in Australia are reported as very high because of the value of the dollar, active unions, and employment competition with the mining sector. Other countries with higher wages such as Europe and the United States will often import a workforce from Asia in order to reduce labour costs, but this is not a viable option in Australia due to restrictions.

Although there is increased education and productivity amongst Australian workers, we did not find that they were substantial enough to counteract the costs of high wages.

A reduction in the amount of labour required to deliver a tunnel would result in cost savings in this area. Since the largest labour costs are attributed to the construction workers rather than professional engineers, optimisation of precast plants, increased technological efficiency and better management would be areas of potential cost reduction. We also recommend collecting information on tunnel progress rates per unit length or area, and perform interviews with construction managers in order to seek out inefficiencies and reduce labour.

Materials/Plant

Materials and plant costs are often very similar across regions. There are only a few main manufacturers that supply the majority of international tunnelling, and as a result, only the associated shipping fees affect Australia. An option to reduce costs in materials and plant that is being investigated in Asia is to move towards standardization instead of optimization. This is an option for both a country as a whole, or for a single client who may be planning on building many similar tunnels. Currently, huge inefficiencies exist in having to set up a custom plant for every job to manufacture precast rings that are unique to a specific tunnel. In addition, equipment such as TBMs are typically only used once and then sold back to the manufacturer for 5-15% of the purchase price, when it could be much cheaper to simply refurbish the equipment between jobs. These changes could potentially reduce costs after the initial increase needed to design tunnels around these pre-determined parts.

Safety and Environmental Regulations

Safety and environmental regulations are very similar throughout the world, with Europe typically being the first to implement new standards and then they are adopted by the United States, Australia, New Zealand, and eventually Asia. There are slightly different regulations based on the location of the project in either a rural or urban environment, but safety and environmental regulations are relatively standardized throughout the world so there is not much potential for cost reduction in this category. Some Australian tunnels have been noted as “over designed” and “over specified” with regards to some safety features, and the removal of excess systems may help remove additional costs.

Market Structure

The level of competition in the Australian tunnelling market is currently very limited, with only six major contractors, three of which share the same parent company. In most other countries, tunnelling projects would have bids from around 10 or more contractors, while in Australia this rarely exceeds four. The large project sizes in Australia for tunnelling works makes it very difficult for smaller companies to contend with these larger contractors and also necessitates the need for joint ventures between the larger contractors. This results in many projects where contractors often end up bidding against themselves. The lack of competition in the Australian market would result in increased costs for tunnelling works since these contractors do not have to be as aggressive in their bidding and may be more complacent in this region than they are in other parts of the world. The construction of Legacy Way in Brisbane marks the first international intervention in the Australian market. A Spanish and Italian joint venture greatly undercut the bidding for the project. Currently this tunnel is under construction, but in the future it would be a good case study for comparison of international tunnelling methods to those in Australia. International intervention in the market may also increase the level of competition and lead to cost reductions.

Increasing market competition is a difficult problem to address because of the experience, knowledge and contacts possessed by large domestic contractors. One option that could be exercised by clients would be to encourage bidding from foreign contractors, which could help spur innovation and trigger cutting of unnecessary costs. Another preferred alternative would be to analyse the effects of splitting large scale contracts into multiple, smaller contracts. This would help spread the risk and allow smaller, less experienced contractors to enter the market. This is a standard practice in places such as Singapore and Hong Kong, where a large tunnelling project might be split into 20 or more contracts that are won by different contractors and joint ventures. The same scale projects in Australia are typically bid as a whole and go to a single contractor or joint venture resulting in decreased competition and increased cost. A thorough analysis would be needed to determine if the cost reduction from increased competition would exceed the increased cost of additional bids.

Government/Public Support

Government support helps to expedite the design phase and advance the project to excavation. If this support wavers or shifts throughout a project, it can lead to changes in scope and time setbacks which cause cost overruns. Some projects can even be abandoned if they lack government support. One example is the Sydney metro, which was cancelled after significant design work and investment. The amount of public support for a project is another indirect variable that can greatly affect tunnelling costs. The lack of a favourable public opinion can result in a reduced amount of traffic and can negatively affect the amount of government support on a project. One finding from our interviews was that in general, Australians do not prefer to spend money on paying tolls to use tunnels even though it may save them time and expenses in the long run. Based on these findings, it is very important to secure both government and public support during the early stages of a tunnelling project in order to avoid potential cost escalations.

Client Knowledge

In Australia, client knowledge is generally regarded by our survey respondents and interviewees an area for improvement. Many clients are unaware of how to create tunnelling specifications which optimise cost saving potentials because of the relative rarity of tunnels when compared to other infrastructure. As a result clients do not understand the unique challenges related to tunnelling, and scopes for projects often include items that are not necessary. Some clients are also very vague about what they want which can lead to issues when putting together bids. The lack of experience amongst clients found in the Australian tunnelling market contrasts with the experience of clients in Europe and Asia and could further explain higher costs in the region.

Similar to other client issues, the solution appears to be increased education. We feel that this recommendation of client education will help to significantly reduce inefficiencies caused by misspecification and also reduce the number of clients that needlessly spend money by hiring consultants too early in the planning process when not enough information is known.

Project Delivery

Contract types in Australia have begun to move towards Private Public Partnerships (PPPs) within the last fifteen years, which contrasts with the contract types in other nations. In addition other nations' PPPs do not operate in the same manner as those in Australia. In Australia these contracts require the private sectors to take on all risk and provide all financing for a project instead of the government. This can lead to increased costs since the private sector must account for a large contingency and also cannot secure bonds and financing at the lower rates available to the government. The PPP model has had both successes and failures. The key advantage is that PPPs result in an expedited start to a project, where there is less chance of projects being delayed after major political changes, but several recent PPP projects have resulted in the private firm backing the project to declare bankruptcy. This is most often a result of delusions about the successes of the project such as forecasting much higher traffic use of tolled tunnels than is realistically possible. In general, it is believed that the PPP model requires some restructuring in order for it to be successful for tunnelling projects.

The cost of bidding in Australia is also very high as a result of the PPP model. Since the private sector takes on the risk for these contracts, they require a high level of cost certainty and result in higher design specifications during bidding. Typically it costs a contractor 30 – 40 million dollars to put together a bid for the largest PPP tunnelling projects in Australia. This cost is completely lost for any contractor that is not selected. The lost money must then be recouped by subsequent projects, resulting in a cycle that increases the costs of every large project undertaken by these companies. These large costs also negatively affect competition in the tunnelling market, as smaller contractors cannot incur this debt for as long of a period of time as larger firms without becoming bankrupt.

Our recommendation is to continue encouraging the PPP model wherever possible as it helps produce projects that otherwise may stagnate, but to revise the process to encourage competition and reduce cost inefficiencies. Although PPPs have been criticised in the past for lack of post-construction revenue, we have found that financiers and contractors have learned from this and are now more cautious when it comes to traffic forecasts and estimates. It may be prudent to attempt to improve public opinion about the use of tolled road tunnels as well. Overall, our concerns and recommendations lie with the risk allocation and high amount of money lost during the bidding process. We would encourage a revision of the PPP model to partially place the risk associated with the contract back on the government. With the ideal being a model where construction risk is allocated to the contractor and the post-construction risk is split more evenly between the public and private parties of the contract. Our recommendation regarding increased bidding costs is to conduct a cost-benefit analysis to ascertain if the higher cost certainty resulting from a higher design percentage outweighs the increase in cost resulting from bids that have been lost.

Note: A frequently asked questions section, and a glossary of technical terminology are available in appendix A (7.1) and Appendix B (7.2) respectively.

Authorship Table

Section	Major Writer	Major Editor
Report		
Abstract	MR/NE	MR/NE
Executive Summary	MR	NE
Introduction	All	MR/NE
Literature Review		
Types of Tunnels	NE	MR
Tunnelling Process	MR	NE
Costs and Variables for Each Tunnel	NE	MR
Financing	NE	MR
Complexity of Comparing Costs and Regulations Globally	NE	MR
Methodology	MR/NE	NE/MR
Results and Analysis	NE/MR	NE/MR
Conclusions & Recommendations	MR/NE	NE/MR
Interviews		
Form A	NE	MR
Form B	MR	NE
Form C	NE	MR
Form D	MR	NE
Surveys		
Survey Questions	NE	MR
Modified for Proprietary Information		
All cost data removed[1]	Jonathan Barnett, AECOM Australia	Kate Wooley, New Zealand

[1] Data may be available upon request. Please contact AECOM.

Table of Contents

Table of Figures

Table of Tables

1.0 Introduction

Throughout the world, tunnels interconnect cities, cut through mountains, transport water and dive deep into mines. These passages have become a necessary part of everyday life and because of their usefulness will only continue to see increased usage and expansion in upcoming years. However, these construction projects are very expensive ventures, costing from millions to billions of dollars (Harris, 2011). In addition, the costs and regulations associated with tunnel construction can vary greatly from place to place and are very difficult to predict since construction occurs underground in unknown territory.

According to AECOM, a global engineering and management support firm with branches in Australia and New Zealand (ANZ), constructing tunnels in these regions is inexplicably expensive, sometimes costing as much as triple the amount in other regions such as Europe. The large budgets associated with constructing tunnels can be broken down into numerous cost drivers, such as the dimensions, end-use, excavation type, labour, materials, and government and safety regulations, which can all vary greatly based on the location of the project. Limited understanding of these cost drivers and whether or not they can be controlled contributes to the disparity in costs. This analysis is further complicated by the immense scale of the tunnelling industry and also because these variables are not strictly comparable across various locations.

An investigation into the costs of tunnelling would allow for possible reductions in costs which could greatly benefit Australia and New Zealand. In the past, there have been similar studies to explain cost discrepancies of tunnels and other infrastructure across Australasia. One similar study focused on comparing spending by scaling costs to 2010 dollars and then converting each cost to dollars per kilometre, but the amount of data used in this study was very limited (Martin, 2011). Another example that parallels this research is a study that was conducted by the government of the United Kingdom (UK). Tunnel costs were compared among European countries to discover whether construction in the UK was more expensive and, if so, why (HM Treasury, 2010).

Although there has been research on infrastructure cost analysis, our goal is to expand upon past research and relate it to ANZ. A tunnel database has been initiated by AECOM that organizes cost information from various projects throughout Europe, Australia, New Zealand, and Asia. Additional information and organization of this database would allow for a better understanding of the costs of tunnelling and would also help explain the regional price variation. This information would benefit the local economy and societal infrastructure while concurrently aiding AECOM's clients in better understanding overall tunnelling costs.

We seek to determine whether tunnelling in ANZ is more expensive than in other regions, and if so, discover the key cost drivers that are responsible for this high expense. We completed archival research to attempt to identify, catalogue and integrate data for tunnels to expand the current AECOM database. This information was used to compare costs between countries in dollars per kilometre and gauge ANZ's position in comparison to other nations. We then completed detailed analysis of tunnelling case studies from ANZ and other regions of the world in order to better understand the relationships between individual cost drivers and final costs. These relationships are known to be very complex and can have an excessive number of variables which are challenging to analyse. We also interviewed knowledgeable cost estimators, contractors, and consultants from both the tunnelling division of AECOM and the tunnelling industry to determine which cost drivers may account for budget variance. After compiling all of the above information, we put together a set of recommendations for how ANZ can potentially reduce tunnelling costs and established if there are any quantifiable benefits resulting from this higher cost.

1.1 Aims and Objectives

The following objectives outline the requirements to achieve the overall goal of the research.

1. Create an accurate method of comparing tunnel project cost-estimates using information derived from interviews with cost estimators.
2. Determine whether tunnelling in ANZ is statistically more expensive than the rest of the world.
3. Accurately define the key cost drivers (direct and indirect) that contribute to the overall cost of tunnel project delivery through interviews and data collection.
4. Gauge Australia and New Zealand's international position in terms of cost for each key driver.
5. Identify and establish any benefits associated with a higher cost rate in Australia.

6. Produce recommendations for the tunnelling industry in ANZ regarding cost reduction in constructing tunnels.

2.0 Literature Review

The complexity of the tunnel design and construction process is incomparable to other infrastructure. It is difficult but necessary to fully comprehend how tunnels are procured and constructed in order to understand how cost variables interact and influence the final costs of projects. In this chapter, we offer background information regarding the tunnelling industry and the associated costs. More specifically, we discuss the varying types of tunnels, including mining, water, and transportation tunnels, and detail the various stages of construction from the first cost estimates and planning through to the actual excavation of the tunnel. We also explain the different cost variables related to tunnel construction and provide background on how projects can be compared globally. Lastly, we discuss the financial implications regarding large infrastructure and the contracting agreements that are dependent on the type of project.

2.1 Types of Tunnels

Tunnels are vitally important to the infrastructure of modern civilization, and are used in many ways to provide sustainable and comfortable living for humanity. The main types of tunnels – mining, water, transportation, cable, and scientific all have differing characteristics and uses which can impact the final cost.

2.1.1 Mining Tunnels

Mining tunnels are used to provide access to mineral deposits within the earth, such as coal for electricity production. They function as passages for extraction during mining, and therefore are designed for temporary use by miners only, and as a result are only constructed with basic safety mechanisms. Unfortunately the low cost of these limited safety mechanisms directly correlates with a high risk for workers, as was the case in the recent Pike River Mine disaster where 29 workers died (Higgins, 2011). Mining tunnels feature ventilation systems to clear toxic fumes produced from the tools used in the mining process and roof supports to mitigate the possibility of collapse as well as escape shafts (Vogel, 2000). Typically, these tunnels have a simple rail system to aid in the transportation of excavated materials. In cases where the mineral deposits are located deep within the earth, the heat is unsuitable for human occupation and air conditioning systems are necessary as well (Harris, 2011)

2.1.2 Water and Wastewater Tunnels

Most water tunnels transport various types of water between sources, processing facilities and consumers. This type of tunnel can be broken down into water tunnels and wastewater tunnels (Grigg, 2003). Wastewater tunnels can be further broken down into sanitary sewers which carry human waste and stormwater tunnels which carry run off from weather and flooding. Both water and wastewater tunnels share similar characteristics such as a waterproof lining, various types of valves and possibly pump stations. Often, sanitary sewers will require thicker linings to resist the higher corrosiveness of their contents (Grigg, 2003). Wherever possible, engineers try to design water and wastewater tunnels to utilise gravity to move their contents from one place to another. When gravity is not an option, these tunnels are fitted with pumping stations (Grigg, 2003). Lastly water tunnels are often used as part of a hydro power scheme, where sets of tunnels transport water from a higher elevation to a lower elevation through turbines to produce electricity.

2.1.3 Transportation tunnels

Transportation tunnels are necessary to provide passage through any natural or manmade obstacle such as passing through a mountain, under a river, or across a congested city. These tunnels may accommodate various transport systems which all have different variables associated with them.

Rapid transit (metro) lines, commuter lines, passenger/freight lines frequently make use of tunnels to avoid obstacles. Rail tunnels typically rank as one of the more complex types of tunnels because of their large size, necessary safety equipment, stationing, and electrical and mechanical equipment (E&M) (Vuilleumier, 2002). Rail tunnels frequently exist beneath cities and often result in vibration issues which are unique to this type of tunnel and need to be accounted for both in the design and cost allowance (Kurzweil, 1979). Many of these factors are exclusively related to rail tunnels and thus make rail tunnels far more expensive than others. For example, the cost of constructing stations is very expensive and is often considered part of the cost of tunnelling. Road tunnels share many of the same features as rail tunnels but serve to facilitate vehicular travel. Although road tunnels do not require stations, and most of the E&M used in rail tunnels, they still require enhanced safety systems such as fire suppression capabilities

(Vuilleumier, 2002). In many ways, the safety systems need to be more advanced in rail tunnels since the possibility of a crash or fire is much higher. To account for this, road tunnels often have more frequent cross passages between bores to let pedestrians escape, or sometimes have completely separate bores or refuges which can act as escape passages and passages for fire fighters (Vuilleumier, 2002). Ventilation systems are also a key consideration made with road tunnels, especially when located in a city where concerns about air quality are often expressed. These ventilation systems are very advanced and often work in conjunction with the fire suppression systems to increase safety. Some road tunnels utilise separate ventilation tunnels, and/or ventilation stacks which typically repurpose shafts that were initially dug for excavation (Mashimo, 2002). These extra special requirements are characteristic of transportation tunnels and typically result in an increased overall cost making them some of the most expensive tunnels to build.

2.1.4 Cable Tunnels

Cable tunnels provide a means of delivering power or data from a distribution point to a client. Often times these tunnels contain fibre optical cables to facilitate long distance telecommunication and computer networking or high voltage electrical cables to meet the needs of growing demand in an area (Mainwaring, 2001). These tunnels may be designed for personnel entry, but as technology has progressed utility tunnels have less need for attention and consequently do not require human safety systems. The basic features required for cable tunnels are access shafts for maintenance and an impermeable lining (Mainwaring, 2001). The relative simplicity of cable tunnels often results in lower costs when compared to most other types of tunnels.

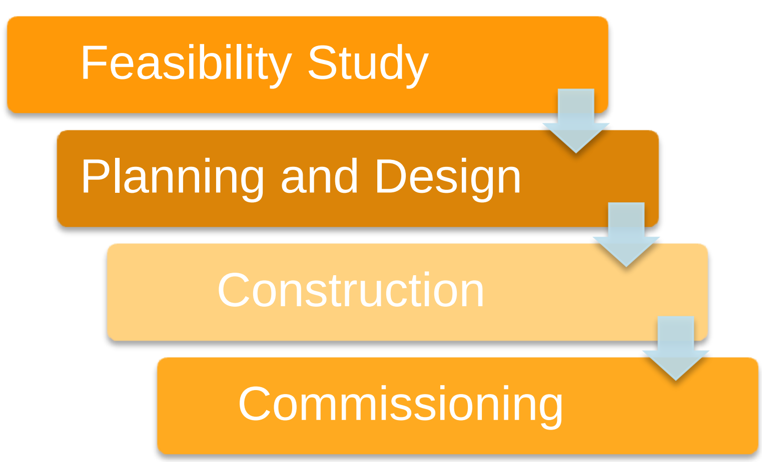
2.1.5 Scientific Tunnels

Scientific tunnels provide an underground environment for laboratories and equipment used by scientists to conduct research and experiments. These tunnels are difficult to classify because of their rarity, and the unique requirements for each one based on the type of experiments that the tunnels are designed for. One shared characteristic is that these tunnels need to be constructed deep under solid rock in order to shield the experiments from background radiation and allow for more accurate results (Lebrun, 2000). The rarity of this type of tunnel makes cost characterisation and analysis difficult.

2.2 Tunnelling Process

Simply defined, a tunnel is any covered passageway. Yet, the process of constructing a tunnel is considered to be a complex challenge in the field of civil engineering (Harris, 2011). The entire process of building tunnels, from the preliminary feasibility study to the final commissioning, is a complex practice with many factors and potential issues to address. The major difference between tunnels and other types of infrastructure is that they are underground. The challenge when working underground is dealing with many unknown variables that can make construction difficult. The breakdown of the tunnel delivery process is displayed in Figure 1.

Figure 1: Tunnelling Process



2.2.1 Feasibility Study

The initial stage of tunnelling involves the implementation of a feasibility study, which involves site investigation (SI), preliminary drawings, and rough cost estimates. The SI is especially important in tunnelling because all of the construction occurs in the unknown expanse underground. In the SI, geological analysis is performed to judge what the soil, rock types and parameters are in addition to potential risks such as faults, shear zones, ground water, and underground services. Often a series of boreholes will be drilled in order to better assess these conditions. In the majority of cases, the proposed tunnel will travel through multiple types of substrate and hazards, making this process even more important. The more information that can be gathered regarding the geological aspects, the more chance there is for avoiding delays and for obtaining more accurate cost estimates since potential issues can be accounted for early on (Parker, 1996). During this stage a preliminary design is put together that is generally considered to be around twenty percent complete depending on the owner's specifications. This design begins to address any planning issues that may be encountered and also allows for a rough cost estimate to be compiled which is helpful to plan for and secure funding.

2.2.2 Planning and Design

As the tunnelling project advances, the feasibility study is used in order to put together various designs and also to establish an estimate, or tender cost for the project. It is at this point that issues such as health and safety and environmental regulations, consents, and overheads begin to be accounted for in both the design and budget. The design will progress from a scheme design (50% complete), to a detailed design (60-80%) to a final issued for construction (IFC) design (100%). With this final design complete, the tender cost for the proposed project can be completed by a cost estimator who has the specialized experience working with construction costs. Throughout this stage designers will often hold public consultations and contact various stakeholders to inform them about the design process and lobby for support.

Depending on the owner's preference and contract type, the contractor will typically get involved in the design process before the drawings are IFC. The project owner will usually solicit bids part way through the design process to either the public or a select group of contracting firms. These contractors will have a certain amount of time to formulate their bids which are essentially representations of how much it would cost them to construct the tunnel, as well as a complete construction schedule. The number of bids for each project can range depending on the number of contractors available to carry out the project as well as their level of interest in the project. Typically the number of bids ranges between two to ten for any given project. This process can be very competitive between firms, and motivates contractors to build the tunnel for the least amount possible to maximise their own profits. More competition in securing a bid will often result in lower prices for the tender costs. A balance exists between contractor's profit and the ability to be selected for the bid because typically the lowest bidder is selected by the project owner.

This is a complicated step since there needs to be a careful balance between detail and time. The plan for the project requires enough detail for successful planning and investment gains, but if it is too specific this step can be overly time consuming and expensive (HM Treasury, 2010).

2.2.3 Construction

After the completion of the planning phase, the project will advance to ground-breaking and construction. At this stage there are many variables to account for. Each tunnel will have a different required set of materials depending on its end-use and the ground type that will be encountered. The construction will require various amounts of material depending on the length and size of the proposed structure. The ground type will also affect the linings and support that the tunnel will need during and after excavation. All of these variables affect the overall complexity of the tunnel and will influence the required workforce to complete the project. The excavation of a tunnel can be accomplished in a variety of ways, including cut and cover, drill and blast, tunnel boring machines (TBMs), roadheaders, immersion, or any combination of these methods. The method of excavation is selected in accordance with the geological analysis completed in the feasibility study.

A cut and cover technique is a simple construction method that can be used for both urban and rural tunnelling projects through soft ground such as clay, silt, sand or gravel. First a trench is excavated in the area where the tunnel is to be constructed. Then the tunnel lining is constructed with a cast-in-place concrete structure. This structure is waterproofed and then covered with the original soil up to ground level. This topsoil then needs to be compacted using heavy vibrating rollers. Compacting has to be carefully carried out in order to avoid invoking too high a stress on the tunnel structure below. This method is advantageous over other soft ground methods when there are geological instabilities present in the soil, or when the tunnel must be constructed close to ground level, but can be limited in urban settings (Mouratidis, 2008).

TBMs are also often used for either soft ground tunnels or soft rock where the drill and blast method cannot be controlled. This multimillion-dollar piece of equipment has a circular plate equipped with disk cutters on one end that act as the cutting teeth of the machine. The plate rotates as the machine advances forward and causes the disk cutters to carve pieces out of the rock which it catches in a conveyor system. These machines can also serve the dual purpose of supporting the tunnels as they move forward by drilling holes into the rock that workers fill with grout and bolts to maintain the tunnels (Boardman, 1960). Short stand up time, or how long the ground can support itself after excavation has occurred, is a common problem with soft ground tunnels and can result in cave-ins if not properly addressed. For this reason, some tunnels are excavated using the top-heading-and-bench method. The top-heading and bench method is when workers first dig a smaller tunnel called a top-heading then excavate below the floor of the top-heading to create a bench. This lowers the risk of tunnel collapse and heightens worker safety. This method is advantageous for gauging the stability of a material before proceeding in the construction. A metallic, cylindrical piece of equipment called a shield is used to further reduce the risk of cave-ins as well by providing temporary support to the surrounding earth. This is a temporary solution until a permanent lining of cast iron or concrete can be installed as a lining for the tunnel (Boardman, 1960). Many TBMs have the ability to place precast concrete, or cast iron rings into place as they continue to bore, which can increase safety and efficiency (Girmscheid, 2003). Another method of tunnelling called pipe-jacking is often used in small diameter tunnels. This method involves using hydraulic jacks at the bottom of the shaft to push a prefabricated pipe through the tunnel behind the TBM or excavator as it moves forward (Craig, 1983).

The drill and blast method is typically used for tunnels through hard rock and are created full-face, which involves excavating the entire diameter of the tunnel at once. Workers use a scaffold called a jumbo to quickly place explosives and increase safety. Drills that are mounted to the jumbo allow it to make several holes in the rock face, which are then packed with explosives by workers. The amount of holes drilled and the type of explosive chosen depends on the rock and tunnel type, but typically dynamite is used (Boardman, 1960). After the tunnel has been completely evacuated, the charges are detonated and the noxious fumes are removed with a vacuum. The leftover debris, called muck, is removed by workers in carts, after which the entire process begins again to advance the tunnel (Boardman, 1960). The stand-up time for this variety of tunnels is usually measured in centuries and excess support for the walls may not be necessary. Additional support in the form of bolts, sprayed concrete or rings of steel beams could be needed though because of breaks or pockets of fractured rock. These inconsistencies could cause potential problems if not addressed during the construction. One of the draw backs of this method is that it is not favourable in urban conditions because of the noise and vibration associated with excavation (Ocak, 2010).

Roadheaders can also be used to tunnel through lower strength hard rock. This method can be advantageous to drill and blast since blasting in urban locations in often restricted due to vibrations and difficulties in transport of blasting agents (Ocak, 2010). These machines can weigh up to 120 tons which makes them stable and stiffer platforms for excavating rock. They consist of a boom-mounted cutting head, a loading device, and a crawler travelling track. Roadheaders also remove muck as they progress through excavation similar to TBMs. These machines have significantly improved safety, reduced ground support requirements and require fewer personnel which make them an ideal choice for constructing some tunnels. The main limitation of this method is that progress is often slower which potentially results in a higher cost (Copur, 1998).

Immersion is the method used when creating tunnels underwater. First a trench is dredged into the riverbed or ocean floor and then a tube is floated to the site and sunk in the prepared trench. These tubes are long, prefabricated sections of the tunnel and are typically made of steel or concrete then sealed to keep water out. After multiple sections have been placed, divers connect the sections and remove the water-tight seals. Any water that may have leaked into the tunnel is pumped out and then the entire tunnel is covered with backfill to ensure it stays in place (Boardman, 1960).

After, or often during excavation, the lining of the tunnel must be installed. The lining type will depend on the geology, depth and end-use of the tunnel and it acts as both a structural support and a waterproofing layer. Traditionally, tunnels have been constructed with spheroidal graphite iron (SGI) lining, which is a form of ductile iron. More recently tunnels have been constructed with a cast in place, or in-situ, concrete lining, that varies in thickness depending on the amount of structural support required (Deere, 1968). A newer technology, referred to as a sprayed concrete lining (SCL), involves spraying concrete onto the walls of the tunnel. This can be combined with different types of reinforcement, such as a steel mesh or some newer steel or poly-propylene fibres which are premixed with the concrete (Austin, 1995). These linings in combination with the precast rings and pipe jacking methods detailed above

provide the structural support for all tunnels. Depending on the type of drainage system, some tunnels may also require an impermeable waterproof lining which prevents the hydrostatic pressure from forcing water into the tunnel (Deere, 1968).Tunnels fully above the water table do not have any special requirements in regards to providing drainage, while tunnels that are partially or fully below the water table require advanced drainage systems to deal with water permeation which is especially important for transportation and cable tunnels (Mahuet, 2000).
After the lining is secured, the final fit-out of the tunnel may commence. This varies widely depending on end-use of the tunnel, but often includes the installation of E&M equipment, the laying of tracks or roadway, and the installation of fire suppression and ventilation systems.

2.2.4 Commissioning

Once the construction of the tunnel concludes, all of the individual parts need to be tested and signed off. A pull out test is often done to test the strength of supports in addition to lining thickness evaluations and waterproof membrane checks. This series of tests confirms that the tunnel is safe to open and also evaluates all of the operation, electrical and mechanical equipment in the completed structure. Every piece of the final tunnel and these various tests must then be approved by the contractor, owner, and regulatory authorities before the final outturn cost of the project can be compiled. After the completion of the tunnel there will still be costs to operate and maintain the infrastructure. These costs will vary depending on the construction techniques, but are typically excluded from the reported final cost of constructing a tunnel.

2.3 Cost and Variables for Each Tunnel

There are numerous factors associated with constructing tunnels, which can all heavily influence the total cost of tunnelling. Overall, the key consideration is whether or not a cost variable will result in a statistically significant variance across international borders. This essential consideration along with a means to measure some of the less tangible variables is crucial in calculating the overall cost of tunnelling.

2.3.1 Geotechnical Risks and Substrate Determination

One of the largest cost factors associated with tunnel construction is determining what kinds of geological conditions exist between the portals or shafts of a tunnel (Hoek, 1990). Modern geotechnical engineers utilize a variety of imaging technologies and boring samples to determine rock type and groundwater penetration. These technologies can provide an acceptable level of confidence in the type of rock that needs to be bored through, but this imaging is neither comprehensive nor fully reliable (Das, 2006). Construction management firms will use past examples of projects in any given region to help develop a proper percentage to allot for contingency to account for any ambiguity in the substrate.

The indeterminacy of geotechnical imaging technologies makes the type of substrate one of the largest factors in the variance of tunnelling costs. The ideal conditions to tunnel through are typically relatively soft homogenous rock, such as the sandstone present around Sydney (Pells, 2002). The complexity increases when boring through gravels or sands, because of the high permeability and low structural stiffness. Tunnelling becomes the most complex when boring through heterogeneous substrates, such as a combination of hard rock, sands, and water pockets. This is because it is difficult to precisely predict the regions that may cause problems, and the type of lining must be designed to withstand all types of conditions (Hoek, 1990). Although substrate type can be a large risk to the cost of a project, it cannot be attributed to the country where the tunnel is being constructed because of the wide range of rock types that can exist in the same region (Kleberger 2006). It may be important to consider that some countries may have mostly one type of rock which might make that country an outlier when comparing international substrates. There have been cases of unexpected water penetration which have drastically increased the price of tunnelling and severely reduced the profit for the contractor. One such case was during the construction of the Burnley tunnel, part of Melbourne’s CityLink project. The Burnley tunnel passes deep beneath the Yarra River, and consequentially resulted in having a very high water pressure surrounding the tunnel. As a result of unforeseen condition in the design stage, some of the 1.8m thick concrete floor panels or inverts were lifted out of place by the water pressure, causing the contractor to lose $154m in damages (Samuel, 2007). Problems like the Burnley tunnel cause contractors to place higher percentage contingencies into the bid price than any other infrastructure projects. This variance in the type of substrate present in different countries has a profound effect on the cost of tunnelling.

2.3.2 Locality

Location can be one of the most vital factors in the cost of a tunnel. It is easier to simplify tunnels into the subcategories of urban and non-urban tunnels. Tunnels constructed in an urban area are often more expensive due to a variety of factors. The purchasing of real estate and easements can cost significantly higher, in addition to the cost of having multiple long term shaft site locations on the surface. Transportation of excavated materials, and construction materials and equipment can be extremely challenging in a city. Often, transport equipment will have limited hours or a weight limit while driving around the city. This often results in around-the-clock workdays to meet these time parameters and minimise the high costs of surface level construction site overhead. Complications also exist for non-urban tunnels such as the cost of long distance transport, or the construction of a plant nearby to provide construction materials. Additionally, if the project is a significant distance away from the labour source, it will be necessary to set up temporary housing and amenities for the workers or offer transportation and compensate the workers for the cost of transit.

2.3.3 Design

The cost of designing and planning a tunnel in any given region may be susceptible to certain regulatory hurdles. Some countries have much more stringent regulations regarding the design of infrastructure. This is necessary to ensure that all safety regulations and the needs of the general population are met by the outcome of a project. This process often involves many different organizations and overseeing bodies. In general, public input is also taken into consideration through several rounds of contribution (Lieske 2008). In some countries such as the United States, Australia and New Zealand, this process can take a significant amount of time, whereas in some less developed countries the design process is not as highly developed and less drawn out Although some studies have tried to quantify the amount of time that goes into the planning process, it is very difficult due to a large number of constantly changing factors, such as contract type, government sentiment and a wide range of project types (Lenferin, 2009). In addition to government regulation, the end-use and location of the tunnel always has a large effect on the amount of time it takes to design a tunnel. Certain tunnels have more complicated systems which take more time to design and approve, such as rail and road tunnels. Other tunnels may take a longer time to design due to complications with the location, such as working in an urban environment where there are a large number of existing structures to work around. Since the average monthly salary for engineers from the United Kingdom, Australia, United States, and New Zealand ranged from $4,356 to $6195 in 2005 Australian dollars it is evident that the length of the design process can have an immense effect on cost (“Engineer Salaries,” 2008).The high cost of designers combined with the variables present in the type of planning process, end-use and location can lead to a wide variance in the costs of designing a tunnel.

2.3.4 Health / Safety Regulations

There are various instances of health and safety regulations that can increase the cost of tunnelling. These safety costs can be subdivided into construction costs and human safety features.

Companies are obligated to provide safety equipment and high levels of insurance. These costs may vary depending on location, because different governments may have differing levels of worker safety regulations and also have varying levels of enforcement. An example of a construction safety cost which must be considered is proper ventilation, which is necessary to provide for the health of workers during construction. These costs can be very high which often results in construction management companies making the bare minimum investment in safety required by the regulations imposed by the government. Although these regulations have resulted in a great improvement in safety statistics in many countries, other countries still lag behind in safety requirements (Hinze, 2008).

Additionally, there are costs associated with providing for the safety of people using a tunnel after construction. Some of these features are dependent on the types of tunnel. In general, safety features are only necessary in vehicular, rail and mining tunnels. These tunnels will require more portals and ventilation shafts than may be necessary during the construction phase. One of the largest safety costs is associated with preventing and suppressing tunnel fires. Protecting against fire involves detection and communication systems to determine the source of a fire. Tunnel fires and smoke can spread rapidly, which necessitates fire suppression and ventilation systems. In addition, there is a need for a means of egress and regular intervals to allow for the swift exit of individuals using the tunnel in question. Lastly, there is a cost associated with protecting structural elements from fire so that the tunnel will not immediately collapse in the event of a fire (Chow, 2007).

2.3.5 Environmental Regulations

Environmental regulations play a role in determining the cost of a tunnel as well. Some countries may have more strict regulations which lengthen the planning process. Many countries utilize some type of a document called an environmental impact assessment (EIA) which analyses the potential effects on the environment and can trigger agencies to get involved in overseeing the design of a tunnel. In this case there may be costs associated with cleanup, removal and disposal of waste products such as industrial waste and construction waste that may not necessarily be required in other countries. Additionally, in countries that have environmentally protected regions, it may be impossible to receive a permit to construct a tunnel in its most cost effective location (Gurtoo, 2007). This could result in a high cost of constructing the tunnel in a different location. Other environmental issues also have costs associated with them such as wetlands destruction and replication, and habitat destruction and rehabilitation. Depending on the location, noise pollution may be regulated, and construction hours may be consequently limited which would drive up costs. Lastly there are costs associated with harm to the environment by the construction process such as unavoidable fines for air pollutants. The control measures required to mitigate against environmental impacts may have a significant impact on the overall cost of the tunnel, and should also be considered in the planning process in the interest of sustainability.

2.3.6 Contingencies

Although there is some variance in the way in which companies formulate bids for projects in different countries, most international construction management firms will have a good idea of the local issues associated with bidding on a project. Typically, due to unforeseen ground conditions that may result in delays, contractors assign a higher contingency to tunnels than they do for other aboveground infrastructure. The differences in these methods should not adversely affect the cost of tunnelling. However as stated above; there is some variance in the amount of money reserved in contingency to budget for uncertainties and risks that may be greater in certain markets. Such risks can include anything related to the design, procurement and construction of the tunnel in question (Touran 2003). This can include be delays, failures, geotechnical issues, and natural disasters such as the incidence of earthquakes.

2.3.7 Material/Labour

The basis for estimating material and labour costs for all types of tunnels is a highly refined process and is well practiced by companies that bid for contracts. In general, this method of estimation is fairly universal across any international construction management companies and cost estimation companies (Xiang Gu 2010). There is an issue with comparing data on tunnelling estimates across different contracting firms, because of a lack of standardization in the industry. It is also important to note that methods of price index comparison between countries can differ, and should be taken into account when using data from different sources.

Variance in the cost of materials depends on location as well. Although the variance of material costs may be greatest when comparing international tunnelling projects, there may also be significant cost deviation between projects located in the same country. Material costs can also vary depending on the type of tunnel because comparing tunnel costs on the basis of unit length is impractical. For example, a water tunnel will simply require a concrete shell, where a rail tunnel would require the shell, rails, emergency egress, lighting, fire safety systems, etc. (Crighton 1992). In addition, the source of materials is a key factor that needs to be considered. Depending on the local economy and market structure, materials may have to be sourced from further away which can be very expensive. Another alternative that is often chosen for tunnelling projects is to have the contractor purchase a local plant to manufacture the materials required for the construction of a particular large scale project.

The cost of labour and the productivity of the labour force are also significant parameters when it comes to variance in overall costs of a tunnel. Government regulation, along with the state of the economy in a given region, can have a profound effect on the cost of labour. Local and national governments can pass legislation requiring not only minimum wages, but also benefits like health insurance, which over time can significantly increase cost of labour (Riegger 2008). In addition, other factors such as the current labour market and the required education of the work force may also be relevant. Australia and New Zealand are consistently ranked among the highest labour rates and GDP per capita (Bureau of Labour Statistics). Given that around half of the cost associated with constructing a tunnel comes from the cost of labour, it is evident that this parameter may be a significant source of cost discrepancies across international borders (Presswire 2010). Because of this, some contracts elect to use migrant workers to construct their tunnels. One such case was the construction of the Kárahnjúkar hydropower project in Iceland, where the contractor set up temporary work camps and brought in a significant population of Chinese workers to construct a dam and over 25 miles of tunnels (Bærenholdt, 2008).

2.4 Financing

Although there are many small privately funded tunnel projects which have traditional financing costs associated with them, the majority of large scale infrastructure projects can only be financially feasible through government sponsored partnerships. It can be very difficult to create a direct profit out of a road or train tunnel, because the revenue made from tolls and tickets is based off of traffic/passenger estimates made before the start of the project which aren't always accurate and have been known to not cover the cost of constructing the tunnel. Typically, the potential profits will not exceed the expenditures so these tunnels would not be constructed but the unaccounted for costs of excess traffic, longer routes and lack of access can possibly make the construction of these tunnels worthwhile. Although the inherent lack of fiscal self-sufficiency of course prompts the government's investment, it should be noted that this cost is transferred directly to the tax-payers. Traditionally, government investment in infrastructure has remained steady at an average of just below 4 percent of GDP around the world. This is somewhat higher in Australia which invests just below 6 percent of its GDP in infrastructure (Chan, 2009).

Government investment in tunnels typically comes from one of two sources, either pay-as-you-go (PAYGO), which is public money from tax revenues, or capital-market financing, which is money borrowed from private sources such as bonds. The breakdown of government investment in Australia in 2006-2007 is as follows, budget appropriations (63%), government trading enterprises (GTEs) (32%) and public private partnerships (PPPs) (5%) (Chan, 2009). Budget appropriations are funds set aside directly by legislating bodies to be used towards the construction of a tunnel. GTEs are technically independent from government and raise investment funds through retained earnings, government budget appropriations and borrowing. Although controversial in regard to the manner in which they are governed, GTEs provide the ability to combat monopolies and provide services where financial risks may have deterred private sector investment. Although PPPs only make up 5% of Australia's infrastructure spending, evidence suggests that the majority of large, recent tunnel construction has been procured by this method. Typically the government will form a PPP with a private company to construct a tunnel and possibly operate it depending on the type of contract agreement (further discussed in section 1.4.1). The government will typically provide the private company with a grant, subsidy or tax break in return (Webb, 2002). PPPs are very controversial because of their high transaction costs and possibly lack of competition in the bidding process. In addition, PPPs often require much higher levels of design at the bidding stage which can draw out the bidding process, and increase costs for all the contractors that place bids. Contrarily, PPPs can more effectively deliver tunnelling projects in a shorter timeframe, and also extensively draw on public sector knowledge. The contractor is typically contractually obligated to provide a tunnel which is rated to last a certain amount of time (usually 50-100 years). In addition the contractor is typically compelled to provide any upgrades or repairs if the tunnel does not meet the required age rating at the end of the partnership (Chan, 2009).

These financing vehicles are all surprisingly similar across most stable market governments, but the key issue with financing transportation tunnels is that they are non-diversifiable risks. That is to say that their revenues come from a single stream, and if the expected flow is not met once the tunnel opens there can be large problems making sufficient revenue to continue operating the tunnel (Chan, 2009). As with any financing situation, the higher the risk, the higher the cost of financing, which means that, transportation tunnels often have a higher cost of financing than other types of tunnels which have a more predictable flow such as water or cable tunnels. All of the above financing methods have very different strengths and weaknesses. Typically there is a balance of cost, risk and the time it takes to complete a project. In general it is worthwhile to compare the breakdown of financing vehicles between different countries to see if there is any correlation between the market price of tunnels and the distribution of asset allocation techniques.

2.4.1 Project Delivery Methods

PPPs can be subdivided into further types of agreements between the contractor and the government which supplies the funding. Design Construct (D&C) partnerships are formed when the government specifies how they want a tunnel to be constructed and allow private contractors to bid on the construction of the tunnel. In this case the contractor assumes all risk associated with design and construction and transfers the tunnel back into the government's ownership once completed. This is the most commonly found form of contract for tunnelling projects in ANZ. Design Build Operate (DBO) is a similar partnership, but includes a contract with the constructor to operate the tunnel for a specified time. Build Own Operate (BOO) is similar to DBO except the project is financed by the private sector and once complete, the tunnel is operated by the same company that designed and constructed it. Build Own Operate Transfer (BOOT) is very similar to BOO, but after a specified number of years (typically around 30), the tunnel is transferred into government ownership. Lastly, an alliance is collaborative partnership where the contractor, a designer, and the government agree to share the fiscal benefits and risks associated with constructing a tunnel, with the project funded by government (Webb, 2002).

These types of agreements are very commonly used in specific types of tunnels such as road and rail tunnels. The key difference between each type of agreement is where the risk is placed and for how long. This can have a huge effect on the overall viability of the project and of course the final cost.

2.5 Complexity of Comparing Costs and Regulations Globally

For the purpose of analysis, tunnels are often generalised by country due to a lack of enough data to form comparisons between different regions within a country. Although there are important cost variations within individual countries, this classification allows for a simpler comparison between costs in individual countries and continents. Each subdivided region within a country has its own variation on cost variables even though the applicability of the majority of variables is dependent on country. An important variable to take into account when comparing construction costs across international borders is the different cost of materials and labour. These can be estimated by construction cost indices which account for the inflation in construction costs within a country. These indices have been developed to allow for the comparison of methodology and data when forming a cost estimate for a contract. These price indices can be measured in three different ways; by input, by output, or by seller. Input price indices encompass the price of inputs and include the costs of wages. This method does not include changes in productivity, increases in profitability or fluctuation of margins. As a result, this method is not fully reflective of increases in construction costs. Output price indices measure the costs of each construction activity associated with completing a project by taking the overall price of completed works. Seller price indices simply measure the final cost of construction by averaging the cost paid by the owner. This can also be an issue because it encompasses some costs that are not directly related to the construction industry, such as the cost of land, finance, and litigation.

Unfortunately, not all countries subscribe to the same philosophy, which causes problems when trying to formulate comparisons. In addition, those data are not consistent, since some countries calculate their indices on a monthly basis, while others calculate them on a quarterly basis. The combination of these factors makes it very difficult to accurately compare the cost variables in construction. In addition, these indices do not include all of the variables we are looking to compare in our study, since the indices only encompass material costs, labour costs, and profit margins. Another issue that makes comparison difficult is that these data are not consistently secured from the same sources. For instance, Australia’s data are derived from expenditures made by various government agencies, while New Zealand’s data are derived from a small number of private construction firms. This is an issue because the price the government might pay for a job can be vastly different from the price a private owner might pay for the same job in the same country. All of these factors combine to produce somewhat imprecise cost comparison tools.
Since not all countries publish construction price indices other methods often need to be used. One alternative is to utilise the index of a geographically, and economically similar country. Another method of comparison is to utilise inflation factors which are based on the GDP of each country, and are widely available for every country. The problem with this method is that it does not account for inflation in the construction industry, but rather in the country as a whole.

Historically, Australia and New Zealand have had some of the highest cost indices when it comes to constructing large scale civil projects. However this variation needs to be taken into account in this study so that tunnel costs can be based off an even level not including externalities. The cost indices can be a useful tool in incorporating complex cost data.

2.6 Previous Studies

In 2010, the United Kingdom (UK) completed a study of the varying costs of infrastructure in Europe. This review showed that the costs of actual tunnel construction were not higher in the UK in comparison to similar European countries, but the total costs of the projects were greater. The study concluded that the planning and pre-construction phases of the project were the source of the heightened costs. This research looked at costs across a number of sectors including high speed rail, railway stations, highways, tunnels, flood defences, and provides a well-rounded example of how a cost factor such as design can influence a project budget. The UK report also listed examples of “Best Practice” tunnels. One example was the Madrid Metro Rail. Several methods utilized in this project saved them approximately 5%. First, the construction emphasized a short time program, which lasted for four years for a 56 kilometre tunnel and included the design and procurement stages. Second, there was a small management team of public administration officials which cut back on supervision costs. Lastly, ten different lines shared overheads and equipment for the whole Madrid network during the construction. These main advances account for the benefit of streamlining the program and management (HM Treasury, 2010).

The British Tunnelling Society (BTS) conducted a specific cost study only encompassing tunnels. This analysis looked at the costs of seven tunnels in the UK and 14 from Europe and investigated the various key cost drivers of tunnelling. This study noted its limitations in lack of available data, the sources of its data, the reliability of the data, the comparability of the data, and the difficulties of achieving a comparative cost baseline. The key tunnelling cost drivers listed in the study included ground conditions, end use, location, third party constraints, length, diameter, construction method, and spoil disposal. The data was also graphed showing cost per meter and cost per cubic meter in relation to tunnel length and diameter. In conclusion, the BTS found that there was little evidence supporting the notion that construction costs in the UK are substantially greater than those in comparable parts of Europe and identified areas of cost escalation in tunnelling (British Tunnelling Society, 2010). A recent Danish study compared the capital costs of various urban rail projects in Europe by route-kilometre. This study used the very simple approach of collecting a small pool of data, converting the currencies and then comparing them on a cost/m basis. The report concluded that the lack of accurate data was a handicap, and failed to address its initial research objectives (Flyvbjerg, 2008). In addition to the small dataset, the main limitations of this report are that the researchers did not remove stations from the comparison, and a significant portion of the data was for aboveground works.

There was only one previous construction cost comparison completed that included Australia. This study investigated the last decade of public transport infrastructure projects in Australasia, ranging from 2000 to 2009. 33 public transport modes (heavy rail, light rail and buses) were represented in the data which specifically included the construction of major new lines and corridors, line extensions, track amplification, rail electrification, airport rail connections and refurbishments of existing infrastructure. The data collected in the survey was scaled up to constant 2010 dollars using only Australian GDP rates, but recommended the use of construction indices in the future. It was also concluded that further research was necessary in order to support or negate the conclusions of the report as the data was very limited by public availability. In addition, this analysis focused on all infrastructures and further investigation is necessary to make any conclusions specifically regarding tunnelling (Martin, 2011).

These previous studies all share several limitations. Some of these studies used various methods to account for inflation and currency exchange. It was recommended from the majority of past research that costs be escalated with construction price indices and that exchange rates are used from the year of the cost to make currencies comparable in future analysis. Each one also only compared tunnels in one or two regions, whether it was Australasia, Europe, or... A world wide comparison would add additional data points to the study and allow for a more complete analysis. In addition, expanding the scope of the analysis would allow for more information to be compiled since it would not be limited to one or two nations.

2.7 Summary

Evidently there are numerous variables that can affect the cost of tunnelling, and almost all of these variables can be affected by location. In an ever-changing industry, it is not surprising that there has been a lack of conformity in assessing the effects of a variety of variables on cost analysis. In contrast, improvements can be made to our current understanding by the analysis of data. Utilizing existing data on tunnelling projects and integrating those data into statistical analyses can help achieve the objective of linking the cost factors with the purportedly high cost of tunnelling in Australia and New Zealand.

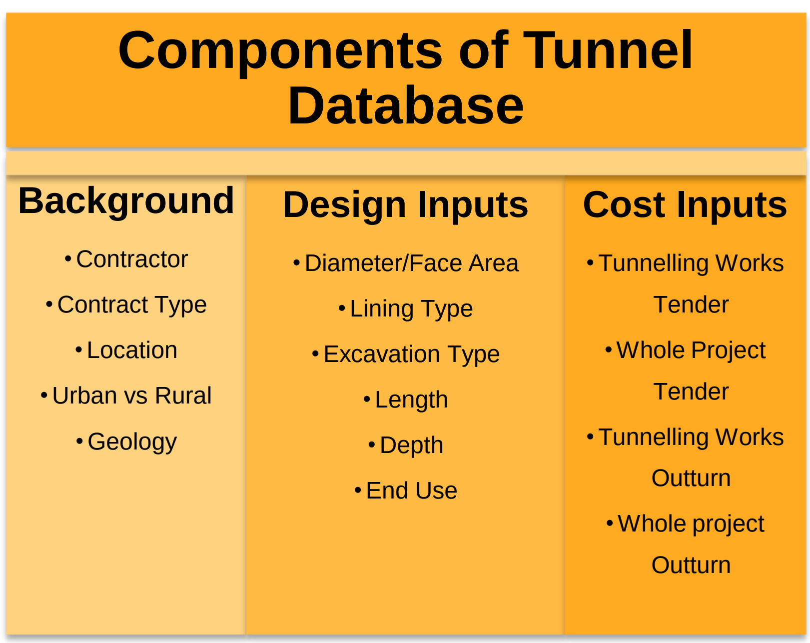
3.0 Methodology

The goal of this project was to provide insight regarding whether tunnel construction is more expensive in Australia and New Zealand (ANZ) and, if so, which factors contribute to these high tunnelling costs. We accomplished this goal by developing and expanding a database encompassing tender and outturn costs of tunnel construction and by providing a method of comparing various international projects to those in Australia and New Zealand. The programme we adhered to is found in Appendix C (1.1). In this chapter, we will discuss the methods used to achieve this goal and to develop recommendations for AECOM regarding the heightened cost of tunnels in ANZ and possible benefits of these higher costs.

3.1 Archival Research

We began this project by reading existing literature and research on the subject of costs of tunnelling projects supplied by AECOM and our independent research. This encompassed many case studies and reports that attempted to break down tunnel budgets and make them comparable across borders. From this literature we ascertained some of the key drivers of tunnel costs. Using this knowledge, we completed an internet search and archival research on tunnelling projects completed in the last 15 years in order to expand upon the tunnel database for any of the variables that were publically available. We chose to use a 15 year timeframe in order to eliminate the variance in cost due to the use of different technologies or the construction to very different standards. This database was originally set up by an engineer in the tunnelling division of AECOM in order to better quantify tunnel costs and compare various projects based on several variables (Figure 2). The database contains a general overview of projects from the Americas, Asia, Europe, and ANZ, and is then is broken down into individual construction projects. When available, the budget breakdowns for these individual projects were entered into the main database in separate worksheets.

Figure 2: Variables in Tunnelling Database



3.2 Compiling the Database

We expanded upon the tunnel cost database by adding additional projects towards an overall goal of about 200 tunnels in various countries. This list was then narrowed down to the projects with the most extensive research and most comprehensive and accurate cost data. Only projects where tunnelling was the majority of the right of way or where the pure tunnelling costs could be extracted were used in the database. The information regarding these projects was collected through publically available reports, case studies, and press releases along with confidential internal data provided by AECOM and other contacts in the industry. The variety of locations, construction dates, and project sizes necessitated conversion from the original costs of each project to present costs in USD and AUD per metre and per metre cubed in order to make the projects comparable. AECOM intends to continue to update this database in the future as new tunnels are completed.

3.2.1 Cost Conversion

In order to compare costs for nations around the world, the tender and outturn costs of each project needed to be adjusted to account for the variance in price over time. Several different methods of price comparison were considered, including Gross Domestic Product (GDP) deflator, Labour Cost Index (LCI), Producer Price Index (PPI), Consumer Price Index (CPI), and various construction-based price indices. The GDP deflator accounted for inflation as a whole for the country's economy, which would not necessarily reflect the fluctuation in the construction industry. The option of combining the LCI with the PPI or the CPI was also rejected based on this observation and a lack of comparable data. We decided to move forward with construction price indices such as the Tender Price Index (TPI) and the Construction Price Index, which best reflected how the price of materials needed to construct tunnels have changed over time. These indices are published by individual countries, and are typically based off of the outturn costs for common construction projects on a quarterly basis. The construction indices for each country are shown in Appendix G (7.8): Table 7 and Table 8. Each cost was multiplied by this inflation factor to move costs to the third quarter of 2011. This inflation factor was country specific, and the formula is shown below

$$Inflation\ Factor = \frac{Construction\ Index\ for\ 3rd\ Quarter\ 2011}{Construction\ Index\ for\ Year, Quarter\ of\ Cost}$$

The inflation factor was also multiplied by an average exchange rate for the third quarter of 2011 where applicable. All currencies were converted to both Australian Dollars (AUD) and United States Dollars (USD). The Australian dollar was chosen as the primary currency because of this study's focus in Australia, and the USD was chosen because it is the most common international comparison currency. These exchange rates can also be viewed in Appendix G: (7.8) Table 6**.** A column titled inflation/exchange factor in the database was linked to a sheet with each country's indices and multiplied by the appropriate exchange factor. After accounting for inflation changes and converting to common currencies, the final prices for each project were calculated in the present value estimate and present value final cost columns in the database.

3.2.2 Distance Normalization

To account for the various sizes of projects in the database, costs were normalized by distance, and the length of twin bored tunnels was doubled. This would theoretically allow a project spanning thousands of metres to be compared with one that is only a few hundred. The industry standard has been to compare tunnels on a basis of cost per meter, but we have also elected to compare the tunnels in our database by cost per meter cubed to account for different bore sizes. The present value estimate and present value final cost columns were divided by the length of each tunnel project in meters and entered into the present value estimate or final cost per meter length columns respectively. These columns were then further normalized by dividing by the face area of each tunnel to account for different bore sizes and to potentially eliminate the added costs associated with larger volume tunnels. These data were entered into the present value estimate or final cost per cubic meter columns. These two sets of data were used to compare tunnelling in ANZ to all of the international projects using statistical analysis.

3.3 Statistical Comparison of ANZ to the rest of the world

The finalized cost database was used in order to ascertain if tunnelling in ANZ is statistically more expensive than in other nations. The normalized columns for estimate and final cost per meter were used in this analysis. When comparing by region we reported values for cost per meter and cost per cubic meter. While for end use comparison we found that the most accurate method of evaluation would be to use the cost/m data because of complications involved in comparing cost/m^3, which is explained in section 4.1.5.

3.3.1 Identification and Removal of Erroneous Data

We found that the inclusion of some tunnels which included costs that were not purely related to tunnelling would greatly skew out results. The data from these columns were graphed in a scatter plot to visually confirm the existence of these data in the sets. Our solution to this problem was to run a test to identify bad data, then individually examine the flagged data to determine if it should be omitted based on bad cost representations. We defined these data as any cost/m which was outside of the fences derived from the following equations.

$$Upper\ Fence = Q3 + 3 * IQ$$

$$Lower\ Fence = Q1 - 3 * IQ$$

Where Q1 and Q3 represent the 25th and 75th percentiles, respectively, of each separate dataset and IQ represents the interquartile range which is defined as the upper quartile minus the lower quartile. The factor 3 is used to identify the outer fences, while the factor 1.5 is used to identify the inner fences. For our analysis 3 was selected so that only the extremes would be flagged (NIST/SEMATECH, 2012). As a result we would not remove any mildly expensive tunnels that could potentially represent valid data. To perform this analysis we plotted the estimate cost/m and final cost/m and separate box plots and set up upper and lower fences based off of the aforementioned equations to exclude inaccurate data. An if-then test was written in Microsoft Excel to output a 1 if the value of a cost was greater than or less than one of the fences, or 0 if it was within the boundary conditions. Each flagged outlier was then further researched to categorize why it should be removed or kept. Tunnelling works with a substantial amount of other works, lack of construction-based indices, or inaccurate dimensions for costs per cubic meter were excluded from our statistical analysis. If there was no support for removing the flagged data, then the data was kept in the analysis. We deemed this procedure necessary since the outlying costs were not evenly distributed across regions and could result in one country appearing much more expensive than others. By removing these data from the set, we could remove any costs that potentially included non-tunnel construction which were not comparable to others. This can be a risky assumption to make, but it was a necessary step to take in order to qualify such a small dataset with such a high variance.

3.3.2 Data Analysis

An unpaired, two tailed T test was completed in Microsoft Excel to determine if there was a statistical difference in cost for the projects in ANZ compared to those throughout the rest of the world. The T-test either rejects or fails to reject our null hypothesis (H_o), which was defined as: there is no statistical difference between tunnelling costs in ANZ and those in the rest of the world. The ANZ costs versus the rest of the world costs for tunnelling will be used as our two data sets. This test was selected because it compares the differences in means between two groups (StatSoft, Inc., 2011). This allows us to account for variation within groups and exclude it from the analysis, which was a major concern. A two-tailed test was selected since prior to the analysis as we did not expect one cost to be greater than the other. An unpaired test was chosen because the samples were independent and contained different sets of individual subjects (Lowry).

We rejected or failed to reject the null hypothesis based on the outputted p-value from the T-test. This value represents the probability of error involved in rejecting the hypothesis of no differences between the two categories of observations in the population. A higher p-value corresponds with less reliability in a result. For example, a value of 0.05 indicates that there is a 5% probability that the relation between the variables found in our sample is due to random chance. This means that the results of our analysis could be replicated 95% of the time. Customarily, in many areas of research, the p-value of 0.05 is treated as border-line acceptable error level. For this reason, we have selected 0.05 as our critical value (StatSoft, Inc., 2011). If the calculated number resulting from our T-test is below 0.05 then the null hypothesis is rejected, while if the value is greater than 0.05 we fail to reject the null hypothesis (Lowry). The T-test of ANZ versus overseas was then followed up by comparing ANZ to Europe, Asia, and the Americas respectively. The first testing separated tunnels only by region into ANZ, Europe, Asia, and the Americas. This wide range of data was then refined to compare tunnels by region and end-use and end-use and location type. For all data sets, the means and standard error were reported and illustrated graphically.

3.3.3 Estimate to Final Price Comparison

The percentage increase from the tender cost to the outturn cost was also calculated by the below formula when there was sufficient information:

$$Percent\ Increase = \frac{Final\ Cost - Estimate}{Final\ Cost} * 100$$

This provided a method for comparing how cost was escalated or lowered for various projects, and identified data that required further investigation for where there was a large gap between the two costs. In addition, this statistic was compared between ANZ and the rest of the world in order to ascertain if cost escalation or savings was location dependent.

3.4 Assessing the Position of the Tunnelling Industry

3.4.1 Interviews

In order to better understand the process of compiling costs and the possible cost discrepancy between ANZ and other nations, we set up various interviews with contractors, cost estimators, and consultants from the tunnelling industry. The questionnaires used can be found in Appendix D: (7.5). Depending on the background of the interviewee, different interview questionnaires (forms) were used to acquire their knowledge. Form A was used with all people interviewed and provides a brief explanation of our project along with some general background questions about the interviewee's experience. Form B focused on cost estimators and entailed questions about how a tender price is put together and how this cost is broken down. Form C was directed at contractors and focused on questions regarding how prices change throughout the tunnelling process and how final costs compare to estimated costs. Form D was aimed at consultants and asked questions concerning how the design process is carried out and the various costs that could be associated with it. All of the interviewees were asked if there were any specific cost drivers that they believed escalated costs in ANZ and where they believed the greatest potential for cost reduction was. If the interviewee had global experience, then they were questioned about if they felt tunnels in ANZ were more expensive than the rest of the world and if so, whether there were any benefits to the higher cost. The information gathered from these interviews was used to direct further research of tunnel projects, determine the major cost drivers of tunnelling costs, and contribute to decisions as to how to break down and analyse the cost variables in the database. Each interviewee was also individually ranked according to their international tunnelling experience by each person who participated in each interview. The average ranking scores were used to weight their quantifiable answers. Tunnelling experience was classified by both the amount of years they worked in the industry as well as what extent of global experience they had.

Some of the potential risks we encountered during these interviews were protecting employee opinions and making sure our results were unbiased. We accomplished this by wording our questions in a non-leading way and also providing full confidentiality for all research subjects by not publishing any identifying information about the research subjects. Knowing that confidentiality can be compromised by means other than reporting an interviewee's name, position, company or experience and information disclosed could reveal an identity to an interested knowledgeable reader. We sent out all interview minutes which included statements that could potentially be used in the final paper for approval which also ensured we were accurately representing how an individual feels. The ranking system was also kept confidential, with only the final results displayed instead of the individually weighted numbers; therefore, it would be impossible to identify a ranking with a specific employee.

3.4.2 Surveys

The qualitative information gained from interviews was supplemented with quantifiable data from a brief survey. The questions in this survey varied depending on whether the respondent was a cost estimator, contractor, consultant, or client and whether or not they had global experience. The set of questions asked in the survey can be found in Appendix E: (7.6). These questions focused on whether or not the respondent believed tunnels were more expensive in ANZ, how he or she would rank a list of cost factors regarding how they affected tunnel costs and the potential for cost savings. The survey was compiled using Davis Langdon's preferred survey software Zoomerang, which hosted the survey online. The survey link was emailed to all people we interviewed and was also directly sent to another list of tunnelling contacts in Australia and New Zealand that we accumulated from various sources with the hope that they would pass the survey on to other contacts. The software then compiled all responses and comments in an Excel spreadsheet for analysis

3.4.3 Analysis

Qualitative information from completed interviews along with quantitative results from surveys were used to support or reject the above mentioned claim regarding if tunnels are higher priced here in Australia. The quantitative information acquired from the survey was graphically analysed on the basis of the respondent's profession, while the qualitative directed further international research towards specific key drivers. These drivers represented areas of cost escalation or cost savings and were further investigated to provide recommendations for ANZ.

3.5 Tunnel Case Studies

After the completion of the statistical analysis of the tunnelling database and interviews and surveys within the tunnelling industry, we compared the individual cost breakdowns of relatable projects. Tunnels were matched for comparison based on cost type, end-use, excavation type, locality, and contract type. We selected 7 similar case studies in the database to analyse the pure TBM tunnelling costs including the cost of excavation, lining, and contractor's overhead, while eliminating all other unrelated costs. These tunnel projects were then compared across different countries to analyse the factors that may go into variance in price, and where higher or lower costs may come from. Information from interviews and surveys were used to support or negate these claims. These conclusions from the above methods helped focus our research on how ANZ can reduce tunnelling costs for specific key drivers and helped provide recommendations based on other countries' practices. This information was also assimilated to assess any possible benefits resulting from potentially higher costs in ANZ when applicable in order to possibly provide reasoning for a higher cost in Australia.

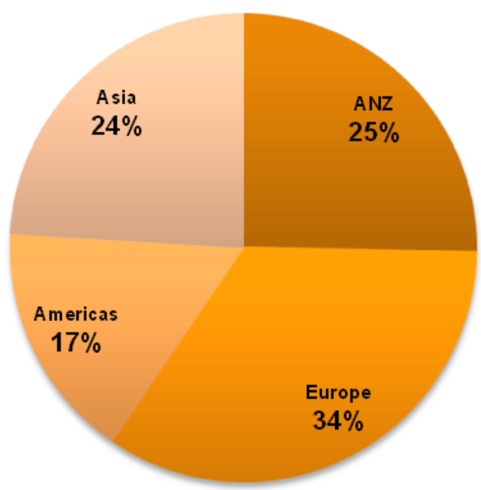
4.0 Results and Analysis

This chapter begins by describing the finalised tunnelling cost database and progresses through several statistical and graphical analyses of the assembled price information. From these tests and graphs, ANZ's tunnelling costs are compared to the rest of the world. This quantitative data analysis is then supplemented with discussion of our interviews and graphs of survey responses. A case study is examined in which the pure tunnelling costs were compared across several projects. Based on these findings, the validity of comparing ANZ as one entity to the rest of the world is then debated, and Australia's position for several key cost drivers was further investigated and reported on.

4.1 Tunnel Database Analysis

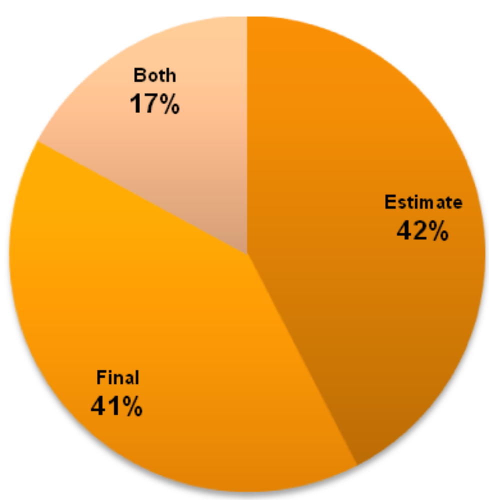
After the original data collection, the tunnelling cost database encompassed almost 200 tunnels in 36 different countries. This number was narrowed down to 158 tunnels in 35 different countries, including Australia, New Zealand, United States, United Kingdom, Singapore, China, France, Mexico, and various others. The full listing is shown in Appendix H (1.1), and the breakdown by region is shown in Figure 3.

Figure 3: Tunnel Breakdown by Region



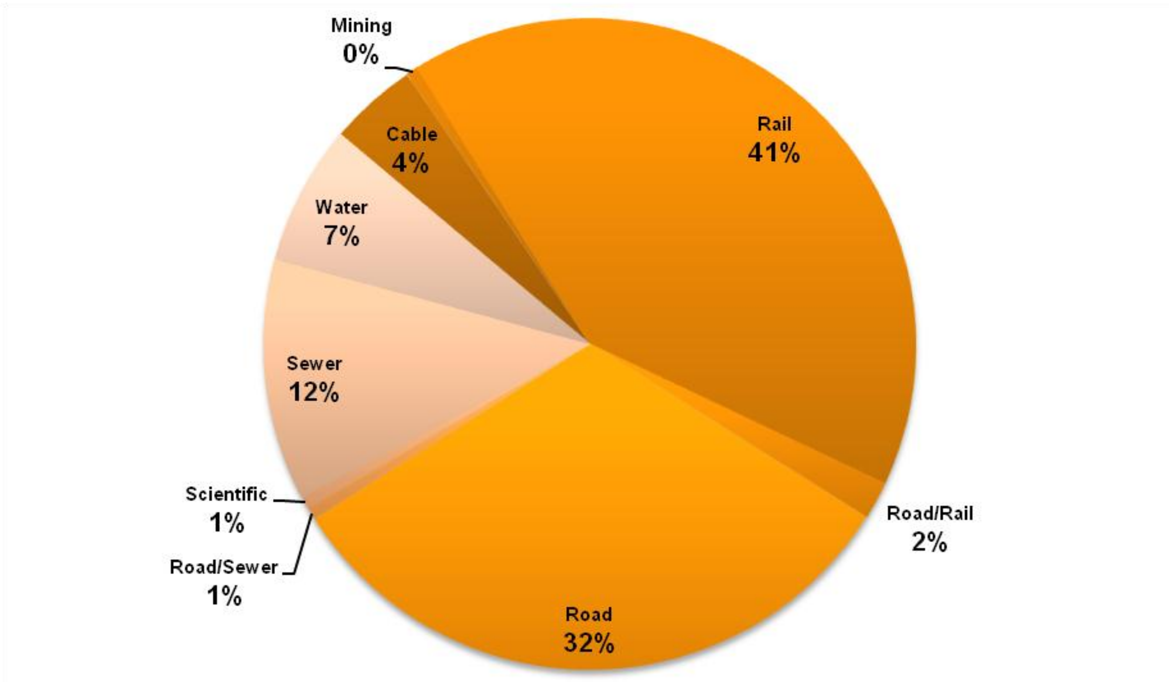
Of the total 158 tunnels, 67 had estimate costs, 64 had final costs, and 27 had both. Figure 4 shows the breakdown of costs in the database.

Figure 4:Tunnel Breakdown by Cost Type



Each tunnel also was broken down into its end-use type. These ranged from cable, sewer, and water tunnels to road and rail tunnels. The main focus of this study was on rail and road tunnels because of their complexity and high costs. There were also a few examples of mining tunnels and combined end-use tunnels. Figure 5 below displays the percentages of each end-use in the overall database.

Figure 5: Tunnel Breakdown by End-Use



All costs were then converted to Australian and United States dollars for the third quarter of 2011 using the indices displayed in Appendix G (7.8). All tables in the main report are displayed in AUD, while USD versions of the tables are displayed in Appendix I (7.10).The construction price indices that were used to account for inflation did not specifically encompass tunnelling materials, but rather construction industry materials and labour as a whole. This is not the ideal method of accounting for changes in prices in the tunnelling industry, but there are not a sufficient number of tunnelling price indices that go back 15 years to account for all of the tunnels in our database and the complexity of establishing a tunnelling index would be beyond the scope of this report. Some of the dates for estimates and final costs were also estimated based on newspaper articles and other publically available sources. These non-exact dates could adversely affect the method used to account for inflation.

These compiled estimates and final costs for Australia and for the rest of the world were then graphed in a box plot with fences as shown in Figure 6 and Figure 7 respectively. Any data points outside of the fences were deemed to be potentially erroneous data, and were flagged for review. It is vitally important to review these flagged data because they may contain valuable information and should not be removed unless there is a plausible explanation for why they appeared. In this analysis, many of the costs we accumulated came with no breakdown or description of what the cost encompassed. Factors such as operating and maintenance fees or rolling stock could have been included without our knowledge. These are factors that we specifically removed from any costs that were separated into various cost categories. Furthermore, a single extremely high cost project could greatly skew our cost comparison. If one project is greatly increasing the mean of our set of numbers then our comparison would be flawed. These higher points were further investigated in our case-study analysis. Based on this reasoning, we found it relevant to remove these points if they represented either poor data points or data that should not be included in this analysis.

Figure 6: Box Plot of Estimate Costs (AUD)

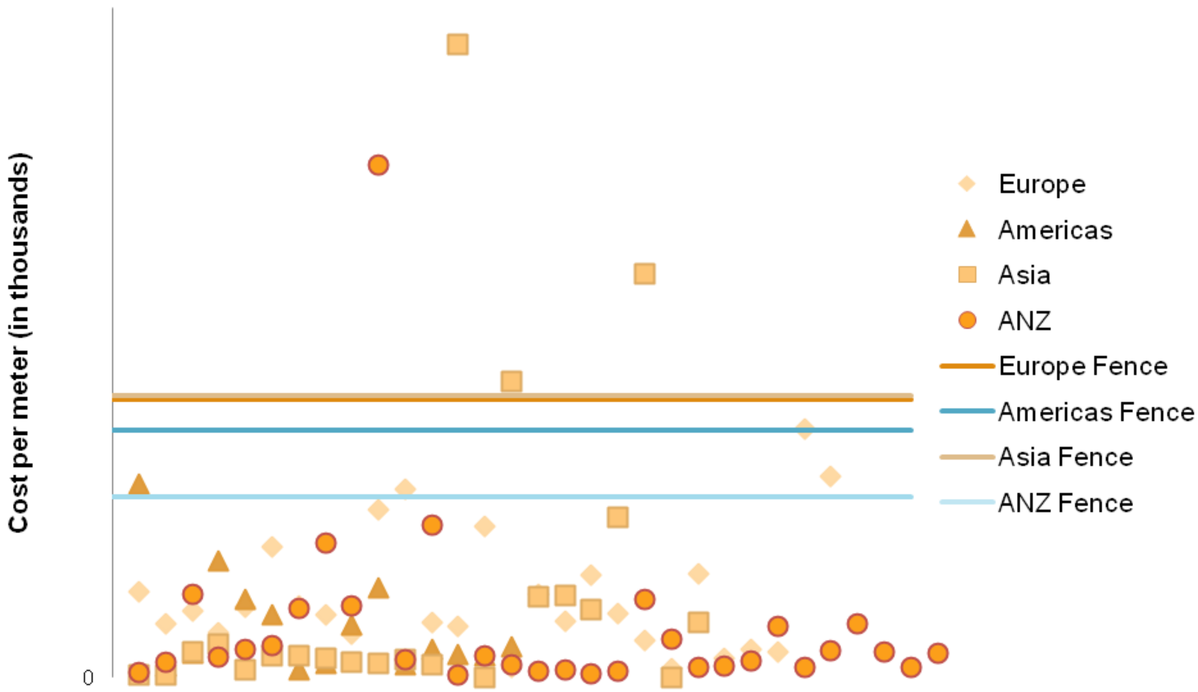
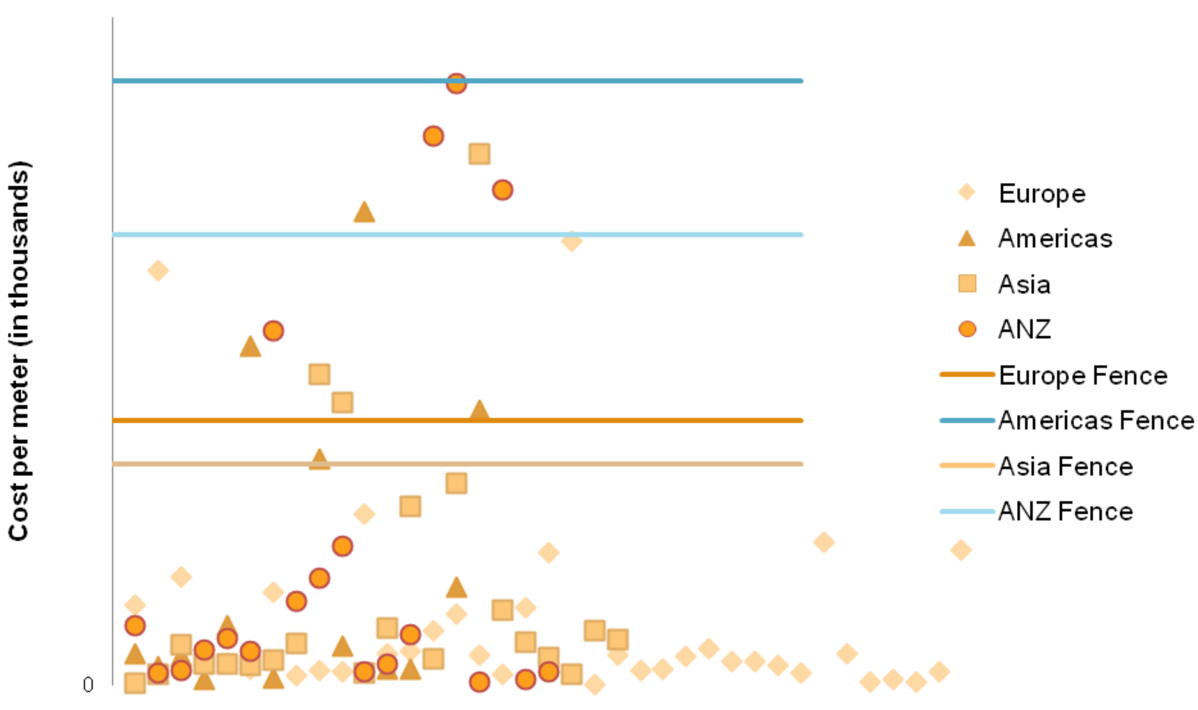


Figure 7: Box Plot of Final Costs (AUD)



4.1.1 Costs of Tunnelling by Region

All cost information was broken down by region and according to whether it was an estimate or a final cost. These numbers were then converted to cost per meter and cost per cubic meter. The averages for each region and the standard deviations were reported in Appendix I (7.10). The estimates and final cost averages for cost per meter and cost per cubic meter were then graphed by region, and standard error bars were used to illustrate the range in data (Figure 8 and Figure 9).

Figure 8: Regional comparison of cost/m

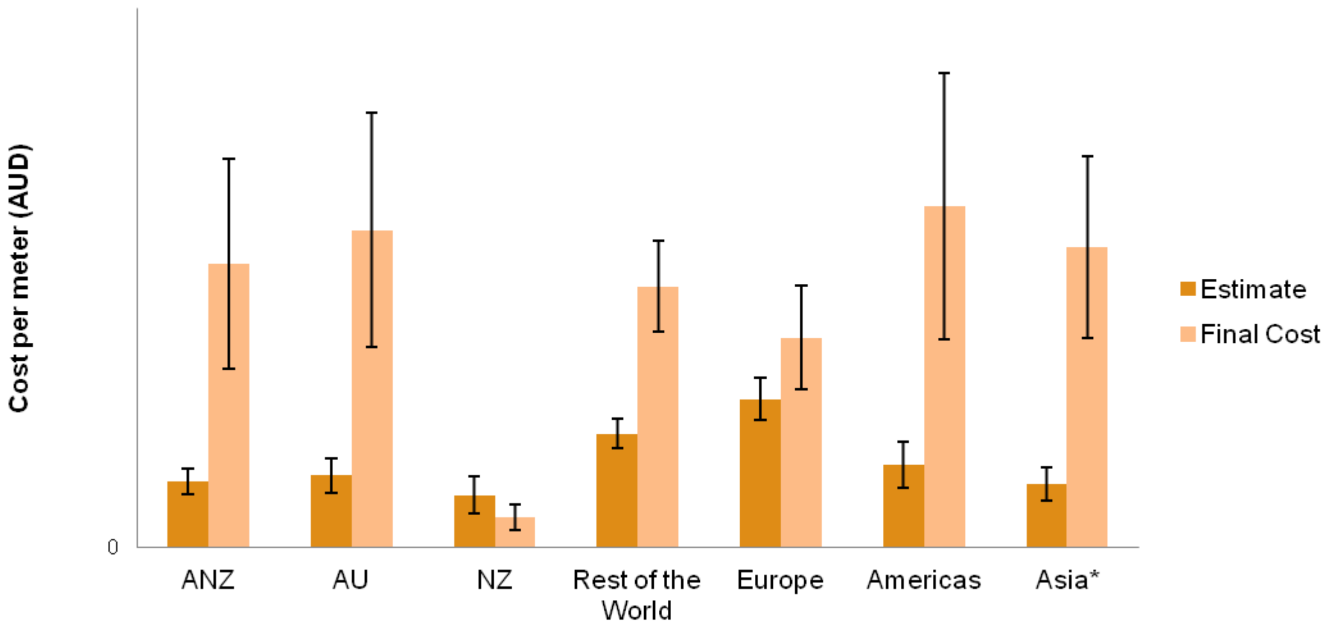
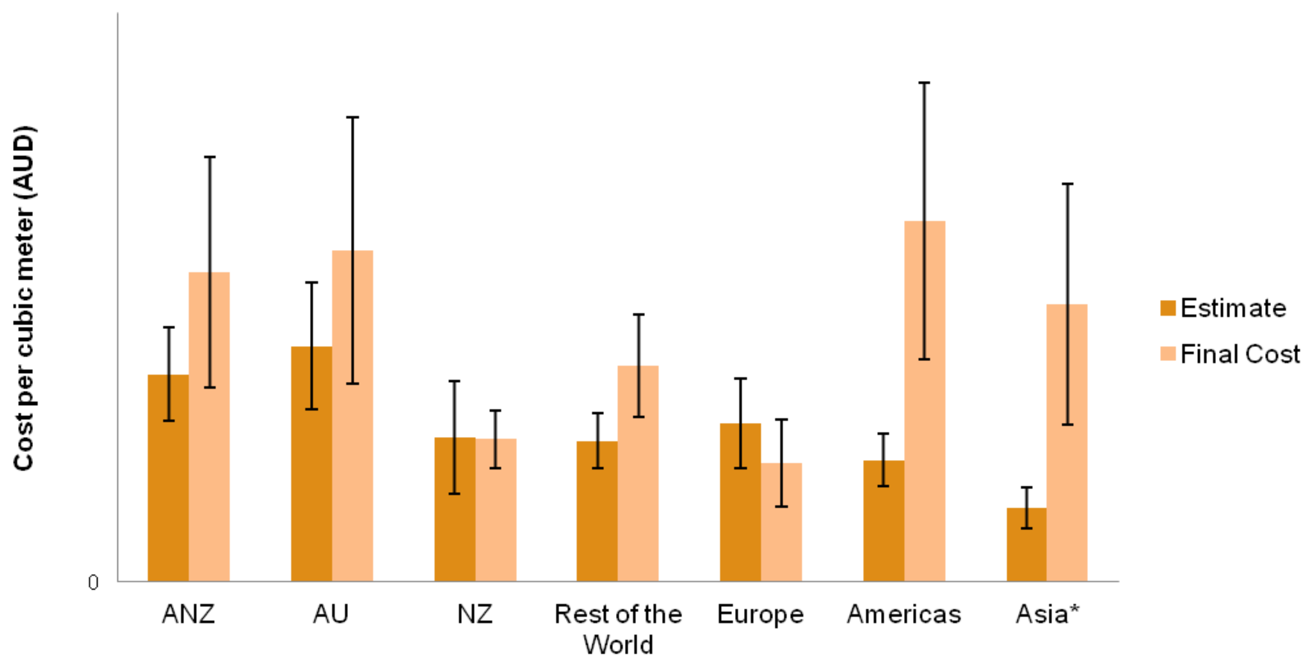


Figure 9: Regional comparison of cost/m^3



* Asia costs include one tunnel from South Africa

Figure 8 illustrates that costs per meter in ANZ appear to be lower than the rest of the world for estimates but slightly higher when compared to final costs, which supports the current sentiment in ANZ that tunnelling is more expensive even though it is only the outturn costs are more expensive. Costs per cubic meter are higher than the rest of the world for both tender and outturn costs (Figure 9). Note the very high standard error bars for all values. The overlapping of these error bars shows that there is no statistical difference between the data even though the averages differ. This represents a large range in data which may be a result of the many variables not accounted for in this analysis. The data suggests that Australia and New Zealand should not be grouped together since there is such a wide variance between the final costs per meter. This analysis rejects the viability of future shared analysis, and this stance is supported by the findings from the interviews we conducted.

4.1.1.1 T-test Analysis

Table 1 below displays the reported P-values for statistical T-tests that were completed. Additional T-tests comparing ANZ to the rest of the world are shown in Appendix I (7.10). No significant difference was found between the means of costs meter and per cubic meter for Australia and those for the rest of the world. The reported p-values for these T-tests were greater than 0.05 so we failed to reject our null hypothesis that there is no statistical difference between the two data sets. Although the mean for final cost per meter in Australia appeared higher than the rest of the world in Figure 8, this test shows that there is no statistical difference between the two data sets. This could be a result of a large range in costs in the dataset, or an inadequate quantity of tunnels.

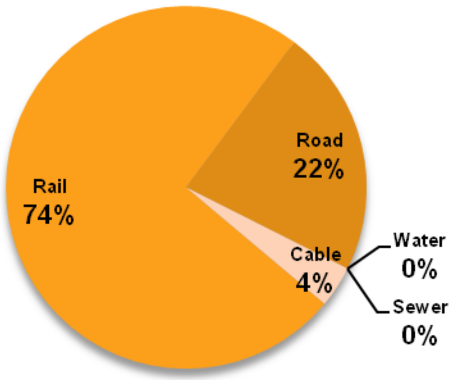
Table 1: Reported T-Test Results for Estimates and Final Costs by Region

	Estimates (AUD)				Final Cost (AUD)			
Comparison	Cost/m	Difference	Cost/m^3	Difference	Cost/m	Difference	Cost/m^3	Difference
AU to Rest of the world	0.1323	No	0.117	No	0.619	No	0.367	No
AU to Europe	**0.012**	**Yes**	0.313	No	0.337	No	0.059	No
AU to Americas	0.291	No	0.587	No	0.895	No	0.879	No
*AU to Asia**	0.736	No	**0.030**	**Yes**	0.907	No	0.767	No

* Asia costs include one tunnel from South Africa

A possible way to narrow down this large range would be to evaluate tunnelling costs by other major cost drivers as well as by region. It is also important to note that according to the T-test, estimates per meter in Australia are statistically different than those in Europe, and estimates per cubic meter in Australia have a statistical difference from those in Asia. As seen in Figure 8 and Figure 9, the average estimate cost per meter in Europe is higher than that of Australia, and the average estimate cost per cubic meter in Asia lower than that of Australia. The data set for the European estimates could have been affected by the large percentage of road and rail tunnels. As can be see below in Figure 10 and Figure 11, end-use is distributed between cable, water, sewer, road, and rail for Australia and Asia, but Europe contains majorly rail and road tunnels. The higher costs associated with constructing these tunnels would be a possible explanation for why tunnels in Europe appear more expensive than those in Australia. Tunnelling in Asia, on the other hand, appears to be less expensive than that in Australia. Possible explanations for this were explored in interviews and surveys and reported below in section 4.2.

Figure 10: Europe End-Uses Tunnel Breakdown (left) and ANZ End-Uses Tunnel Breakdown (right) - Estimates



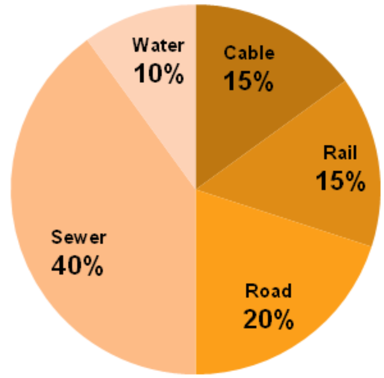
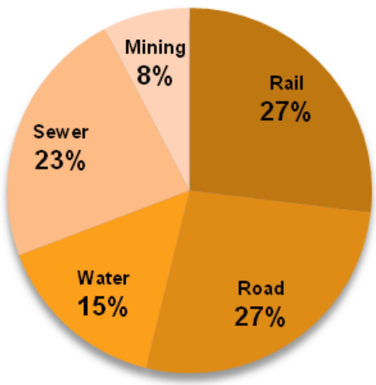


Figure 11: Asia End-Uses Tunnel Breakdown - Estimates



One limitation of using a T-test is that it operates under the assumption that the two samples are randomly drawn from normally distributed populations and that the measures of which the two samples are composed are equal interval (NIST/SEMATECH, 2012). The compiled data was mostly taken from publically available information which could skew our sample population. This test also assumes that the numbers are directly comparable which, for some tunnels they may not be, and this could also alter the result.

4.1.1.2 Percentage Increase, Estimate to Final

The below Table 2 shows the percent change from estimated costs to final outturn costs. This table helps explain the divergence with Australian costs between estimate and final costs when compared internationally. Clearly this cost escalation is not present in New Zealand, which helps confirm the theory that Australia and New Zealand should not be co-analysed because of potentially different cost factors. A similarly large increase between estimate and final costs can be clearly seen with tunnels in the Americas. European and tunnels seem to come out under their intended budgets, which is notable since tunnels in Europe were by far the most expensive in the estimate table and were also statistically more expensive in estimate cost per meter than Australia. This analysis suggests that contractors in Europe have a better sense of final costs when placing bids. Another possible explanation is that tunnelling companies in Europe better account for inflation and financing changes during the life of the project, but this area is not encompassed in our study and merits further research. Asia also experiences similar decreases in project costs from estimate to outturn. Note that this data is very limited as both estimates and final costs were difficult to find during our research and is displayed in the number of projects column.

Table 2: Percent Increase, Estimate to Final Cost

Regional Comparison		
Country	Number of Projects	Average Percent Increase
ANZ	**9**	**33.29**
Australia	7	43.92
New Zealand	2	-3.90
Rest of the World	**13**	**-15.42**
Europe	6	-9.05
Americas	2	9.30
Asia*	5	-37.92

* Asia costs include one tunnel from South Africa

4.1.2 Costs of Tunnelling by End-Use and Region

Tunnel costs were then compared by both end-use and region. A T-test was done to assess if any of the different end-uses were statistically similar and could be combined for our analysis. The results are shown below in Table 3.

Table 3: T-Test Comparing End-Uses by Region

Reported P Values	Estimates (AUD)				Final Cost (AUD)			
Comparison	Cost/m	Difference	Cost/m^3	Difference	Cost/m	Difference	Cost/m^3	Difference
Road to Rail	0.144	No	0.2685	No	0.541	No	0.053	No
Water & Sewer to Cable	0.162	No	0.781	No	0.329	No	0.397	No
Transportation to Utility	**1.80E-06**	**Yes**	0.306	No	**0.0338**	**Yes**	0.357	No

As can be seen in the table, no statistical difference was found between road and rail tunnel costs, nor was there a statistical difference between cable, sewer and water tunnel costs. A statistical difference was found between transportation (road/rail) tunnels and utility (cable/sewer/water) tunnels. The complexity and added features of transportation tunnels may attribute to this difference. This grouping is both statistically acceptable and necessary in order to be able to compare the data with fewer variables. These groupings are also reasonable because road and rail tunnels have many of the same features after rolling stock and stations have been removed, and cable, sewer, and water tunnels are also very similar with only small differences in lining types.

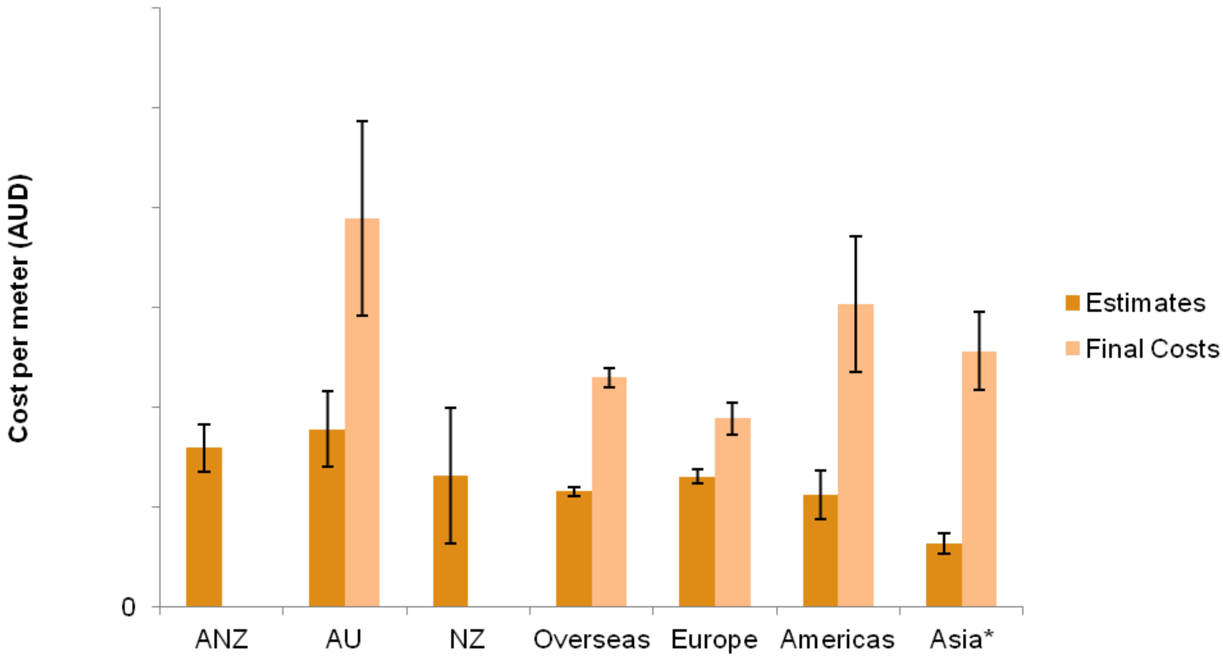
The analysis that compared tunnels by end-use did not utilize the cost per cubic meter data. As seen in the above Table 3, the T-test results were not consistent and these items could not be grouped together as they were with cost per meter. This is the result of inconsistencies derived when dividing by the different face areas of the tunnels and as a result would only partially account for the large cost differences between these two categories of tunnels.

The averages for each region and end-use were calculated and graphed. Standard error bars were used to represent the variance in the sample mean based on the sample size in a 95% confidence interval using the following equation:

$$Standard\ Error = z * \frac{Standard\ Deviation}{\sqrt{n}}$$

The z-value for a 95% confidence interval is 1.96, and n represents the sample size. Overlapping standard error bars show that the data is similar, but non-overlapping error bars do not necessarily mean there is a statistical difference in the data sets.

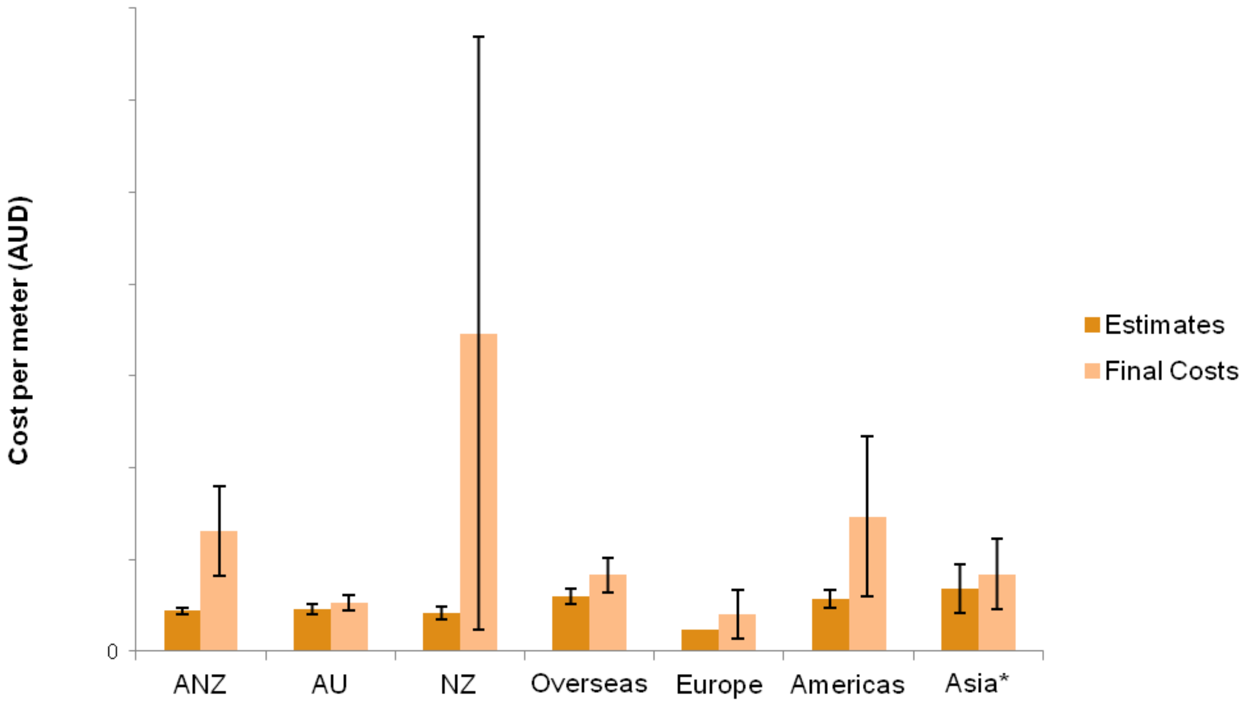
Figure 12: Transportation Tunnels Cost Comparison



* Asia costs include one tunnel from South Africa

Figure 12 displays the means with standard error bars of estimate and final costs per meter of transportation tunnels by region. It is apparent from this graph that estimate costs for constructing these tunnel types in Australia are slightly higher than those in the rest of the world, specifically in Asia. Some of the possible reasons for this are described in Section 4.2. The high average estimate cost in Australia compared to New Zealand should also be noted. Since the data was very limited for New Zealand road and rail tunnels, there is no statistical difference between the data sets, but it is worthwhile to note the variation in support of our claim that Australia and New Zealand should not be placed in one cast category. The final cost information further supports the conclusion that Australia is more expensive to tunnel in than the rest of the world. Australia's final costs per meter appear much more similar to the Americas and higher than Europe or Asia, while the cost for final tunnels in Europe is much lower in comparison. For these tunnels, no examples from New Zealand were present in our database so all conclusions must be made solely between Australia and other countries from this graph. A T-test showed no statistical difference between the averages for Australia and the rest of the world, but this could be due to the limited data set resultant from breaking down the projects into end-use and region. The number of tunnels in each category, averages, standard errors, and T-test information can be viewed in Appendix I (7.10).

Figure 13: Utility Tunnels Cost Comparison



* Asia costs include one tunnel from South Africa

The above graph, Figure 13, illustrates the means with standard error bars of the estimate and final cost per meter for utility tunnels. This graph contrasts the transportation tunnels graph and shows that costs for cable, water, and sewer tunnels in Australia are slightly lower or very similar to tunnels in the rest of the world. It is interesting to note that these tunnels have more expensive estimated costs in Asia, where usually costs are very low. In addition, costs in Australia and New Zealand are extremely similar for estimates. One possible reason for this is that both countries have experience building this type of tunnel and there is less complexity in putting together an estimate for a cable, water, or sewer tunnel than there is for road and rail tunnels. The final cost information agrees with the previous conclusion that constructing utility tunnels in Australia is slightly less expensive than the rest of the world, and very comparable to Europe, Asia, and the Americas. The cost discrepancy between Australia and New Zealand supports the theory that the two should not be compared together as ANZ. This range may be accounted for by the large standard error in the New Zealand data set. In our database, New Zealand only had two final costs for these types of tunnels, one of which was a high-cost hydro tunnel and results in a high variance in the data.

4.1.3 Costs of Tunnelling by End-Use and Locality

The transportation tunnels and the utility tunnels from every country were each separated according to locality (urban vs. rural). The average costs per meter for urban and rural tunnels were then reported and graphed with standard error bars in Figure 14 and Figure 15.

Figure 14: Locality Comparison - Estimates

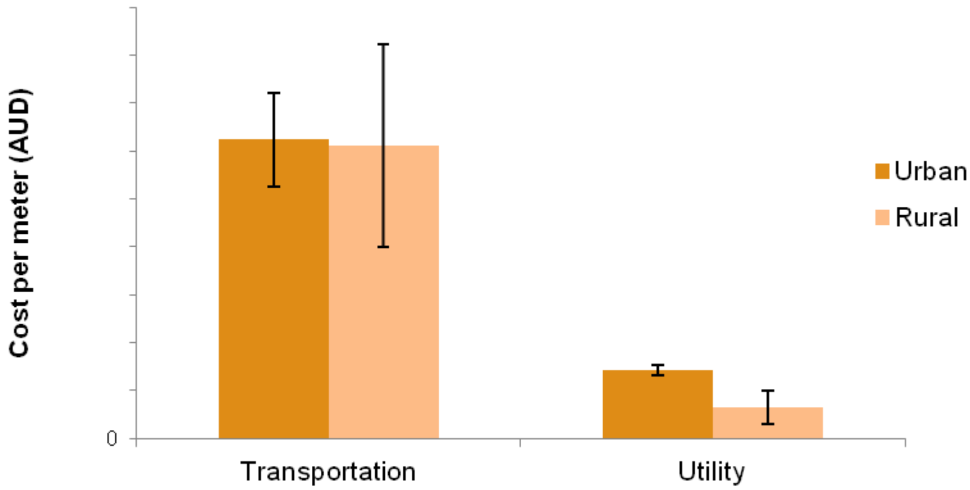
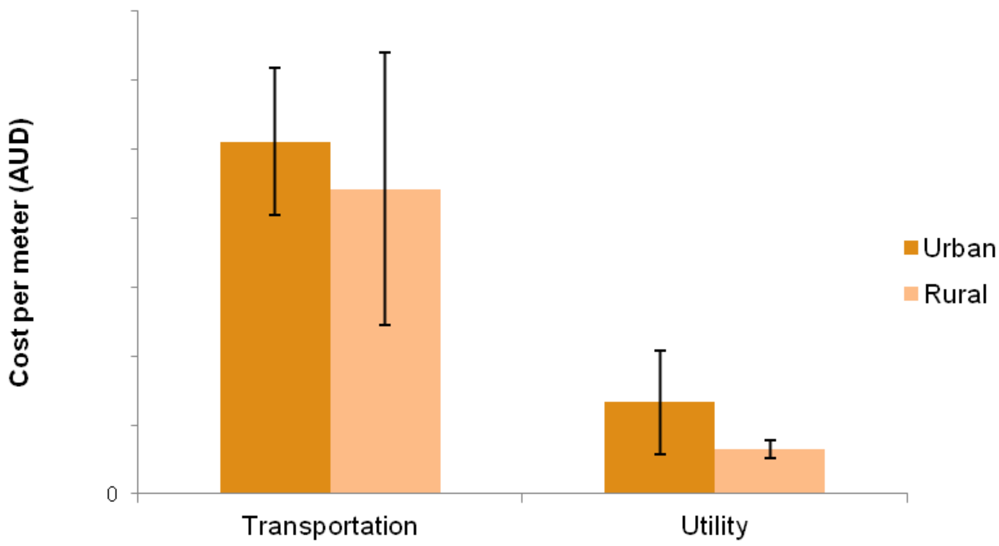


Figure 15: Locality Comparison – Final Costs

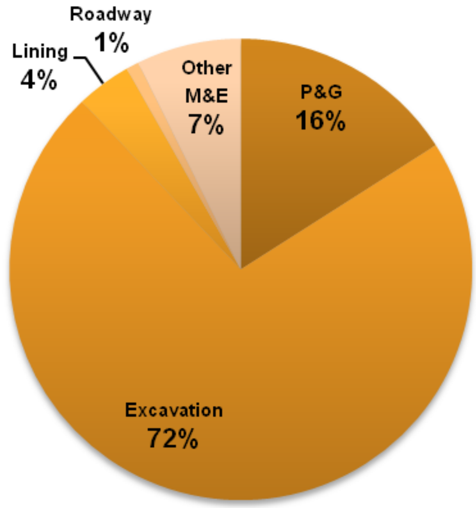


As seen above, for transportation tunnels it appears that there is no significant difference between urban and rural costs per meter for both estimates and final costs. It is important to note that although the urban costs appear consistently higher, the range of the error bars makes this inconclusive. Lastly, for utility tunnel costs, it appears that urban tunnels average expensive, but the extra expense is not statistically relevant due to the error bars. This shows that the cost differences attributed to this variable are not significant in comparison to other cost drivers; therefore, it is not necessary in our analysis to compare tunnels by locality, but the differences should still be kept in mind.

4.1.4 Tunnel Component Breakdown

A selection of tunnel cost breakdowns, based on available data, were calculated as a percentage of the total cost of tunnelling and graphed below. Figure 16 shows the averaged breakdown of four different international road tunnels, along with a second chart showing the average breakdown of five different international rail tunnels. Similarly, Figure 17 shows the average breakdown of five different utility tunnels, encompassing sewer, water and cable.

Figure 16 Road tunnel cost composition breakdown (left) and Rail tunnel cost composition breakdown (right)



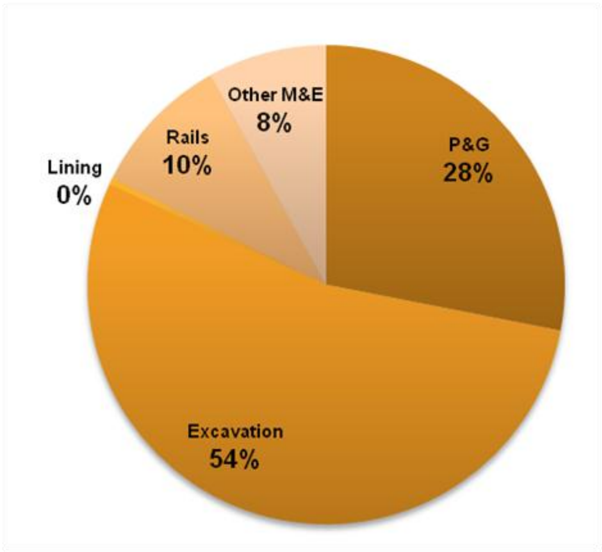
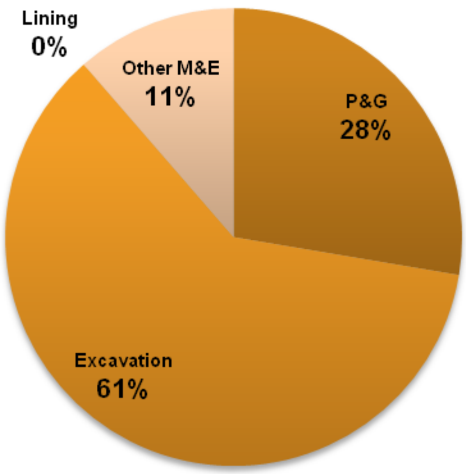


Figure 17 Utility tunnel cost composition breakdown



The above charts provide a baseline for evaluating the key differences between constructing different types of tunnels. Although there wasn't sufficient data to obtain an international comparison, this data can assist in future analysis because it details the key costs such as excavation and P&G, and the insignificant costs such as lining and some of the fit-out. The difference in the P&G between the road and rail tunnels may be attributed to the wide definition of what falls in that category, as well as the small dataset. Additionally, the utility tunnels are strongly influenced by the inclusion of a cable tunnel, which drastically increased the average M&E cost.

4.1.5 Limitations of Cost Data

The limitations associated with these data include that the majority were only publically available information and as a result many costs do not have breakdowns or explain which items were specifically included in the price. For our data collection, we accepted information on costs for tunnels as long as the majority of the works was in tunnelling. In the database we have separate sets of columns for pure tunnelling costs, and for total project costs. Total project costs often included sections of road, rail or bridges. These issues make cost comparison very difficult. We attempted to remedy this by removing he costs for aboveground road, aboveground, and bridges from the data, but this may not have removed all problematic data points since full cost breakdowns were not always available. It is safe to say that this practice has raised the average costs for each region by a small amount. Our assumption is that given the quantity of tunnels in each region, the variance between these higher costs is negligible. The data used were also reduced in number by public availability as many project costs from more recent projects have not been released from the private sector. One of the reasons for this is that contractors are hesitant to publish data for the most recent seven years in order to maintain their competitive edge in the market, and also because after seven years it is much harder to become hindered in litigation resultant from falsified data. Accordingly, cost data sourced from contractors was of questionable quality. We believe this because contractors often modify their costs by removing some partially related costs to make it seem like they met the budget on projects that they went over on. Lastly, our combined estimate and final cost data was limited because a number of projects in the database are still under construction and do not have final costs associated with them yet.

4.1.6 Limitations of Non-Cost Data

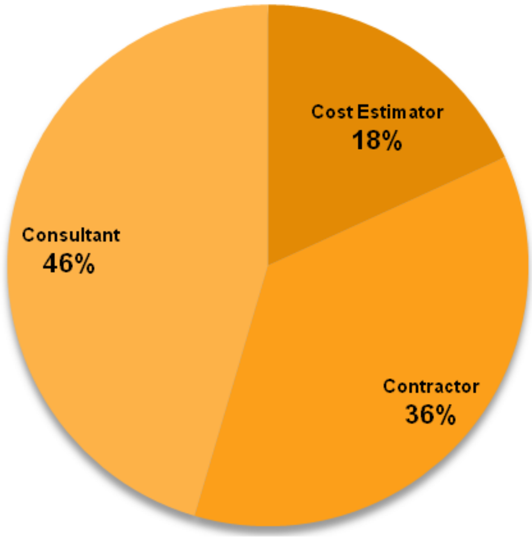
There are many limitations with the sourcing and analysis of non-cost data. One limitation involves using the diameter of tunnels for normalization. Reported tunnel diameters often did not characterize the measurement as an inner or outer diameter and for several other projects the face area had to be estimated based on number of lanes and height requirements. For cut and cover and drill and blast excavated tunnels, a diameter measurement is often not representative of the work or is not available. This would make the cost per cubic meter measurement for some tunnels inaccurate. Similarly the amount of cross passages, shafts, and station excavations were inconsistently included in the total bore lengths. When available, we noted the number and size of these additions, but often this information was not publically disclosed. Similarly, it was often difficult to quantify the exact ratio of excavation types in a project and therefore it was problematic to analyse the cost per meter cubed for each excavation segment. Another potential limitation is the lack of comparability between different projects. We completed the analysis on the basis that our sole variable was the location of the tunnels and end-use, this method does not account for an uneven distribution of different factors within continents. We accounted for this by selecting specific tunnels with comprehensive data to compare to similar projects in other countries as case-studies. In addition, we compared the globalised cost of selected variables to get a basis for which variables influenced tunnel costs the most regardless of location.

4.2 Interviews and Survey Results

4.2.1 Interviews

Although our interviews followed different patterns depending on the role of the interviewee in the tunnelling process, we still received relatively consistent responses to the questions common across the different questionnaires. The interviews were structured in such a way as to gauge the interviewee's position and experience in the industry, then determine their opinion on the main cost drivers for tunnels, ask them whether or not they agree with that the perception that tunnelling in ANZ is more expensive, and finally determine where they think cost reductions are possible. We interviewed a total of 11 people, two cost estimators, four contractors, and five consultants (Figure 18). It is important to note that after we conducted our first few interviews we determined that Australia and New Zealand should not be considered a single entity in our questions, so we decided to focus more on the costs and factors in Australia compared to the rest of the world.

Figure 18: Interview Breakdown



4.2.1.1 Interview Responses

Invariably, almost every interviewee thought that the key cost drivers were some combination of the cost of labour, bidding, and/or market structure. In addition they also consistently discounted the possibility of some other cost drivers being relevant.

Geology was often a key concern by the interviewees when it came to discussing cost escalation over the life of the project. Most responses indicated a need for more comprehensive site investigation but mentioned the reluctance to spend money doing this in the feasibility stages of a project. It should be noted that no respondents characterised Australia as having more difficult geology for tunnelling. In particular, some indicated that tunnelling in Asia was much more geologically complex and certain parts of Australia, such as Sydney, are some of the easiest places to tunnel.

Labour was the key factor that mentioned by every interviewee. It is evident that labour costs in general are regarded as more expensive in Australia. A few different reasons were given to explain this cost escalation. The first distinction was that the cost of engineers and consultants was not the key labour cost, because of relatively average salaries and the small ratio of the project devoted to design. We were told that the main labour costs were associated with the workers who actually construct the tunnels. We were given two main explanations for this from different interviewees. The first was that in order to compete with the mining tunnel workers, the contractors must give them a significant amount of overtime per week. The high cost of overtime combined with the fact that most tunnels need to be excavated 24 hours a day to meet schedule results in very high labour costs. Secondarily, the unions have an effect on the wages paid to the tunnelling workers. It is difficult to do anything without the consent of the unions, whose policies can vary depending on the state in Australia. One interviewee noted that overseas there are efforts to significantly reduce the number of workers required to run TBMs and work in precast plants, which is promising for cost reduction, but merits further research.

Health, safety and environmental regulations were not cited as a possible cost driver for several reasons. Many international construction companies utilise in-house regulations no matter where in the world they work. Additionally, some respondents noted that Australian standards can lag behind European standards, and New Zealand standards can lag behind both.

Materials, plant and equipment were also not cited as a source of higher costs. Tunnelling materials have similar costs around the world and the differences in cost are not very pronounced. In most cases in Australia, plant and equipment for tunnelling is sourced from overseas so the only increased cost would be shipping which is typically negligible.

Public and government support were also cited by some interviewees as a possible explanation for high tunnelling costs in Australia. A change in government backing can delay or even cancel projects, resulting in cost overruns. It was also noted that often a project that lacks support from the public will not have high usage. This can adversely affect projected toll incomes and injure the financial status of the owner of the tunnel. Based on this finding, it appears important to secure both government and public support early on for any tunnelling project.

Market structure was a key concern mentioned by some respondents. Contractors from Australia claimed that the market here was very competitive, while conversely, consultants and cost estimators stated that there was extremely limited competition in Australia. The problem seems to stem from the small size of the market. Leighton Holdings, which encompasses John Holland, Thiess, and Leighton Contractors often ends up bidding against itself on many contracts. Other contractors with the capacity to complete large tunnelling projects include Baulderstone and Transfield, and McConnell Dowell has the capacity to complete smaller tunnelling projects. Typically there are 3-4 bidders for any contract, but the size of these contracts often necessitates the use of joint ventures between the already sparse numbers of contractors. Most non-contractor interviewees felt that there was too much comfort in the way these contractors operate their businesses, and thought their complacency was possibly a cost issue.

Contract types were often brought up as a possible component of high cost. The focus of our questioning was on PPPs, which most respondents admitted were utilised in most large tunnelling projects in the last 15-20 years. Each respondent had his or her own opinion on the role of PPPs and their sustainability as a project delivery device, but the prevailing opinion was that they have both advantages and disadvantages. The key benefit is that PPPs result in an expedited start to a project, where there is less chance of projects getting sidetracked after major political changes. The disadvantage of PPPs is that it puts the risk of the project in the private sector instead of the public sector as most people believe it should be. This increased risk along with the fact that private companies cannot obtain bonds and financing at the same low rates available to government results in greater final costs for the whole project.

The mention of the high cost of bidding in Australia as an impact to final costs seemed to be a common theme among the responses from interviewees. The PPP contracts that are frequently used in Australia require a high level of cost certainty and result in higher design specifications during bidding. As a result, bidding costs have been quoted as high as 30 to 40 million dollars per contractor. This cost can be completely lost when they are not selected as the winner of the bid, so this lost money needs to be recouped by subsequent projects. This cycle results in an increase in the cost of every large project approximately equivalent to the combined cost of bidding for all the losing contractors. Although all international bidding necessitates this added cost, the extremely high cost of compiling bids in Australia tends to lead to a significantly larger increase.

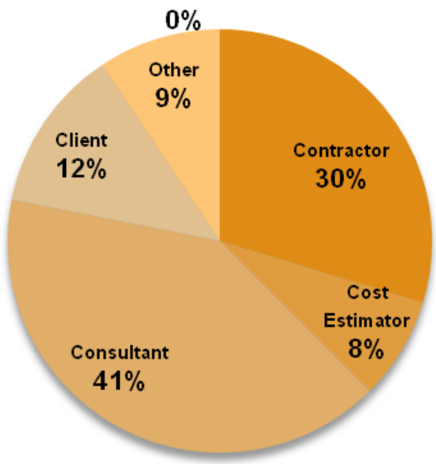
We received a fairly mixed response after asking if he or she believed that the cost of constructing tunnels in ANZ was more expensive. The most common response for this query was that they were unsure. This was to be expected, and confirms the importance of this research area. We posed a follow up question to those who thought that tunnelling in ANZ was more expensive than the rest of the world, which was whether they thought there was any benefit to the increased costs. Every respondent said that there were no benefits to the increased cost, and the response that we received from others was that tunnels are generally built to the same standard globally.

Throughout all of our interviews we were told that the main area in which cost savings can be made is the design stage. Other stages of the procurement and construction process are fairly well refined and are quite lean since the scope of the project is fixed at this point. This does not mean that the design process is not refined, but at this time big picture decisions can be made which can potentially save a lot of money over the life of the project. Choices such as the alignment, shaft location, material use, and a number of other properties can affect the final cost significantly. Other interviewees indicated that during this stage there were often cost overruns associated with changes in the scope. These major changes can possibly be attributed to the naivety of clients in Australia. Several international correspondents indicated that clients tend to know what they want more in other parts the world than they do in Australia.

4.2.2 Surveys

We received 54 complete or partial responses to the online survey sent out as of the 22nd of February, 2012, the collated responses can be seen in Appendix F (7.7). The assortment of the respondents' roles in the tunnelling process and the variety of end-uses that the respondents have experience working on are summarised in Figure 19.The breakdown of the regions in which respondents have delivered projects is shown in Figure 20.

Figure 19: Survey Respondent Breakdown by Role (left) and Survey Respondent Breakdown by End-Use (right)



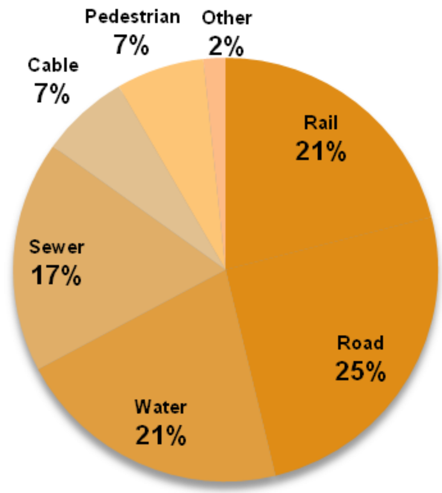
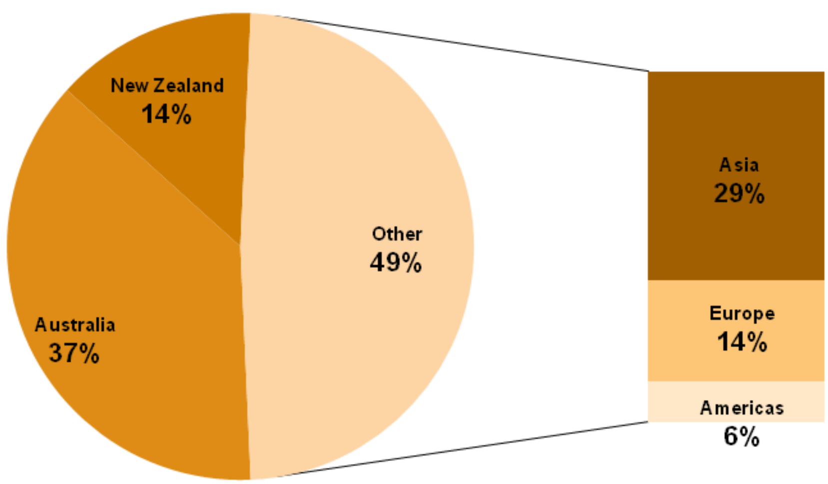
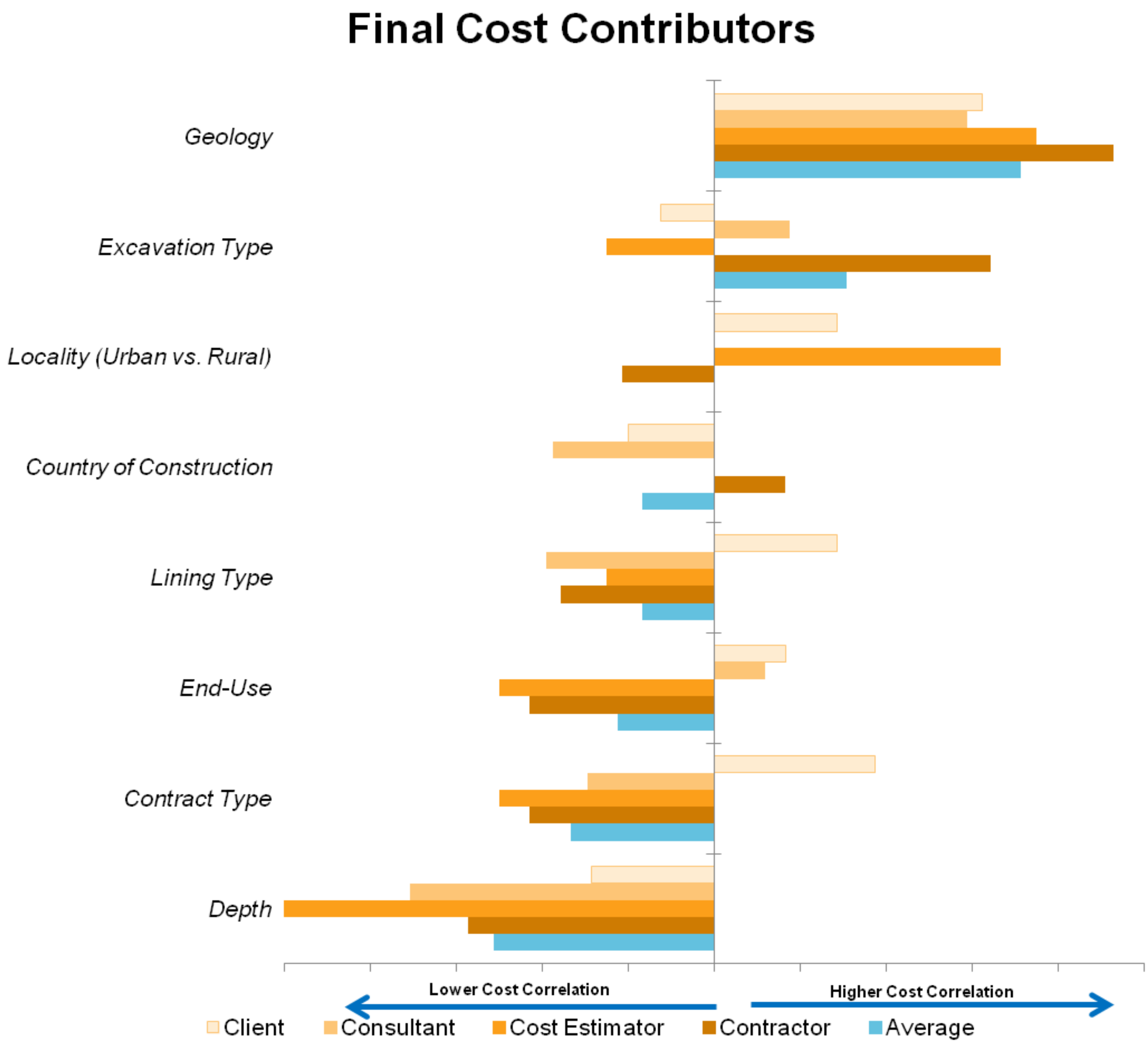


Figure 20: Survey Respondent Breakdown of Experience by Region



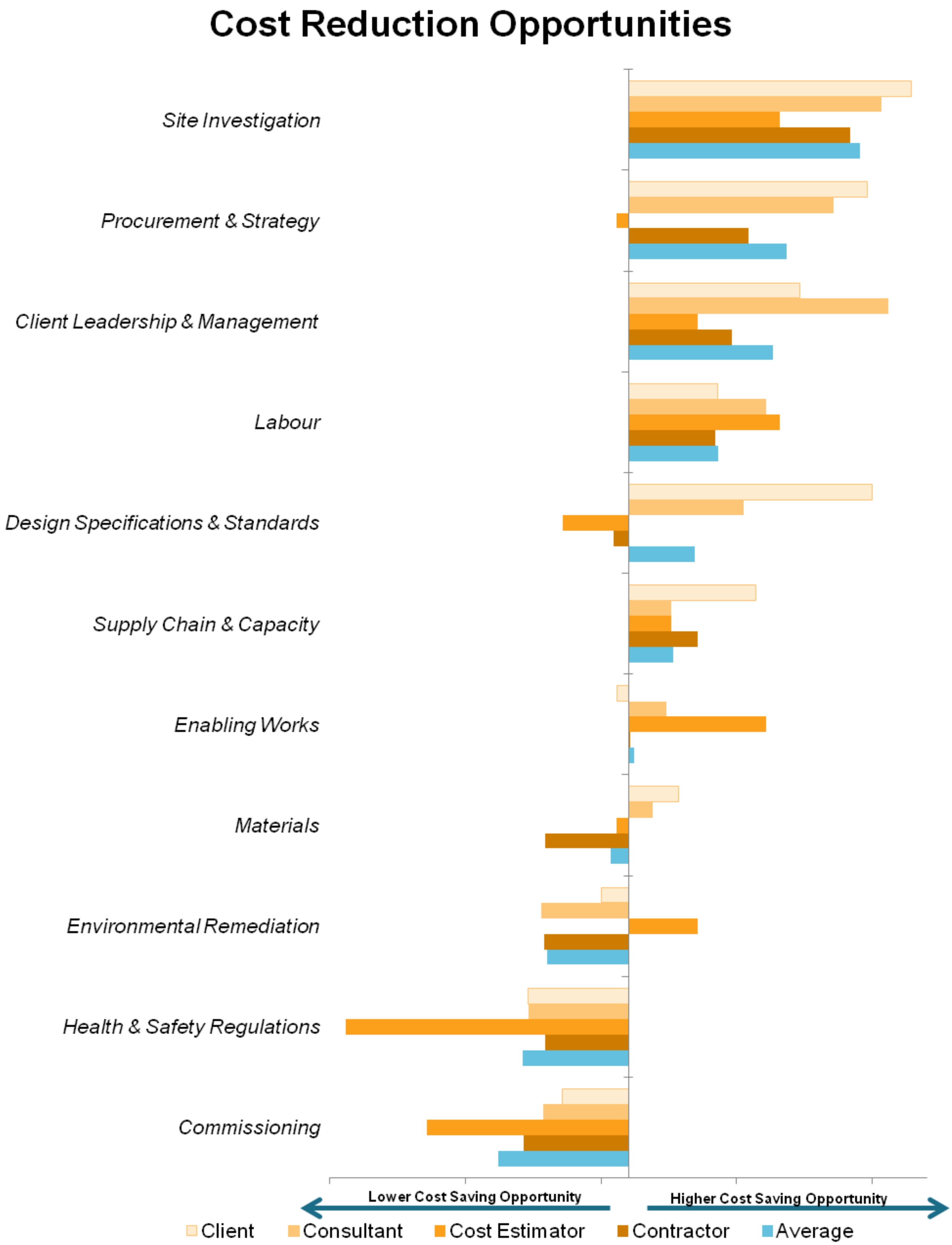
As seen in the above graphs, we received a good proportion of responses from each role, as well as an excellent distribution of responses from individuals who have worked on the main four types of tunnel end-use. Lastly the regional distribution is more heavily oriented in ANZ, but has a good starting place in many other regions which will help provide international perspective. The following chart (Figure 21) displays the sentiment of the survey respondents as to the influence of eight different cost factors on final cost.

Figure 21: Survey Response Distribution for Contributors to Final Cost



As seen in the above chart, geology and excavation type are the primary choices for cost factors. This is good to keep in mind when pursuing analysis. For example, given the choice, it would be prudent to choose to ignore the effects of depth in favour of geological factors. It is also interesting to note the sentiment by cost estimators and contractors that end-use does not have a very high correlation on the final cost of tunnelling. The final interesting result from this analysis is the emphasis that clients put on the type of contract when compared to the remaining parties. This is probably because of their familiarity with the issues related to contract agreements, whereas their peers may not be as involved and are resultantly less informed. The next chart (Figure 22) shows potential cost reduction opportunities in 11 different areas.

Figure 22: Survey Response Distribution for Cost Reduction Opportunities



This chart further illustrates the respondents' sentiment that geology is a very important cost factor because of the unanimous reaction that site investigation results in a high cost saving opportunity. The data shows that clients feel more strongly about site investigation than any other party. This conflicts with the interview responses which had indicated that clients were fairly ignorant of the need for high levels of site investigation. It follows that clients are aware of the geotechnical risks, but are potentially unwilling to spend the money on SI early in a project. It is also interesting to note the unanimous reaction that there was some potential for cost savings in labour. Contrarily, when queried, all interview respondents denied this possibility. The next interesting point is the contradicting ranking of design specification and standards. Clients and consultants ranked this area highly for cost reduction which shows their desire for more regulated specifications and standards in the design phase. The contrasting low ranking by contractors and cost estimators is potentially due to their knowledge about the uniqueness of each tunnel, and also because they may think that possibilities for regulations may not exist. This may be due to a lack of client knowledge about the complexities of tunnelling or could potentially be a good cost saving opportunity, and this variable merits further research. It is clear from these responses that the respondents do not feel there is much potential for cost savings in health and safety regulations and commissioning which agrees with outcomes from our interviews. The next chart (Figure 23) depicts the distribution of answers to the question: Do you personally feel that tunnelling is more expensive in Australia and New Zealand when compared to other countries? The 49% of respondents that had answered "Yes" were then directed to a question about what the higher costs were linked to, for which the distribution of responses is also seen in Figure 23. These same respondents were also queried about any possible benefits to a higher cost as illustrated in Figure 24.

Figure 23: Survey Response - Is tunnelling more expensive in ANZ? (left); Survey Response – High Cost Source (right)

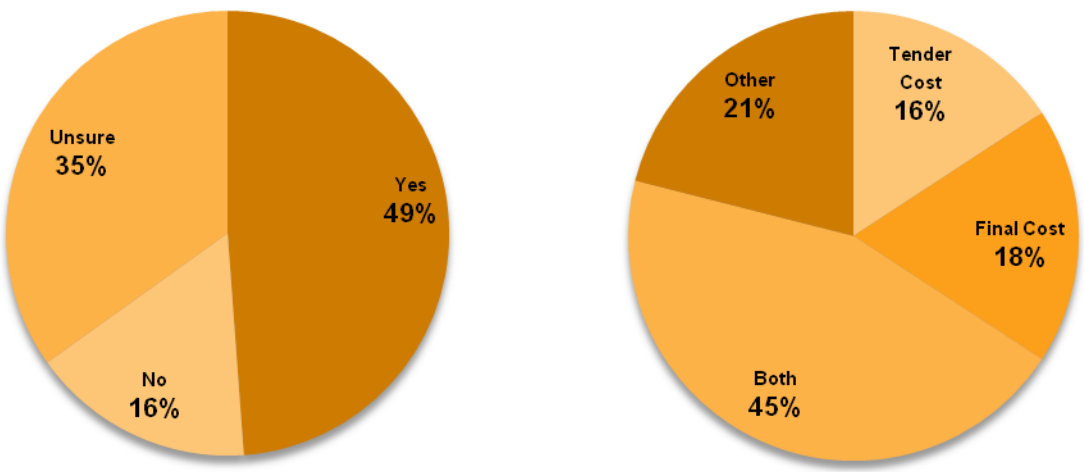


Figure 24: Survey Response – Benefits to Higher Cost

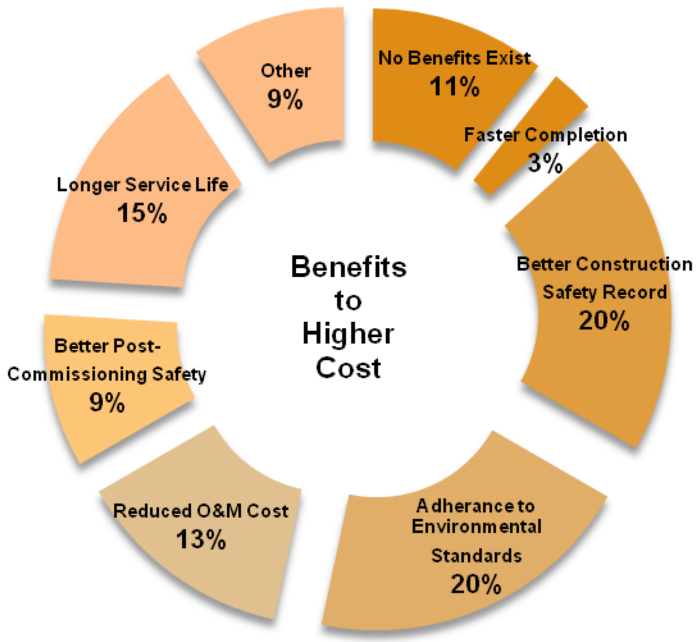


Figure 23 (left) definitively shows the current sentiment in ANZ, which is highly characterised by uncertainty about the cost of tunnelling (35%) and a general feeling that costs are higher (49%). Figure 23 (right) shows the areas where respondents feel higher costs are coming from. This chart shows general uncertainty regarding whether estimates or outturns contribute more to expenses with an even split between tender cost (16%) and final cost (18%), with 45% of respondents claiming that both tender and final costs were the source of disparities. Figure 24 shows the distribution of responses for benefits to a higher cost rate. In general there are no significant responses, but instead a fairly even spread can be seen in each category. This suggests that there are probably some small benefits to a higher cost, but these benefits are not very noticeable or quantifiable.

4.3 Individual Comparisons

Comparing specific examples of tunnel projects against similar global projects helps visualise both the global cost disparities as well as illustrate the challenge of comparison with so many variables present. We randomly selected tunnels for comparison for which cost breakdowns were available. Then we removed as many variables as possible, leaving only location, geology, and special circumstances to be discussed and qualified. In our selection we chose recent TBM bored, urban, rail projects from around the world, and normalised them by distance and unit area. The results of this analysis are shown in Table 4. The desired end result was to isolate the pure tunnelling costs, which solely included tunnel excavation, lining, and contractor's overhead and profit for the TBM segment of each tunnel.

Table 4: Individual Comparisons, All costs given in average Q3-2011 AUD

		Cross River Rail		CBD Rail Link		Additional Waterfront Harbour Crossing		Toulouse Metro		Noord-Zuidlijn Line		University Link (ULINK)		MRT DTL3	
Date Started		Proposed		Proposed		Proposed		Proposed		April, 2003		2008		June, 2011	
Date Finished		Proposed		Proposed		Proposed		Proposed		Under Construction		Under Construction		Under Construction	
Location		Brisbane, Australia		Auckland, New Zealand		Auckland, New Zealand		Toulouse, France		Amsterdam, Netherlands		Seattle, Washington		Singapore	
Locality		Urban		Urban		Urban		Urban		Urban		Urban		Urban	
End Use		Rail		Rail		Rail		Rail		Rail		Rail		Rail	
Type	**Length (m)**	TBM	19000	TBM	5070	TBM	5700	TBM	15160	TBM	3800	TBM	6950	TBM	75600
Outer Diameter (m)		7.0		6.9		15.5		7.7		6.5		6.3		7.0	
Depth (m)		-		20		20-40		-		20-30		-		-	
Geology		-		Sandstone		Sandstone		-		-		Clay, silt, sand, gravel. Active seismic region.		Soft Ground	
Tunnelling Estimate Cost/m															
Tunnelling Estimate Cost/m^3															

Although no determinate inferences can be made regarding generalising this data by region because of the extremely limited data set, the comparison can is still valuable. It provides a method for analysing the factors contributing to the costs and illustrates the complexity of comparing tunnels with numerous cost variables. Since all of the costs are estimates, it can be inferred that the estimates were probably determined from previous benchmark rates utilised by contractors, which are typically averaged from previous projects in the region. Some conclusions can be drawn from these data to support or negate our previous conclusions as a result. As noted previously, this data should not be taken without qualification but should be assimilated with other analyses to form a more comprehensive understanding of the problem. It appears from this analysis that tunnelling in Australia and New Zealand is not greatly more expensive than it is in other regions. This conclusion is very limited though from the small dataset used in the comparison.

The first interesting finding from this analysis is the similarity in cost/m^3 for the majority of the projects compared. The Cross River Rail, Toulouse Metro, ULINK, and MRT DTL3 costs differ by only \$70/m^3 and. This is notable for several reasons. Each project is of medium-long length which is in accord with our previous finding that start-up costs tend to be normalised by the long length of the tunnels. This may suggest that other factors have more of a direct correlation on cost rather than the isolated factors listed above. In addition, the diameters of the set only range from 6.3m to 7.7m, which allows for more direct comparison of costs. This helps explain the very low cost/m^3 associated with the Additional Waterfront Harbour Crossing. The extreme size of this tunnel will require much less material cost per cubic meter and resultantly has a lower cost per cubic meter even though it has the highest cost per meter of the set. This supports the argument that costs per meter do not adequately compare tunnels with different bore sizes. Tunnels excavated by TBMs with specifically reported diameters are the best candidates for cost per cubic meter comparisons. The significantly higher cost/m^3 associated with the Noord-Zuidlijn Line can be partially explained by the alignment chosen for this project. This tunnel travels straight under many historic buildings in Amsterdam, and concerns about vibration and settling during the boring process resulted in a much slower construction schedule and much higher costs. This also helps to demonstrate another facet of the complexity involved with comparing projects, because of the unquantifiable variables that exist with every project. These results exemplify the complexity associated with comparing tunnels across various cost factors and aids in explaining the high standard deviations found in our database analysis. Since the excavation type and end-use were kept constant in this analysis and resulted in similar global costs, it is possible that these are the key cost drivers for tunnelling rather than location.

4.4 Comparison of Australia and New Zealand

The results of our interviews first led us to believe that tunnelling costs in Australia should not be compared to New Zealand for several reasons. Construction labour rates are very different in each country with Australia's construction salary averaging 1.42 times greater than that of New Zealand ("Engineer Salaries," 2008). This can lead to a significant cost differential between the two countries since we were told by our interviewees that the cost of labour typically accounts for 30-40% of the overall cost. This may also be due to different strengths and role of unions in each country. Another reason why the two countries should not be linked is that material costs vary widely between the two. New Zealand was often cited in our interviews as having more expensive construction materials and plant costs. Lastly, the data is difficult to analyse since New Zealand has only completed a small quantity of projects over the past 15 years, and does not plan to construct a larger amount over the next 15 years.

Although many major variables can vary between the two countries, there are many variables which are similar and might help explain why the countries are often related. One of these similarities is that both Australia and New Zealand experience limited contracting market competition. Other parallels that exist between the countries are the similar environmental, regulatory and bidding processes each has to go through before a tunnel can be constructed.

Our analysis of tunnel costs helps conclude that Australia appears to be more expensive than New Zealand, possibly because of tunnelling labour costs. Although similarities between the Australian and New Zealand tunnel delivery cost factors exist, the results of our interviews and statistical analysis firmly confirms that the two countries should not be analysed as one entity.

4.5 Investigation of Cost Escalation

After quantitatively and qualitatively concluding that tunnels in Australia are among the more expensive tunnels in the world, we investigated several sources of possible cost escalation. As a result from our literature review, acquisition of tunnelling cost data, interviews, and surveys we selected the following list of variables to concentrate on:

- Geology
- Labour
- Market Competition and Bidding

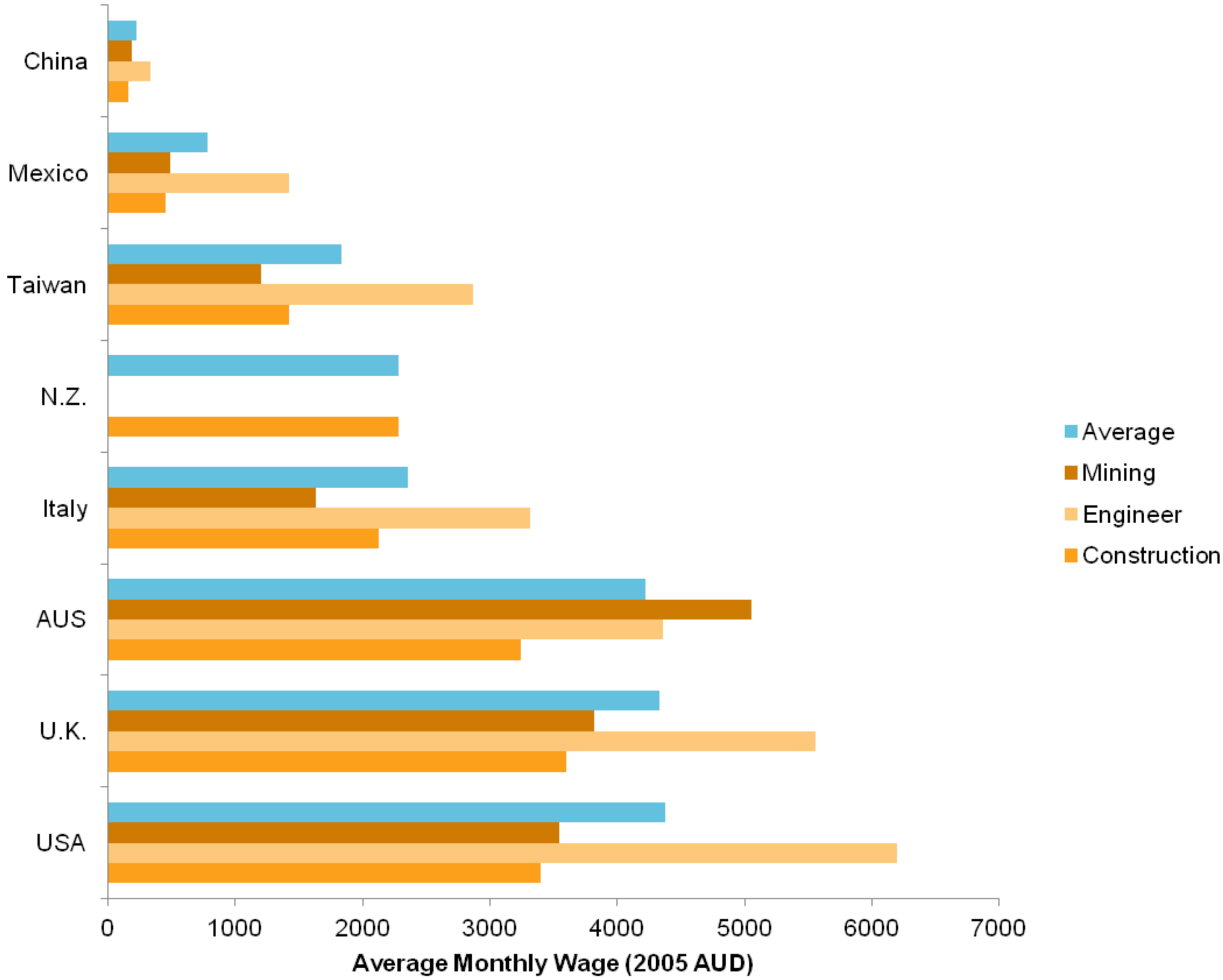
4.5.1 Geology

Unexpected geological factors are variables which cost escalation is often blamed on. It is evident that geological problems can often result in delays as well as unforseen environmental problems which need to be fiscally accounted for. Geology is very specific to a region, but not necessarily characteristic of a country, so it is difficult or impossible to accurately analyse the average geology encountered in a country. The results of our interviews suggest that Australia does not have particularly difficult geology to tunnel through, and tends to have fairly easy substrate to bore through in some regions such as Sydney.

4.5.2 Labour Costs

The respondents from our survey ranked average labour costs as fourth out of a list of 11 cost factors on their potential for cost savings. This indicator along with the assumptions made previously from our interview analysis prompted further research into the causes and potential cost savings related to labour. In order to facilitate this analysis, the net monthly income for workers in the mining, engineering and construction sectors was researched. Figure 25 below displays the average wages for two countries from each of our comparison regions.

Figure 25: Monthly Wages by Country [Source: http://www.worldsalaries.org]



It is clear from this comparison that the United States, United Kingdom, and Australia have the most expensive wages related to tunnelling. Although the available source data (Appendix J 0) is from 2005, we feel it is relevant to our analysis since the majority of the tunnels in the database utilised labour from this time period. There is a similar correlation between the average tunnel cost in each region (where data exists for more than one tunnel) and the average wages for each country as seen in Table 5.

Table 5: Average Estimate Costs by Country

Country	Average Cost (Q3 2011 AUD)	Number of Tunnels
China	$22,695	6
New Zealand	$43,413	9
USA	$50,744	10
Australia	$59,809	20
Italy	$88,451	3
UK	$135,063	7

Another interesting finding from Figure 25 is that Australia is the only country in which engineers do not get paid as highly as miners. This is a key point, because contractors in Australia must pay competitive wages to tunnel workers in order to employ them in tunnels rather than mines. This typically involves paying a certain amount of overtime wages per week to keep up. Since a significant amount of the cost of the tunnel is derived directly from labour costs, this is a significant finding.

4.5.3 Market Competition and Bidding

The market competition in Australia appears to be very limited, with only six major domestic contractors capable of completing large scale projects and one major foreign contractor that commonly bids on Australian projects. These six are McConnell Dowell, Transfield, Baulderstone, Thiess, John Holland, and Leighton, but the latter three all share Leighton Holdings as a parent company. This statistic coupled with the high availability of tunnelling projects in Australia leads to a concern about the lack of competition in the market. In addition, Australia is currently advancing towards larger scale projects where many smaller contractors cannot compete in bidding. With this in mind, the Australian tunnel contracting market begins to look like an oligopoly, especially since these contractors often join together to bid as joint ventures. This can be a problem when viewed from an economic stand point, where the level of market competition directly correlates with prices (Gupta, 2001).

We were told by our interviewees that bids placed by these contractors are significant for the largest PPP contracts. If a company's bid is not selected for several projects a large debt is created which many smaller contractors cannot survive. Other than the one major foreign contractor Obayashi, international competition has also been rare in the Australian tunnelling market until very recently. The Brisbane Legacy Way Project was recently awarded to an Italian and Spanish joint-venture of Ghella and Acciona that greatly undercut the bids of local contractors. The end result of this project will show if an international company has the ability to cut costs of tunnelling in Australia. It is scheduled to be completed in 2014. Our all firmly denied any lack of competition in the Australian market, but this answer was potentially biased. Interviews with personnel from the tunnelling industry outside of contracting pointed towards the lack of market competition as a very realistic possibility for increased costs in Australia.

5.0 Conclusions and Recommendations

Our research concluded that tunnel construction in Australia and New Zealand is not statistically more expensive than the rest of the world when compared by region or end type due to a large variance in the sample means. It was found that Australia averages higher than the rest of the world for construction of transportation tunnels, but not for utility tunnels. This analysis was based on 158 tunnel projects gathered from 35 countries throughout ANZ, Europe, the Americas, and Asia. These costs were compared by region, end-use, and locality, and were separated according to tender or outturn costs. The higher average cost found for transportation tunnels is significant since rail and road projects are typically more publicized. This finding helps explain the sentiment that tunnelling in Australia is more expensive than in the rest of the world. There was a large range in costs in our database which exemplifies the numerous cost drivers that contribute to overall costs and the potential for cost reductions in ANZ.

Tunnel cost information gathered in our database was compared using a variety of methods to isolate the main factors that contribute to cost disparity between regions. The initial comparison separated costs into estimates and final costs and then divided tunnels by region, into ANZ, Europe, the Americas, and Asia. Costs for all projects were divided by the tunnelling length to account for variation in size. This is the current standardized method for tunnel comparison in the industry. Costs per cubic meter were also investigated by dividing costs per meter by the face area of the tunnel. This helps to account for varying diameters of tunnels, but is not an accurate method for all projects due to the existence of non-circular tunnels. The statistical test carried out on these data sets showed no statistical difference for either costs per meter or costs per cubic meter.

Tunnels were then separated into end-uses – road, rail, sewer, water, and cable. No statistical difference was found between road and rail tunnels, and no difference was found between sewer, water, and cable tunnels. This was followed by a T-test comparing transportation tunnels to utility tunnels, where there was a statistical difference. This supports the conclusion that tunnels can be separated into these two categories for any cost comparisons. Lastly, these tunnels were further divided by locality into either urban or rural environments. The T-test comparing these tunnels showed no statistical difference and a large range of costs was noted. This directs us to conclude that locality is not as significant factor in tunnelling costs in comparison to other variables; however, this analysis did show that the estimate costs of utility tunnels average slightly higher in urban regions than rural. The effect of different excavation methods such as cut and cover, drill and blast, TBM, and roadheaders were also investigated. It was found that during data collection, the variables and costs associated with different types of excavation within a single tunnel were not consistent and merits further review in the future. Due to a limited data set, tunnels were not further broken down in this analysis.

In order to remove as many variables as possible, we compared individual costs of six recent urban, TBM bored, rail projects. These tunnels were compared using cost per meter and cost per cubic meter. It was found that the costs per cubic meter of these tunnels were very similar and differed by only $70/m^3. Since the excavation type and end-use were kept constant in this analysis and similar global costs resulted, it is possible that these are key cost drivers for tunnelling. Although inferences about regions as a whole should not be made from the results of this analysis, it still aids in understanding and illustrating the effects of several cost factors on unit cost as well as the sensitivity in analysis with such a small dataset.

Interviews with 11 individuals in the tunnelling industry and 54 responses to an online survey further identified the sentiment that tunnelling in ANZ is very expensive and helped provide an explanation for this feeling. The potential for cost escalation and cost reduction for several factors was ranked and discussed. The key cost drivers mentioned in these interactions were geology, labour, materials/plant, safety and environmental regulations, government and public support, market structure, the cost of bidding, contract type, and client knowledge. These factors related to Australia only because the two were found to have many quantifiable differences and should not be grouped together.

Everyone that we spoke with stated that he or she did not agree with grouping Australia and New Zealand together for tunnelling cost comparisons. Many of the aforementioned cost drivers differ in Australia and New Zealand. Australia is known for its higher labour costs, while New Zealand has significantly low wages in comparison. New Zealand has much less active unions and as a result many of the tunnels there are less expensive than those in Australia. New Zealand is also known to have very high costs for material and plant which is not apparent in Australia. In addition, the costs reported in our database appeared to be very different and not comparable, especially for road and rail tunnelling. The experience in tunnelling in New Zealand is also much less than that in Australia. The market for tunnelling in New Zealand is not forecasted to greatly increase in future years and as a result there is significantly less interest and potential for change in the country than there is for Australia. As a result we focused on Australian cost drivers in our interviews and reported on potential for cost reductions only for Australia.

5.1 Recommendations for Future Research

5.1.1 Data Collection

We recommend that AECOM continue to add data to the database as it is made available on future projects. Over time, this will help overcome some of the statistical insignificance related to not having enough data points. We also recommend consolidating and optimising the database in several ways. First, we would suggest completely separating the tunnel excavation types within individual projects because of the different variables and costs involved with tunnels that are inconsistent across different excavation types. Second, we would suggest consulting various knowledgeable geotechnical engineers to produce a quantifiable geological difficulty rating scale which can be applied to each tunnel. These steps would help reduce or eliminate variables which would lead to a more statistically significant analysis because it would address the two most influential drivers of tunnel cost. Lastly, the analysis could benefit from the addition of a dataset that quantifies the cost of bidding versus the location and contract type. This is a key factor that has come up in our qualitative analysis, but we have no quantitative information to back up this finding.

In order to supplement these data, it is important to continue qualitative research. Our next recommendation is to produce and send out a lengthier, globalised survey which focuses in depth on the key areas of cost savings listed above, but takes an international perspective. In addition, this survey should seek out cases of significant cost reduction in the global market that can be further studied and possibly implemented in Australia.

We also recommend collecting data on tunnel progress rates per unit length or area, and perform interviews with construction managers in order to seek out inefficiencies or possible anomalies in the data that might represent an opportunity for labour reduction.

5.1.2 Analysis

Since the results of the qualitative portion of our survey suggest that in general, some end-uses are not comparable, it would be best to divide the data up into groups by end-use, then analyse with location being the independent variable. The key to such a complex analysis is a large quantity of data and the careful elimination of conflicting variables.

We also recommend comparing bid prices with the type of project delivery method and performing a cost-benefit analysis to determine if the added cost reliability is worth the increased price resulting from losing bids.

It is important in all analysis to focus on integrating findings from many different sources since in this case the quality and reliability of the data is typically lower. Findings can then be qualified with multiple sources of information that point towards the same conclusion.

We also recommend continuing to investigate why such a range in tunnelling costs exists within a country, especially for Australia, which could help lead to major cost reductions.

Lastly, we feel that all future studies should exclude Australia and New Zealand from co-analysis as a result of their contrasting cost drivers.

5.2 Benefits of Tunnel Costs in Australia

In general, few tangible benefits of higher tunnelling costs in Australia were recorded. Interviewees and survey respondents were queried regarding if there was any increase in safety and productivity or any reduction in operation and maintenance fees as a result of higher tunnelling costs in Australia. It seems from our analysis that there may be some small benefits, but they are difficult to define or quantify such as. The few listed benefits regarded higher worker productivity, better construction safety records, greater adherence to environmental standards, reduced operation and maintenance costs, better post-commissioning safety, and longer service life. Interviews suggested that these benefits did not outweigh increased costs, but future investigation could further research these statements.

5.3 Cost Drivers and Potential for Cost Reduction in Australia

The following list of key cost drivers were researched and are discussed below. Recommendations for these cost drivers were also provided when relevant. Although this advice is aimed at the Australian market, some changes may be applicable elsewhere in the world.

- Geology
- Labour
- Materials/Plant
- Safety and Environmental Regulations
- Market Structure
- Government/Public Support
- Project Delivery
- Client Knowledge

It was discovered that the design stage has a large potential for cost reductions in these categories, as at this point in a project the scope of the project is not completely set. In addition large decisions such as choosing the alignment, dimensions, and lining type during this stage can result in significant cost variance during construction. As the tunnel progresses into the excavation stage it is much more difficult to make significant changes to the project that may result in cost escalations.

5.3.1 Geology

Geological conditions are the cited cause for the majority of cost overruns in tunnel construction. The majority of our interviewees stated that investment in the site investigation was very important and almost always comes backs with a return. This is also a cost driver that is specific to tunnels, which differ greatly from other infrastructure because they are underground through relatively unknown conditions. Geological conditions vary throughout the world, with major problems being caused by water permeation, fault lines, very soft materials that will not support themselves, and the variation of materials from soft sand or gravel to extremely hard rock. The conditions in Australia are not overly difficult to excavate through in comparison with the rest of the world.

We advocate that during the early feasibility stage, clients significantly increase the amount of site and geotechnical investigation undertaken. We recognise the fundamental problem encountered when trying to convince clients to spend more money in the early stages of a project, when the overall viability, constructability and financing is still unknown, but all of our research subjects described a direct correlation between the amount of SI and cost savings. To accomplish this, we recommend providing more comprehensive education to clients who are considering constructing any type of subsurface works. Although this issue is not inherent to Australia, it is still an area that has almost unanimously been cited as an area which has one of the largest potentials for decreased risk and final cost reduction.

5.3.2 Labour

Labour costs typically account for 30-40% of the overall budget for a tunnelling project as described by our interviewees. Variances in these costs between countries may account for more expensive or less costly tunnelling. Labour costs in Australia are reported as very high in comparison to other countries in the rest of the world, especially Asia. The Australian dollar currently has a very high value, unions are very active in Australia, and there is competition with the mining sector to employ labourers. As a result, wages are very high for tunnelling workers and a significant amount of overtime is paid on every project. There is also a lack of hierarchy in pay scale in Australia, where many tunnelling engineers and some management positions have very similar salaries to tunnellers. Other countries with higher wages such as Europe and the United States will often import labour from Asia in order to reduce labour costs, but this is not a viable option in Australia due to labour restrictions. Although there is increased education and productivity amongst Australian workers, we did not find that they were substantial enough to counteract the costs of high wages.

The often overlooked potential for cost savings in this area is a reduction in the amount of labour required to deliver a tunnel. Since the largest labour costs are attributed to the construction workers rather than professional engineers, reason suggests identifying ways to reduce construction labour. Optimisation of precast plants, increased technological efficiency and better management can all help reduce the labour required to produce a project. We would advise pursuing technologies which can help reduce labour requirements by the following:

- Increasing TBM performance
- Reducing TBM labour requirements
  - More multitasking
  - More mechanisation
- Increasing equipment longevity

5.3.3 Materials/Plant

Materials and plant costs are often very similar across regions. There are only a few main manufacturers that supply the majority of international tunnelling. As a result, the only major difference in cost for this factor in Australia is the associated shipping fees. An option to reduce costs in materials and plant that is being investigated in Asia is to move towards standardization instead of optimization. This would allow for more TBMs and roadheaders to be re-used and would also result in standardized mass produced lining segments, which could potentially reduce costs after the initial increase needed to design tunnels around these pre-determined parts.

In some Asian countries there is a trend towards standardisation of tunnels and their components that is worth pursuing and assessing. This contrasts with the current practice where, it is financially worthwhile to spend the time designing and optimising the thinnest possible tunnel lining and the smallest possible diameter. If the government were to take a larger role in providing standard tunnel requirements, less time would need to be spent on design that is specific to each alignment and geology. The economies of scale resultant from standardisation of tunnelling components and equipment can potentially result in cost savings and decreased risk. This is true for both a country as a whole, or for a single client who may be planning on building many similar tunnels. The resistance to this shift would suggest that this might result in the overbuilding of some tunnels which don't need thicker linings or a larger diameter. While we can recognise the customisation required for different tunnels, the key benefit is that each tunnel end-use could be built to the same diameter with the same precast concrete rings. This would result in tunnels that would be able to share plant and equipment and would significantly reduce costs. As it stands, huge inefficiencies exist in having to set up a custom plant for every job to manufacture precast rings that are unique to a specific tunnel. In addition equipment such as TBMs are typically only used once and then sold back to the manufacturer for 5-15% of the purchase price, when it could be much cheaper to simply refurbish the equipment between jobs. These are very general examples, but they serve to augment the potential shift in thinking from optimisation to standardisation.

5.3.4 Safety and Environmental Regulations

Safety and Environmental regulations are very similar throughout the world. Typically Europe is the first to implement new standards and then they are assimilated into the rest of the world. These regulations have also been cited as slightly lower in Asia than the rest of the world. There are slightly different regulations based on the location of the project in either a rural or urban environment, but safety and environmental regulations are relatively standardized throughout the world and there is not much potential for cost reduction in this category. Some Australian tunnels have been noted as "over designed" and "over specified" with regards to some safety features, and the removal of excess systems may help to remove additional costs.

5.3.5 Market Structure

The level of competition in the Australian tunnelling market is currently very limited with little to no international intervention. The major contractors in Australia are John Holland, Leighton Contractors, Thiess, Baulderstone, Transfield, and McConnell Dowell. John Holland, Leighton Contractors, and Thiess are all part of the same parent company, Leighton Holdings, and McConnell Dowell focuses on smaller tunnelling projects. In most other countries, tunnelling projects would have bids from around 10 or more contractors, while in Australia this rarely exceeds 4. In addition, contracting firms that are owned by the same company have been known to end up competing for the same bid which could result in complacency. The large project sizes in Australia for tunnelling works makes it very difficult for smaller companies to contend with these larger contractors and also necessitates the need for joint ventures between the larger contractors. This results in many projects where contractors often end up bidding against themselves. The lack of competition in the Australian market would result in increased costs for tunnelling works since these contractors do not have to be as aggressive in their bidding and may be more complacent in this region than they are in other parts of the world. The construction of Legacy Way in Brisbane marks the first international intervention in the Australian market. A Spanish and Italian joint venture greatly undercut the bidding for the project. Currently this tunnel is under construction, but in the future it would be a good case study for comparison of international tunnelling methods to those in Australia. International intervention in the market may also increase the level of competition and lead to cost reductions.

Increasing market competition is a difficult problem to address because of the experience, knowledge and contacts possessed by large domestic contractors. Although this issue would typically call for government intervention and regulation we believe there are other alternatives. One alternative that could be exercised by clients would be to encourage bidding from foreign contractors, which could help spur innovation and trigger the cutting of unnecessary costs. Another preferred alternative would be to analyse the effects of splitting large scale contracts into multiple, smaller contracts. This would help spread the risk and allow smaller, less experienced contractors to enter the market. This is a standard practice in places such as Singapore and Hong Kong, where a large tunnelling project might be split into 20 or more contracts that are won by different contractors and joint ventures. The same scale projects in Australia are almost always bid as a whole and go to a single contractor or joint venture which decreases competition and has a direct correlation on cost. It is notable that this would need a thorough analysis to determine if the cost reduction from increased competition would exceed the increased cost of additional bids. In this case client education to inform government planning boards and private infrastructure consortiums of these potentials for cost savings would be beneficial.

5.3.6 Government/Public Support

Legislation change during the lifetime of a tunnelling project can create possible delays and lead to increased costs. Government support, especially during the early stages of the project, helps to expedite the design phase and advance the project to excavation. If this support is lost or shifts in the middle of a project, it can lead to changes in scope and time setbacks which cause cost overruns. Some projects can even be abandoned if they lack government support such as the Sydney metro which was cancelled after significant design work, whose cost would have had to have been absorbed into the costs of other projects. The amount of public support for a project is another indirect variable that can greatly affect tunnelling costs. The lack of a favourable public opinion can result in a reduced amount of traffic and can negatively affect the amount of government support on a project. One finding from our interviews was that in general, Australians do not prefer to spend money on paying tolls to use tunnels even though it may save them time and expenses in the long run. Based on these findings, it is very important to secure both government and public support during the early stages of a tunnelling project in order to avoid potential cost escalations.

5.3.7 Project Delivery

Contract types in Australia have begun to move towards Private Public Partnerships (PPPs) within the last fifteen to twenty years which contrasts with the contract types in other nations. In addition other nations' PPPs do not necessarily match up with how PPPs in Australia operate. In Australia these contracts require the private sectors to take on all of the risk and must provide all of the financing for a project instead of the government. This can lead to increased costs since the private sector must account for a large contingency and also cannot secure bonds and financing at the same low rates available to the government. The PPP model has had both successes and failures. The key advantage is that PPPs result in an expedited start to a project, where there is less chance of projects being delayed after major political changes. Several recent PPP projects have resulted in the private firm, which is backing the project to become bankrupt. This is most often a result of delusions about the successes of the project. For example, some of the completed projects forecasted much greater traffic use of tolled tunnels than was realistically possible which skewed the profits for the investors. In general, it is believed that the PPP model requires some restructuring in order for it to be successful for tunnelling projects.

The cost of bidding in Australia is also very high as a result of the PPP model. Since the private sector takes on the risk for these contracts, they require a high level of cost certainty and result in higher design specifications during bidding. Typically there is a significant cost to put together a bid for the largest PPP tunnelling projects in Australia. This cost is completely lost for any contractor that is not selected as the winner or the bid. The lost money must then be recouped by subsequent projects, resulting in a cycle that increases the costs of every large project undertaken by these companies. These large costs also negatively affect competition in the tunnelling market, as smaller contractors cannot incur this debt for as long of a period of time as larger firms without becoming bankrupt.

Our recommendation is to continue encouraging the PPP model wherever possible as it helps produce projects that otherwise may stagnate, but to revise the process to encourage competition and reduce cost inefficiencies. Although PPPs have been criticised in the past for lack of post-construction revenue, we believe that financiers and contractors have learned from this and are now more cautious when it comes to traffic forecasts and estimates. It may be prudent to attempt to improve public opinion about the use of tolled road tunnels, since our findings have indicated that people in Australia tend to spend the time taking alternative routes rather than spend money on the toll. For the most part, our concerns and recommendations lie with the risk allocation and high amount of money lost during the bidding process. We would encourage a revision of the PPP model to partially place the risk associated with the contract back on the government. Ideally, we would like to see a model where the construction risk is allocated to the contractor, and the post-construction risk is split more evenly between the public and private parties of the contract. This is necessary since governments can more sustainably handle financing a project because they can acquire bonds at lower rates than private companies are able. Another issue with PPPs is that the high level of design certainty required at bid necessitates a high expenditure to meet this standard. The cumulative value of the losing bids must be made up in future bids which results in an inefficiency which needs to be addressed. Our recommendation for this is to conduct a cost-benefit analysis in order to ascertain if the higher cost certainty resulting from a higher design percentage outweighs the increase in cost resulting from bids that have been lost.

5.3.8 Client Knowledge

In Australia, client knowledge is generally regarded by our survey respondents and interviewees an area for improvement. Many clients are unaware of how to create tunnelling specifications which optimise cost saving potentials because of the relative rarity of tunnels when compared to other infrastructure that they have experience in. As a result clients do not understand the unique challenges related to tunnelling, and scopes for projects often include items that are not necessary. Some clients are also very vague about what they want which can lead to issues when putting together bids. Currently, there is not a very high amount of interaction between contractors and clients. The lack of experience amongst clients found in the Australian tunnelling market contrasts with the experience of clients in Europe and Asia and could further explain higher costs in the region.

.As with other client side issues, the solution appears to be increased education. We feel that this recommendation of client education will help to significantly reduce inefficiencies caused by misspecification and also reduce the number of clients that needlessly spend money by hiring consultants too early in the planning process when not enough information is known. In addition, bringing in a contractor earlier may induce extra costs, but could potentially aid inexperienced clients in the design process and save money throughout the lifetime of the project.

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7.0 Appendices

7.1 Appendix A: Frequently Asked Questions (FAQs)

1. Where did the data come from?

    a. The data comes from various confidential and publically available sources, such as internal cost breakdowns, and press releases about contract awards.

2. How do you know if the data is reliable?

    a. Wherever possible, the data has been chosen from the most reliable sources, such as directly from the companies involved, or from public press-releases. Other potential limitations on the data are discussed in sections 4.1.5and 4.1.6.

3. What is included in the cost of tunnelling?

    a. This depends on the und-use of each tunnel and the availability of cost breakdowns. With the exception of the individual comparisons section of the report (4.3), we included the controversial factors such as the cost of stationing, mechanical and electrical equipment, land acquisition, and contractors P&G in general since those factors are included in the tunnels for which we only had full project costs.

4. What currency are the costs in?

    a. Average 3Q 2011 AUD.

7.2 Appendix B: Glossary

Bench: The unexcavated ground on the lower face of a tunnel.

Bore: The diameter of the excavated section.

Client: The project owner; for whom the tunnel is being constructed.

Cross Passage: A tunnel used to connect adjacent, parallel tunnels.

Cut and Cover (C&C): A method of tunnelling involving the excavation of a trench, construction of the lining, and the subsequent covering of the structure.

Design & Construct (D&C): A method of procurement, in which the design and construction activities are contracted to a single contractor.

Drill and Blast (D&B): A method of excavation involving the use of explosives.

Earth Pressure Balance (EPB): A type of TBM, typically employed in permeable soils, which increases the pressure in the cutting chamber to balance the intake of water and prevent subsidence.

Electrical & Mechanical (E&M): All of the equipment used in the final fit-out of a tunnel, from railroad tracks, to ventilation systems.

End-Use: The designed service of the completed tunnel.

Face: The area of the bore perpendicular to the drive alignment.

Fault: Any fracture in the substrate through which the tunnel is driven.

Fire Life Safety (FLS): A term used to describe the safety systems of a tunnel.

Grout/Grouting: Used to fill in voids in porous substrate to improve ground conditions.

Heading: The top section of an excavation which typically is excavated before the bench

Immersed: An underwater tunnel, where prefabricated tubes are floated into position then sunk into an excavated trench and connected.

In-Situ Concrete: Concrete that is cast in place inside the tunnel.

Ingress/Infiltration: Penetration of groundwater into the tunnel.

Invert: The lowest point in the tunnel face.

Jumbo: Equipment on which drills are mounted for D&B tunnelling.

Micro-tunnelling: a method of excavation for small bores which does not involve trenches.

Mined Tunnel: Any tunnel excavated from underground

Mixed Face: When 2 or more ground conditions lie in the path of the drive.

Outturn: The final cost of a project.

Pipe Jacking: A method of excavation in which hydraulic jacks force a pipe behind the excavator as it moves forward.

Plant: The factory set up to manufacture tunnelling components, such as precast concrete segments.

Polypropylene Fibre: Synthetic fibres often premixed into concrete to add strength.

Preliminaries & General (P&G): A loosely defined set of costs related to the contractor. Typically dealing with provision for payment, overheads, risk, etc

Procurement: The activities undertaken by a client to obtain a completed project.

Roadheader: A piece of excavation equipment that consists of a cutting head mounted on an articulate boom.

Rock Anchor/Bolt: Steel bars that are grouted into drilled holes in the tunnel walls to provide long-term support.

Segment: The prefabricated arc shaped component that makes up the internal lining of a tunnel.

Settlement: The lateral movement of the ground surface directly above a tunnel.

Shaft: The vertical excavation used to provide access and ventilation to the tunnel.

Shield: Protective steel tube that encases the TBM during soft-ground tunnelling.

Site Investigation (SI): A thorough investigation encompassing, surface and subsurface exploration in order to obtain all design parameters and address any

Spoil: The excavated material, displaced by the tunnel.

Sprayed Concrete Lining (SCL) (Shotcrete): Concrete sprayed pneumatically through a hose onto the surface of a tunnel for fast stabilisation.

Stand-Up Time: The amount of time a tunnel can support itself post-excavation, and before any type of structural reinforcement or lining is installed.

Steel Fibre Reinforced (SFR): A type of concrete lining, which is reinforced by steel fibres that are premixed into the concrete.

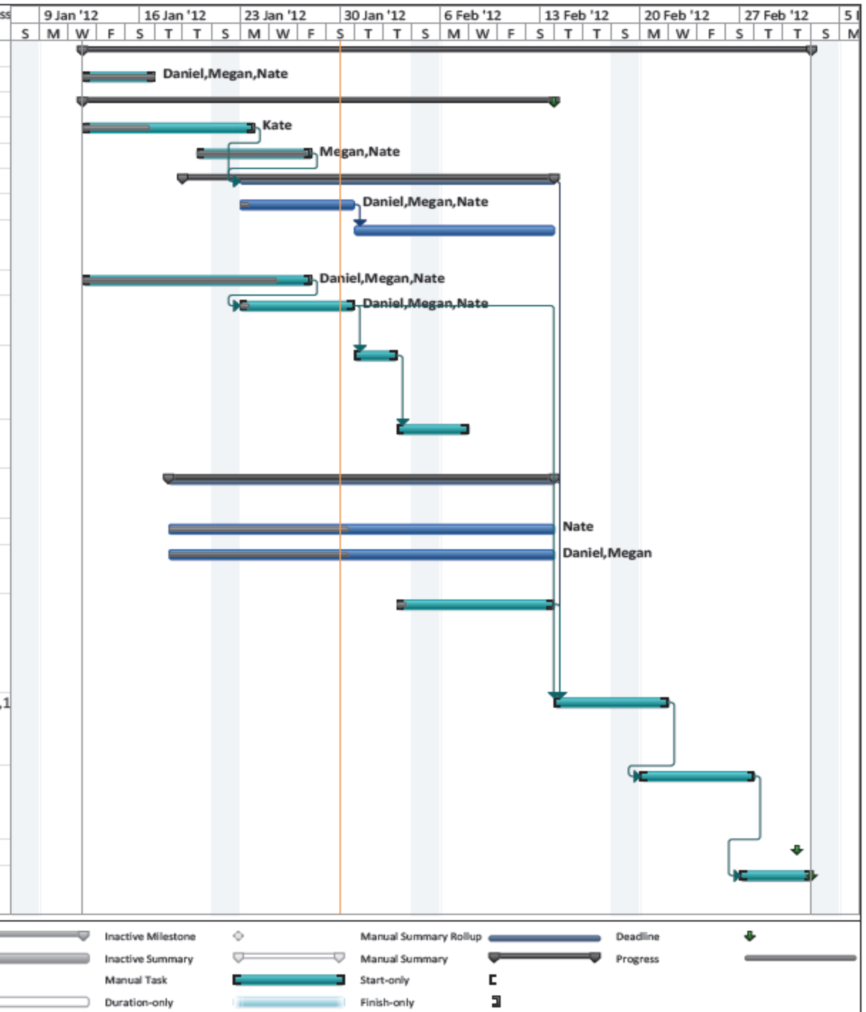
Tender: The proposed price of a project, by the contractor, based off of an estimate of the bill of materials.

Tunnel Boring Machine (TBM): A machine used to excavate tunnels with a circular diameter. TBMs typically run along tracks and have rotating circular cutting heads.

7.4 Appendix C: Gantt Chart

Figure 26 Gantt Chart

ID	Task Name	Duration	Start	Finish	Predecess
1	**Tunnels Cost Database Programme**	**37 days?**	**Thu 12/01/12**	**Fri 2/03/12**	
2	Make edits to paper	3 days	Thu 12/01/12	Mon 16/01/12	
3	**Input information into database**	**23 days**	**Thu 12/01/12**	**Mon 13/02/12**	
4	Set up interviews	8 days	Thu 12/01/12	Mon 23/01/12	
5	Compile Interview Questions	6 days	Fri 20/01/12	Fri 27/01/12	
6	**Complete interviews**	**18 days**	**Thu 19/01/12**	**Mon 13/02/12**	**4,5**
7	Interviews within AECOM	6 days	Mon 23/01/12	Mon 30/01/12	
8	Interviews with Contractors	10 days	Tue 31/01/12	Mon 13/02/12	7
9	Read existing literature	12 days	Thu 12/01/12	Fri 27/01/12	
10	Ascertain key drivers of tunnel costs from literature	6 days	Mon 23/01/12	Mon 30/01/12	9
11	Gauge ANZ's position in terms of cost for each key driver	3 days	Tue 31/01/12	Thu 2/02/12	10
12	How can ANZ reduce tunnelling costs	3 days	Fri 3/02/12	Tue 7/02/12	11
13	**Internet trawl for tender prices and final outturn costs**	**19 days**	**Wed 18/01/12**	**Mon 13/02/12**	
14	in ANZ	19 days	Wed 18/01/12	Mon 13/02/12	
15	worldwide for past 10-20 years	19 days	Wed 18/01/12	Mon 13/02/12	
16	Use case studies already in AECOM database, interviews, and literature to analyse distribution of costs	7 days	Fri 3/02/12	Mon 13/02/12	
17	Compare the cost distributions across different countries and projects	6 days	Tue 14/02/12	Tue 21/02/12	6,10,13,1
18	Establish if there are quantifiable benefits to higher tunnel costs	6 days	Mon 20/02/12	Mon 27/02/12	17
19	Final Draft				
20	Final Edits to Paper and Presentation	5 days	Mon 27/02/12	Fri 2/03/12	18



Project: Tunnels Cost Database P
Date: Mon 30/01/12

Page 1

7.5 Appendix D: Interview Questionnaires

7.5.1 Form A

Background on us:

We are university students from a small engineering university called WPI in Massachusetts, USA. We have been in Melbourne for the past three weeks working on the project described below as a requirement for our degree. We have little under 5 weeks left in Melbourne and thank you for your time.

Background on project:

Perception in the industry and in particular by Government Agencies is that overall tunnelling costs in Australia and New Zealand (ANZ) are significantly higher than the rest of the world, but particularly compared with Europe.

There have not been any comprehensive studies confirming or denying this perception, however visiting "experts" have reinforced this viewpoint.

There is a general scarcity of data regarding recent tunnelling costs in the region.

Objectives of project:

Determine whether or not the hypothesis of higher ANZ tunnelling costs is true.

If true, determine the factors that contribute most heavily to the higher costs.

Determine what advantages (if any) result from higher tunnel costs.

In order to complete our objectives:

We will need qualitative data (from interviews) describing the direction in which to pursue further research.

We also need any possible non-confidential cost data regarding the breakdown of tunnel bids. (If Possible)

General Questions:

1. What is the role you have most commonly had on tunnel projects?
   - Contractor
   - Cost Estimator
   - Consultant
   - Other: Please Specify
2. How many years experience do you have in the tunnelling sector?
   - Less than 5 years
   - 5-10 year
   - Over 10 years
3. Have you worked on any tunnelling projects outside of Australia?

   If Yes, Specify which countries:
4. What types of end-uses have the tunnelling projects you been involved been for?
   - Rail
   - Road
   - Water

- Sewer
- Cable
- Other: Please Specify

5. Can you explain your position in your company and what extent of involvement you have in the tunnelling sector (In ANZ and globally)?
6. Have many tunnelling projects have you been involved in, and when did you start working on tunnelling projects? (Which end-uses, cost range, project skill)
    a. In the past 15 years?
7. Can you list the three most recent tunnelling projects that your firm has worked on, and explain your firm's extent of involvement with them?
8. How specifically does your firm differ from other firms?
    a. And how has this affected your business model and methodology when it comes to preparing bids and/or estimates (N/A to consultants)?
9. What percentage of your business is related to tunnelling or projects that require a component of tunnelling?
    a. Is this percentage different globally than in ANZ, if so why?
10. What would you list as the main challenges encountered when constructing tunnels compared to other infrastructure?
11. Have there been any recent (<15 years) technological advancements or improvements in procurement proceedings in the field that have significantly affected the way you work on tunnelling projects?

7.5.2 Form B (Cost Estimator)

Compiling Estimates

1. When compiling a cost estimate, which main categories do you use to break down various costs?
2. Are there certain cost factors that are often indeterminate or less precise that cause a lot of variance in the estimate?
3. Please rank the following according to how you think each contributes the most to the final estimate?
    a. What type of project delivery system are you typically involved in, and what do you find most advantageous about that/these type(s). (Design complexity, in-house resource availability, flexibility, scheduling, time, politics, financial reasons.)

- Fixed price Contract-
- Cost plus-
- Design & Construct-
- Project Management Agreement-
- Construction Management Agreement-
- Managing Contractor Contract-
- Warranted Maximum Price Contract-
- Build Own Operate Transfer-

Contract Type/Procurement Rote -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Lining Type -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

End-Use -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Excavation Type -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Geology -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Country of Construction -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Depth of Tunnel -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

4. In your opinion, to what extent do each of these parts of the design and construction process can lead to the greatest overall variance between estimated costs and final outturn costs on a scale of 1 to 10.
    - Preliminary Design/Bidding
    - Design
    - Construction
    - Post-Construction/commissioning
5. When compiling an estimate which indices do you use to account for inflation?
    a. How long does a project need to take for you to consider the effects of inflation?
6. Over the past 15 years, has there been any major legislation in ANZ that has significantly affected the way in which you compile estimates and the overall cost of tunnelling?

<u>Indirect Factors and Regulations</u>

1. How do you account for indirect factors? (ie. Market structure and capacity, governance and procurement approach, etc.)
    a. Do you feel any of these variables have a large effect on cost estimates in ANZ specifically?
    b. How do you convert these qualitative factors into quantitative numbers?
2. How do you account for tunnelling in an urban environment vs. a rural one?

3. Are there any major differences that you have noticed in design standards or regulations between different locations? in Australia (State legislation) or Overseas (If so specify which countries)?

   With Regard to:

   - Health & Safety:
   - Design Specifications:
   - Material Specifications:
   - Environmental Regulations:
   - Labour costs:
   - Engineering skills and industry capacity:

   If so to what extent to these affect the estimate?

<u>Bid Involvement</u>

1. How similar is the tender cost to the final cost?
   a. What accounts for the difference in cost?
2. At which point of the bidding process do you typically become involved?
3. What is your level of involvement with the designer, and do you have any influence on the direction of the project?

<u>Tunnelling in ANZ vs. other parts of the world</u>

1. Do you personally feel that tunnelling is more expensive in ANZ?
   a. If so, what factors do you think attributes to this?
   b. Do you feel that there are any resulting benefits? (less required maintenance, better safety record, increased design life, increased efficiency)
   c. Does it appear that certain types of tunnels are more expensive?
   d. Do you have specific examples to support this?
   e. Is there a difference in the approach to constructing tunnels in ANZ versus other parts of the world?
2. Do you agree with the statement that both cost estimates and final costs are more expensive in ANZ than the rest of the world?

7.5.3 Form C (Contractor)

<u>Industry/Market Structure:</u>

1. There are few major tunnelling contractors in Australia. Do you think this is because there is such a small market, or are there high barriers to entry?
   a. With such a small market; how does that affect the sustainability of the business and the methodology behind placing bids?
   b. What would you describe as the biggest barrier to becoming a contractor in the tunnel market? (Experience, project size, machinery, financing)
2. Can you describe the level of competition you have experienced among contractors when competing for a bid in ANZ on a scale of 1 to 10 where 1 is not competitive at all and 10 means extremely competitive?
   a. Is this affected by the size of the project?

    b. Is this affected by the location of the project?
    c. Does the level of competition significantly affect the tender costs of projects in ANZ compared to other countries?

3. On average what ratio of your projects are bid as joint ventures or alliances?
    a. If so, what are the advantages? (Greater chance of being selected for the bid, less financial risk, wider expertise)
4. What would you list as the most noticeable differences between contracting in ANZ and contracting in other parts of the world?
    a. Does it appear that any of these differences attribute to variances in costs? (Follow up: do you have any data to support this?)

<u>Contract:</u>

1. Do you find any significant differences in the procurement process in ANZ when compared to the rest of the world? (Provide examples)
2. Have you worked on multiple types of contracts?
    a. If so, what type of project delivery system do you typically choose, and what do you find most advantageous about that/these type(s). (Design complexity, in-house resource availability, flexibility, scheduling, time, politics, and financial reasons.)

- Fixed price Contract-
- Cost plus-
- Design & Construct-
- Project Management Agreement-
- Construction Management Agreement-
- Managing Contractor Contract-
- Warranted/Guaranteed Maximum Price Contract-
- PPP's (Public Private Partnerships)
- Build Own Operate Transfer

3. Can you quantify the time that goes into preparing a bid?
    a. Can you give a breakdown (percentages or ratios) of how much time goes into each activity?
    b. Which area do you think could see the biggest time savings?
4. Can you describe the number of people required to set up a bid, and their roles and level of involvement?
5. During which stages of the procurement process do you think the most time and money can be saved?

6. Please rank the following factors according to how you think each attributes the most to the final bid?

Contract Type -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Lining Type -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

End-Use -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Excavation Type -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Geology -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Country of Construction -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Depth -

(No Cost Correlation) 1 2 3 4 5 6 7 8 9 10 (Significant Cost Correlation)

Design:

1. At which point in the design process do you typically get involved? (Study, concept, preliminary, detailed design, final design...)
    a. How integrated do you get into the design of a project? (Scale of 1 to 10, with 10 being completely integrated and 1 being not involved)
2. How much flexibility do you have in design when working with a consultant? (Scale of 1 to 10)
    a. Is this different when working on a government project?
3. Do you often see major changes to the scope during this stage that could result in cost escalation?
    a. If so, is this more noticeable in Australia than in other countries?
4. Are there any major differences that you have noticed in design standards or regulations between different locations in Australia (State legislation) or Overseas (If so specify which countries)?

With Regard to:

- Health & Safety:
- Design Specifications:
- Material Specifications:
- Environmental Regulations:
- Labour costs:
- Engineering skills and industry capacity:

How does each of these affect the estimate?

Regulations and Compliance:

1. To what extent do you feel that the cost of compliance with the following standards is noticeably higher in ANZ than the rest of the world?

- Environmental
- Health and Safety

    a. If so: Can you provide any specific examples?

2. Over the past 15 years, has there been any major legislation in ANZ that has significantly affected the way in which you bid for contracts and the overall cost of tunnelling?
3. Most major tunnelling projects in ANZ are government sponsored. To what extent do you think this leads to greater scrutiny and level of compliance?
    a. If so: Does this increased compliance lead to significantly higher costs?

Risk and Contingency:

1. Does the country in which you are bidding on a project affect the amount of contingency you allocate in the bid?
2. On average, what percentage of the bid price is left for contingency in your ANZ tunnelling projects?
    a. How does that breakdown differ from other infrastructure projects?
    b. How is that different from other parts of the world?
3. What timescale does a project have to be for you to consider the effects of inflation?
    a. How exactly do you typically account for this, and is this different depending on location?
4. To what extent is risk dependent on geological uncertainty?
    a. Is this more of a noticeable problem in ANZ when compared to other countries?

Inputs:

1. Do you source your materials locally for ANZ projects? What percentage of materials is sourced locally?
    a. Do you see this as specific to ANZ, or is it standard around the world?
2. What percentage of your labour force typically is locally sourced? Is it more cost effective to bring in people from other locations?
    a. If so, is a specific skill in tunnelling projects necessary? (Specify)
3. Do you find the cost of labour to be particularly high in Australia, and if so is there any noticeable benefit? (More skilled labour, more productivity)
4. Can you describe how financing is typically handled with your projects, and do you know of any major differences in the way this is handled between ANZ and the rest of the world?

Construction:

1. Do you own, or rent the majority of your equipment? What percentage of each?
2. Have you encountered the ability to reuse specialized equipment like TBMs or are they typically only utilized once for specific jobs?
    a. If so, what is the typical life cycle of this high-cost machinery?
3. Do you find that the speed in which you complete the project is one of the most important factors for reducing cost?
    a. Does this affect the number of TBMs used in the construction process?
        i. If so, how is this determined? (Cost-benefit analysis, arbitrarily, experience)

4. Can you describe the variance in the size of your workforce during the various stages of a project? (Percentages if possible)

- Preliminary Design/Bidding -
- Design -
- Construction -
- Post-Construction/Commissioning -

5. Is there any major difference in insurance costs between countries you have built tunnels in?
6. Is it easier to stay on schedule in countries that have higher design standards?
    a. If so: Do you think this is due to experience or higher reliability?
    b. If not: Do you think this is because of more time required to meet regulations?
        i. Also, do you think there is a benefit to this? (Better tunnel, more cost effective, better safety record)
7. Do you often try to use prefabricated materials in your tunnelling projects? (Percentage if possible)
    a. Is this common in ANZ vs. the rest of the world? Is this because of ANZ's economic and market ability to run these plants?

Project Scope / Outturn:

1. How often do projects come in under budget? (Percentages)
    a. If rarely/never: Is this because any cost savings gets consumed by an increase in the scope?
    b. If sometimes/most of the time: Is this because of an excessive contingency, or some other factor, combination of factors?
2. Do you feel that tunnels in ANZ require less maintenance than tunnels in the rest of the world?
    a. Is this because of improvements made in the design process, or the construction process? (Is it worth it?)
3. In your opinion, for your ANZ tunnelling projects, which of the following areas often result in the greatest cost escalation? (Scale of 1-10 if possible)

- Feasibility –
- Design -
- Pre-construction -
- Construction -
- Commissioning –

4. Do you feel that these escalated costs have any long term value? (Such as a longer tunnel lifetime, increased safety, increased efficiency, less maintenance)

7.5.4 Form D (Consultants)

Design:

1. Can you list and briefly describe your firm's involvement in the three most recent tunnelling projects your firm has designed?
2. To what extent does the design of a tunnel depend on indirect factors? (ie. Market structure and capacity, governance and procurement approach, etc.)

   a. Do you feel that any of these vary greatly in ANZ compared to other nations?If so specify countries and factors

3. What kind of design changes would you make when designing a tunnel in an urban instead of a rural project?
   a. To what extent do you believe that these changes greatly increase the cost of the tunnel?
4. How flexible is the design in a project when working in the private sector? (From 1 to 10 where 1 is not at all flexible and 10 is extremely flexible)
   a. Is this different when working on a government project? (If so how flexible is that on the same scale)
5. Do you often try to design for the use of prefabricated materials in your tunnelling projects? (If so what percentage prefab)
   a. Is this common in ANZ vs. The rest of the world? Is this because of ANZ's economic and market ability to run these plants?
   b. What are the advantages to this in the design and construction process if any?
6. During which stages of the design process do you think the most time and money can be saved?

Regulations and Compliance:

1. To what extent do the government regulations and compliance affect the overall design of a tunnel in ANZ?
2. To what extent do the Environmental Impact Assessment and other environmental regulations affect the design process, and how much time is typically consumed completing the process in ANZ?
3. Are there any major differences that you have noticed in design standards or regulations between different countries? In Australia (State legislation) or Overseas (If so specify which countries)?

   With Regard to:

   - Design Specifications:
   - Material Specifications:
   - Environmental Regulations:
   - Engineering skills and industry capacity:

   If so to what extent do these affect the design? (Ranking if possible)
4. Over the past 15 years, has there been any major legislation in ANZ that has significantly affected the way in which you design tunnels?

Risk and Contingency:

1. To what extent does the amount of site investigation and geological analysis affect tunnel design?
   a. Do you believe that increased studies would favourably affect costs because of greater certainty?
   b. In your opinion, is ANZ more challenging to tunnel in because of geological factors?
2. Because of the high level of geological uncertainty, are tunnels typically over designed with high safety factors when compared to other infrastructure?

Project Scope / Outturn:

1. Do you feel that tunnels in ANZ are designed with higher standards than tunnels in the rest of the world? (Better safety, more efficiency, less maintenance)
   a. Is this because of improvements made in the design process, or the construction process? (Is it worth it?)

Tunnelling in ANZ vs. other parts of the world

1. Do you personally feel that tunnelling is more expensive in ANZ?
    a. If so, what factors do you think attribute to this?
    b. Does it appear that certain types of tunnels are more expensive?
        i. Do you have specific examples to support this?
    c. Is there a difference in the approach to designing tunnels in ANZ versus other parts of the world?

7.5.5 Closing (All Forms)

Where do you see the key opportunities to reduce the cost of tunnel delivery in ANZ? (Rank by opportunity for cost savings)

Design	Low---------------------Medium---------------------High
SI / GI	Low---------------------Medium---------------------High
Env. Remediation	Low---------------------Medium---------------------High
Health & Safety Regs.	Low---------------------Medium---------------------High
Materials	Low---------------------Medium---------------------High
Labour	Low---------------------Medium---------------------High
Enabling Works	Low---------------------Medium---------------------High
Commissioning	Low---------------------Medium---------------------High
Client Leadership	Low---------------------Medium---------------------High
Procurement Stage	Low---------------------Medium---------------------High
Supply Chain (Eng.)	Low---------------------Medium---------------------High
________________	Low---------------------Medium---------------------High
________________	Low---------------------Medium---------------------High
________________	Low---------------------Medium---------------------High

Do you have any data that we could use to support these assumptions?

Are there any other contacts you would recommend us to speak with in regard to our project?

7.6 Appendix E: Tunnels Research Survey

We are three engineering students working on a university tunnel research project in collaboration with AECOM. Through our research, we seek to investigate the various factors that influence the cost of tunnelling projects in Australia and New Zealand. This preliminary survey will help provide qualitative information to guide our research. The survey takes less than 5 minutes to complete and your input is greatly appreciated.

Page 1 - Question 1 - Choice - One Answer (Bullets) [Mandatory]

How many years of experience do you have in the tunnelling sector?

- Less than 5 years
- 5 - 10 years
- 10 - 20 years
- Over 20 years

Page 1 - Question 2 - Choice - Multiple Answers (Bullets) [Mandatory] [Up To 2 Answers]

Have you worked on any tunnelling projects outside Australia?

- No
- Yes
- If Yes, please specify which countries

Page 1 - Question 3 - Choice - Multiple Answers (Bullets) [Mandatory]

Which types of tunnel projects have you been involved in?

- Rail (heavy/light/metro)
- Road
- Water / Hydro-power
- Sewer / Wastewater
- Cable
- Pedestrian
- Other, please specify

Page 1 - Question 4 - Choice - One Answer (Bullets) [Mandatory]

What is the role you have most commonly held on tunnel projects?

- Contractor
- Cost Estimator

- Consultant
- Client
- Other, please specify

Page 2 - Question 5 - Rating Scale - Matrix [Mandatory]

Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project. (1=low, 5=high)

	1	2	3	4	5	Unsure
Contract Type	❍	❍	❍	❍	❍	❍
Lining Type	❍	❍	❍	❍	❍	❍
End-Use	❍	❍	❍	❍	❍	❍
Excavation Type	❍	❍	❍	❍	❍	❍
Geology	❍	❍	❍	❍	❍	❍
Country	❍	❍	❍	❍	❍	❍
Locality	❍	❍	❍	❍	❍	❍
Depth	❍	❍	❍	❍	❍	❍

Page 2 - Question 6 - Rating Scale - Matrix [Mandatory]

In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings. (1=low, 5=high)

	1	2	3	4	5	Unsure
Design Specifications & Standards	❍	❍	❍	❍	❍	❍
Site/Ground Investigation	❍	❍	❍	❍	❍	❍
Environmental Remediation	❍	❍	❍	❍	❍	❍
Health & Safety Regulation	❍	❍	❍	❍	❍	❍
Materials	❍	❍	❍	❍	❍	❍
Labour	❍	❍	❍	❍	❍	❍
Enabling Works	❍	❍	❍	❍	❍	❍
Commissioning	❍	❍	❍	❍	❍	❍
Client Leadership & Management	❍	❍	❍	❍	❍	❍
Procurement Strategy	❍	❍	❍	❍	❍	❍
Supply Chain & Capacity	❍	❍	❍	❍	❍	❍

Page 2 - Question 7 - Choice - One Answer (Bullets) [Mandatory]

Do you personally feel that tunnelling is more expensive in Australia and New Zealand when compared to other countries?

- Yes [Skip to 3]
- No [Skip to 4]
- Unsure [Skip to 3]

Comments

Page 3 - Question 8 - Choice - Multiple Answers (Bullets)

Which benefits (if any) do you believe are associated with the higher cost of tunnels in Australia and New Zealand

- No Benefits Exist
- Faster Completion
- Better Construction Safety Record
- Greater Adherence to Environmental Standards
- Reduced Operations and Maintenance Cost
- Better Post-Commissioning Safety
- Longer Service Life
- Other, please specify

Page 4 - Question 9 - Open Ended - Comments Box

Would you like to make any further comments regarding tunnel costs that would be relevant to this research?

Page 4 - Question 10 - Name and Address (U.S)

If you would you like to be involved in more in-depth research regarding tunnel costs provide your email address below and we will contact you shortly.

- Email Address

Page 4 - Question 11 - Name and Address (U.S)

If you would like to receive information on the results of this research please provide the following details.

- Name
- Company
- Email Address

Page 4 - Heading

Thanks for completing the survey. If you could please pass the link to this survey on to any of your tunnelling colleagues to complete we would be very grateful.

7.7 Appendix F: Survey Responses

1. How many years of experience do you have in the tunnelling sector?		
Less than 5 years	18	33%
5 - 10 years	14	26%
10 - 20 years	11	20%
Over 20 years	11	20%
Total	54	100%
2. In which countries have you worked on tunnelling projects?		
Australia	40	74%
New Zealand	15	28%
If Others, please specify which countries	26	48%

Respondent #	Response
1	Thailand and Loas
2	UK and Hong Kong
3	Malaysia
4	United States
5	hong Kong
6	England
7	Canada, India, Denmark(Greenland)
8	Canada
9	UK
10	mainly in Canada, but also Asia, South America.
11	UK, Hong Kong, Singapore
12	United Kingdom
13	Hong Kong, Singapore, UAE, Philippines, Fiji, Thailand, Laos, Indonesia, Malaysia, South Africa, Papua

	New Guinea		
14	Singapore		
15	US		
16	Papua New Guinea		
17	Hong Kong, Singaopre, Malaysia		
18	United Kingdom, Thailand		
19	HK, Singapore, Thailand		
20	Sri Lanka,		
21	None		
22	UK		
23	UK and Ireland		
24	UK, USA, Malaysia, Hong Kong, Thailand, Singapore		
25	UK		
26	Philippines		
3. Which types of tunnel projects have you been involved in?			
Rail (heavy/light/metro)		25	46%
Road		30	56%
Water / Hydro-power		25	46%
Sewer / Wastewater		21	39%
Cable		8	15%
Pedestrian		8	15%
Other, please specify		2	4%
Respondent #	**Response**		
1	Only limited experience - two cut and cover tunnels		
2	Mine access and mining		
4. What is the role you have most commonly held on tunnel projects?			
Contractor		19	35%
Cost Estimator		5	9%
Consultant		26	48%
Client		8	15%
Other, please specify		6	11%

Respondent #	Response
1	Land use planning and approvals
2	Mainly involved with pavements in tunnels. I have recently been doing some work on Airport Link in Brisbane assisting with the pavement construction in the tunnel. That project could provide some excellent recent history and if I can assist with providing contacts let me know.
3	Engineer involed with lowering tunnel floor, daylighting, drainage & general maintenance. No new tunnel.
4	Senior Mgmt
5	Design Engineer
6	Client Representative in Alliance

5.) Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project.: Contract Type

		What is the role you have most commonly held on tunnel projects?				
	Total*	Contractor	Cost Estimator	Consultant	Client	Other, please specify
	41	14	4	18	8	4
1 (No Cost Correlation)	1	1	0	0	0	0
2	4	2	1	1	0	1
3	12	3	1	6	1	2
4	13	4	1	7	3	1
5	10	4	1	3	4	0

	Total*	Contractor	Cost Estimator	Consultant	Client	Other, please specify
(Significant Cost Correlation)						
6 (Unsure)	1	0	0	1	0	0

5.) Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project.: Lining Type

		What is the role you have most commonly held on tunnel projects?				
	Total*	**Contractor**	**Cost Estimator**	**Consultant**	**Client**	**Other, please specify**
	41	14	4	18	8	4
1 (No Cost Correlation)	0	0	0	0	0	0
2	3	2	0	1	0	0
3	12	4	2	7	1	2
4	15	5	1	8	3	1
5 (Significant Cost Correlation)	10	3	1	2	3	1
6 (Unsure)	1	0	0	0	1	0

5.) Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project.: End Use

		What is the role you have most commonly held on tunnel projects?				
	Total*	**Contractor**	**Cost Estimator**	**Consultant**	**Client**	**Other, please specify**
	41	14	4	18	8	4
1 (No Cost Correlation)	2	1	1	0	0	0
2	3	2	0	1	0	0
3	8	4	0	2	1	1
4	14	2	2	8	3	0
5 (Significant Cost Correlation)	11	5	1	6	2	3
6 (Unsure)	3	0	0	1	2	0

5.) Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project.: Excavation Type

	Total*	What is the role you have most commonly held on tunnel projects? Contractor	Cost Estimator	Consultant	Client	Other, please specify
	41	14	4	18	8	4
1 (No Cost Correlation)	0	0	0	0	0	0
2	0	0	0	0	0	0
3	7	1	2	4	2	0
4	14	3	1	6	5	1
5 (Significant Cost Correlation)	19	10	1	7	1	3
6 (Unsure)	1	0	0	1	0	0

5.) Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project.: Geology

	Total*	What is the role you have most commonly held on tunnel projects? Contractor	Cost Estimator	Consultant	Client	Other, please specify
	41	14	4	18	8	4
1 (No Cost Correlation)	0	0	0	0	0	0
2	0	0	0	0	0	0
3	2	0	0	1	1	0
4	8	1	1	5	1	0
5 (Significant Cost Correlation)	30	13	3	11	6	4
6 (Unsure)	1	0	0	1	0	0

5.) Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project.: Country of Construction

	Total*	What is the role you have most commonly held on tunnel projects? Contractor	Cost Estimator	Consultant	Client	Other, please specify
	41	14	4	18	8	4
1	0	0	0	0	0	0

	Total*	Contractor	Cost Estimator	Consultant	Client	Other, please specify
(No Cost Correlation)						
2	2	0	0	2	0	0
3	8	2	1	3	2	1
4	17	6	2	10	2	1
5 (Significant Cost Correlation)	7	4	1	1	1	2
6 (Unsure)	7	2	0	2	3	0

5.) Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project.: Locality (urban vs rural)

		What is the role you have most commonly held on tunnel projects?				
	Total*	Contractor	Cost Estimator	Consultant	Client	Other, please specify
	41	14	4	18	8	4
1 (No Cost Correlation)	1	1	0	0	0	0
2	1	0	0	1	0	0
3	7	3	0	3	1	2
4	16	7	1	7	3	0
5 (Significant Cost Correlation)	13	3	2	5	3	2
6 (Unsure)	3	0	1	2	1	0

5.) Thinking about factors that can contribute to tunnel costs, please score the following according to how much of an influence you believe it has on the final cost of a tunnel project.: Depth

		What is the role you have most commonly held on tunnel projects?				
	Total*	Contractor	Cost Estimator	Consultant	Client	Other, please specify
	41	14	4	18	8	4
1 (No Cost Correlation)	0	0	0	0	0	0
2	5	1	1	4	0	0
3	16	8	2	4	3	2
4	13	3	1	9	3	0

5 (Significant Cost Correlation)	5	2	0	0	1	2
6 (Unsure)	2	0	0	1	1	0

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Design Specifications and Standards

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	2	2	1	0	0	0
2	6	3	0	2	0	1
3	8	2	1	4	1	0
4	17	8	2	6	4	2
5 (High Cost Saving Opportunities)	6	1	0	3	2	1
6 (Unsure)	4	0	1	3	1	0

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Site Investigation / Ground Investigation

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	0	0	0	0	0	0
2	2	1	1	0	0	1
3	5	2	0	2	1	1
4	21	8	3	10	3	1
5 (High Cost Saving Opportunities)	13	5	1	5	3	1
6	2	0	0	1	1	0

(Unsure)						

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Environmental Remediation

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	2	0	0	1	0	1
2	8	5	0	2	1	0
3	16	6	2	7	4	2
4	10	4	2	3	2	1
5 (High Cost Saving Opportunities)	0	0	0	0	0	0
6 (Unsure)	7	1	1	5	1	0

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Health and Safety Regulations

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	5	1	2	3	0	0
2	10	6	1	1	3	0
3	14	4	1	7	3	2
4	10	3	1	5	2	1
5 (High Cost Saving Opportunities)	2	2	0	0	0	1
6 (Unsure)	2	0	0	2	0	0

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Materials

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4

1 (Minimal Cost Saving Opportunities)	1	0	0	0	0	1
2	6	5	1	1	0	0
3	18	8	2	8	4	2
4	13	2	2	6	3	1
5 (High Cost Saving Opportunities)	1	1	0	0	0	0
6 (Unsure)	4	0	0	3	1	0

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Labour

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	1	0	0	0	0	1
2	4	4	0	0	0	0
3	13	3	3	5	4	2
4	15	5	0	10	2	0
5 (High Cost Saving Opportunities)	7	4	2	1	1	1
6 (Unsure)	3	0	0	2	1	0

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Enabling Works

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	0	0	0	0	0	0
2	3	2	0	1	0	0
3	20	9	2	6	4	2
4	10	4	1	6	1	1

	Total*	Contractor	Cost Estimator	Consultant	Client	Other, please specify
5 (High Cost Saving Opportunities)	1	1	1	0	0	0
6 (Unsure)	9	0	1	5	3	1

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Commissioning

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	3	0	0	2	0	1
2	8	5	2	2	1	0
3	18	7	2	6	4	2
4	4	1	0	3	1	0
5 (High Cost Saving Opportunities)	1	1	0	1	0	0
6 (Unsure)	9	2	1	4	2	1

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Client Leadership and Management

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	0	0	0	0	0	0
2	3	2	0	0	0	1
3	14	6	3	3	3	2
4	12	4	0	6	3	0
5 (High Cost Saving Opportunities)	11	4	1	6	2	1
6 (Unsure)	3	0	1	3	0	0

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Procurement Strategy

	Total*	What is the role you have most commonly held on tunnel projects?

	Total*	Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	0	0	0	0	0	0
2	1	0	0	1	0	0
3	13	7	4	3	1	1
4	18	7	1	7	5	1
5 (High Cost Saving Opportunities)	8	2	0	5	2	1
6 (Unsure)	3	0	0	2	0	1

6.) In your opinion, what do you believe are the key opportunities to reduce the cost of tunnel delivery in Australia and New Zealand? Please rank by opportunity for cost savings.: Supply Chain and Capacity (Engineers)

	Total*	What is the role you have most commonly held on tunnel projects?				
		Contractor	Cost Estimator	Consultant	Client	Other, please specify
	43	16	5	18	8	4
1 (Minimal Cost Saving Opportunities)	0	0	0	0	0	0
2	4	0	0	3	0	1
3	16	9	3	3	2	1
4	18	6	2	9	5	2
5 (High Cost Saving Opportunities)	1	1	0	0	0	0
6 (Unsure)	4	0	0	3	1	0

7. Do you personally feel that tunnelling is more expensive in Australia and New Zealand when compared to other countries?

Yes	21	49%
No	7	16%
Unsure	15	35%
Total	43	100%

Respondent #	Response
1	More so in Australia
2	Extremely So (Unions and rest of BULLSHIT)

	required to meet about 9 assorted standards
3	I assume we are comparing with non-western countries which have cheaper labour and less restrictions
4	Labour costs
5	Labour & Materials
6	High labour costs Distance from some suppliers
7	Labour in particular seems very high compared to other countries
8	not working in area
9	This may be influenced by current high exchange rate
10	There are frequenst claims that costs are higher in Australia, but when accurate and relevant comparisons are drawn this is often found to be untrue. Its important to compare apples with apples.
11	Since 2000, tunnelling costs in Australia have increased 4-5 fold
12	- High labour cost base - Typically fire life & safety best in world - Design (architectural)driving up underground cost (ie stations)
13	Feedback from European colleagues (in particular Spain).
14	Most probably because of our higher labour costs, higher contractor margins and more stringent safety and environmental compliance requirements
15	Probably similar compared with developed countries.
16	labour is more expensive.

8. Do you feel these higher costs are mainly due to:

a higher tender cost	6	17%
a higher final cost	7	20%
a combination of the higher tender and final costs	17	49%
Other, please specify	8	23%

Respondent #	Response
1	Don't know if tunneling costs are higher in Aus/NZ.
2	unsure

3	higher costs related to what?
4	Current Exchnage rates make costs look high compared to UK for example.
5	Environmwnral, EIS requirements
6	not familiar with NZ & Aus
7	See Q7
8	We dont think big enough or long term enough to have a straegy that would allow efficiency in volume

9. Which benefits (if any) do you believe are associated with the higher cost of tunnels in Australia and New Zealand

No Benefits Exist	8	23%
Faster Completion	2	6%
Better Construction Safety Record	15	43%
Greater Adherence to Environmental Standards	15	43%
Reduced Operations and Maintenance Cost	10	29%
Better Post-Commissioning Safety	7	20%
Longer Service Life	11	31%
Other, please specify	7	20%

Respondent #	Response
1	I am unsure
2	No knowledge
3	unsure
4	don't know the relative costs of this area compare to my area of work.
5	Higher safety standards e.g deluge rates and exit spacing in road tunnels, than european standards have higher cost but potentially higher benefits in a fire.
6	not familiar with NZ & Aus
7	Fire life and safety (road/rail tunnels)

10. Would you like to make any further comments regarding tunnel costs that would be relevant to this research?

Respondent #	Response
1	Integration of best practises and technologies accross various tunneling clients. i.e Understanding what mining technologies are avaialble when designing a water tunnel are important to best cost outcome.

	2	Aust is costing it's self out of future developemy, On costs are some 56% of actual cost BEFORE any margin is applied to contract risk or contractor return on funds and effort invested
	3	The design life of many tunnels is often 100 years in ANZ - is this the case elsewhere and does this affect the quality/price of the design?
	4	A very common reason for high cost is lack of clarity in project requirements by uninformed clients or consultants
	5	This is a good initiative as it would be good to know why tunnel costs are higher (or seem higher) in NZ and if so how much. Please ensure that NZ and Australia are separately reported. I look forward to the results. Thanks
	6	In my view the ongoing increase in safety standards for each new tunnel is signifiantly adding to the costs. There needs to be a more rigourous evaluation of what is essential and what represents value for money
	7	None
	8	There is a lot of wastage in tunnel construction, a lot of waste money in consultancies overseeing each other.
	9	good geological and geotechncial studied are key to efficiently designing the tunnel linning and choosing the most effective means of construction.
	10	no
	11	In terms of rail tunnels there is a significant relationship between the configuration of the tunnels connecting the underground stations and the underground rail stations themselves. The cost of underground rail stations is generally a very significant component of the overall cost of any underground rail scheme (I am assuming that your definition of "Tunnels" only refers to the main "running" tunnels between stations and not the stations, so all my responses are made on that basis.
	12	In Australia tunnelling projects are relatively few and far between, so when major projects appear there has traditionally been less competition in the market place, hence the resulting higher project costs. This situation is changing with the GFC and we are seing international Contractors coming to Australia with more aggressive offers.

	13	The main costs of construction are mainly with the construction of the civil works. The main cost of the operation and maintenance relates to the M&E systems in particular the Fire Life Safety systems and the ITS systems.
	14	Not at present

7.8 Appendix G: Conversion Factors

7.8.1 Exchange Rates for 3rd Quarter 2011

Table 6 Exchange Rates for 3rd Quarter 2011

	Per United States Dollar	United States Dollar per...
AUD	0.95075	1.051801
EUR	0.7066	1.415228
GBP	0.62056	1.611448
HKD	7.79294	0.128321
ILS	3.53892	0.282572
NZD	1.14978	0.869732
SGD	1.22342	0.817381
TWD	28.95654	0.034535
VND	20537.55	4.87E-05
ZAR	7.09617	0.140921
AED	3.67233	0.272307
IEP	0.7066	1.415228
JPY	77.77383	0.012858
DFL	1.78	0.561798
NOK	5.48637	0.18227
CHF	0.82307	1.214963
INR	45.79869	0.021835
MYR	3.01018	0.332206
DKK	5.26488	0.189938
KRW	1079.5	0.000926
FRF	0.7066	1.415228

7.8.2 Construction Price Indices and Inflation Rates

Table 7 Construction price Indices

	European Union (27 countries)	European Union (15 countries)	Germany	Ireland	Spain	France	Italy	Netherlands	Sweden	United Kingdom	Norway	Australia	United States	New Zealand	Israel	China	Japan	Switzerland
Q4 2011	:	:	:	:	:	:	:	115.50(p)	:	:	130.3	159.6	99.1	:	252.9	1476	:	
Q3 2011	119.69	119.53	115.6	91.1	126.96	124.88	:(cp)	115.47	125.9	:	129.13	159.4	98.8	1614	251.3	1452		132.6
Q2 2011	119	118.85	115.5	90.8	126.78	124.37	:(cp)	115.07(p)	125.4	118.6	128.64	159.5	98.4	1601	248.6	1425	:	:
Q1 2011	118.32	118.16	114.4	91.8	125.63	123.65	:(cp)	114.57(p)	124.1	116.10(p)	127.23	156.8	98.5	1558	240.7	1385	:	131.2
Q4 2010	116.59	116.43	112.6	93.9	122.74	120.99	:(cp)	113.50(p)	123	115.70(p)	125.86	157.2	98.8	1539	234.3	1367	:	:
Q3 2010	116.27	116.11	111.7	94	122.26(p)	120.42	:(c)	113.20(p)	122.6	115.80(p)	124.63	156.0	97.5	1533	232.8	1342	:	128.5
Q2 2010	116.2	116.06	111.7	93.4	122.38	119.99	:(c)	113.07(p)	122.4	116.00(p)	124.17	153.9	97.4	1521	232.3	1315	:	:
Q1 2010	114.66	114.47	110.4	91.9	119.42	117.9	:(c)	112.27(p)	120.7	115.4	122.56	153.7	98.0	1519	231.2	1297	:	128.5
Q4 2009	114.08	113.87	109.3	91.2	118.79	117	:(c)	111.4	120	115	121.67	153.0	99.5	1515	226.4	1273	:	:
Q3 2009	114.02	113.82	108.9	91	118.72	116.68	111.47	112.2	119.2	115	120.69	152.9	98.3	1494	224.0	1253	:	127.3
Q2 2009	114.06	113.87	109.3	91.9	118.56	116.42(e)	111.63	112.57	119	115.2	119.77	154.2	98.4	1486	216.8	1242	:	:
Q1 2009	114.82	114.63	109.8	97.2	118.67	116.51(e)	111.93	113.26	118.4	116.9	119.67	157.3	101.8	1472	208.6	1245	101.3	126.6
Q4 2008	114.71	114.49	109.8	100	117.92	116.51(e)	111.37	112.43	117.8	116.7	119.46	161.3	102.6	1449	211.2	1281	:	:
Q3 2008	115.59	115.37	110.6	101	120.46	118.43(e)	112.6	113.47	118.7	115.7	118.16	163.3	102.6	1436	230.8	1355	:	131.7
Q2 2008	113.76	113.54	108.6	103	118.21	116.25(e)	110.32	111.87	116.8	113.8	117.2	159.8	104.0	1405	222.4	1360	:	:
Q1 2008	111.46	111.25	107.4	107	113.25	113.69(e)	108	110.1	114.1	112.2	116.07	156.6	105.2	1384	208.9	1239	110.2	129.1
Q4 2007	110.08	109.91	106.3	109	113.59	111.34(e)	106.83	107.77	113	109.9	114.29	153.5	106.4	1374	207.2	1150	:	:
Q3 2007	109.54	109.39	106.5	111	112.31	110.76(e)	106.8	107.87	112.6	108.8	112	151.6	107.2	1358	197.0	1175	:	127.6
Q2 2007	109.07	108.97	106	113	112.55	109.99(e)	106.7	107.3	111.1	107.9	110.97	149.3	106.5	1340	191.8	1074	:	:

Q1 2007	107.7	107.64	104.3	114	110.29	108.47(e)	105.8	106.47	109	107	108.3	146.7	108.2	1335	186.1	1020	100.2	125.3
Q4 2006	106.02	105.95	104.1	113	108.34	106.81(e)	103.47	104.47	107.2	105.4	106.33	145.2	107.8	1330	183.2	990	:	:
Q3 2006	105.38	105.36	102.7	112	108.09	106.35(e)	103.23	103.9	106	104.7	103.8	143.4	107.0	1310	187.2	985	:	123.3
Q2 2006	104.38	104.4	101.6	109	106.71	104.84(e)	102.87	102.53	104.5	104.5	102.93	141.0	106.1	1300	186.5	980	:	:
Q1 2006	103.1	103.13	101.3	105	104.23	103.33(e)	101.55	101.83	102.4	104.5	101.93	138.8	105.7	1283	184.4	970	98.2	119.8
Q4 2005	101.2	101.19	100	104	100.71	101.30(e)	100.5	100.5	100.9	102.3	101.13	137.1	104.1	1273	178.9	970	:	:
Q3 2005	100.43	100.43	100.2	100	100	99.98 (e)	100.47	100.13	100.5	101.2	100.17	135.9	101.3	1248	179.6	963	:	118.7
Q2 2005	99.57	99.56	99.7	98.6	99.75	99.30 (e)	99.9	99.73	99.8	99.3	99.7	134.8	99.3	1229	169.6	955	:	:
Q1 2005	98.8	98.81	100.1	97	99.54	99.42	99.08	99.6	98.7	97.3	99.03	133.1	96.9	1210	165.6	945	97.8	115.8
Q4 2004	97.47	97.46	97.9	95.9	97.22	99.07 (e)	97.57	99.13	97.5	95.9	97.84	130.3	96.3	1191	164.4	930	:	:
Q3 2004	96.9	96.92	99	93.8	96.68	98.56 (e)	97.03	99.13	97	94.9	97.2	127.1	94.4	1181	161.1	933	:	116.3
Q2 2004	95.92	95.97	99	90.6	95.63	97.98 (e)	95.84	98.73	96.1	93.7	96.4	124.7	92.8	1165	160.6	952	:	:
Q1 2004	94.02	94.08	96.8	87.9	92.7	95.28 (e)	94.2	97.6	94.3	92.7	95.4	121.2	90.3	1144	155.9	940	97.7	113.4
Q4 2003	92.83	92.91	95.7	85.3	91.49	93.08 (e)	92.57	98.03	93.5	92	94.4	116.7	88.5	1133	152.6	895	:	:
Q3 2003	92.45	92.56	95.7	82.9	91.59	92.49 (e)	92.4	98.2	93	91.3	93.96	115.2	86.8	1122	153.3	895	:	111.2
Q2 2003	91.98	92.09	96.6	80.4	91.12	92.20 (e)	92.2	97.9	92.3	90.2	93.7	112.8	85.4	1121	149.1	878	:	:
Q1 2003	91.19	91.32	95.9	77.8	90.89	91.55	91.93	97.83	91.7	88.6	93.5	109.8	85.1	1116	153.2	855	95.8	110.2
Q4 2002	90.21 (s)	90.32	95.1	77	89.96	90.26 (e)	90.1	97	90.4	88	92.17	108.1	83.2	1110	145.1	840	:	:
Q3 2002	89.74 (s)	89.85	95.2	74.5	89.62	89.96 (e)	89.9	97.03	90.2	87	91.53	107.6	82.3	1111	143.1	875	:	110.7
Q2 2002	89.45 (s)	89.57	95	73.5	89.09	89.06 (e)	89.37	96.43	89.4	87.6	90.77	106.5	82.2	1113	141.9	890	:	:
Q1 2002	87.80 (s)	87.9	94.8	71.6	88.74	88.21 (e)	89.1	96.04	88.2	82.4	90.14	105.5	81.7	1109	133.4	915	97.3	112.0
Q4 2001	86.79 (s)	86.87	94.4	72.5	87.76	87.22 (e)	86.73	94.6	87.4	81.8	89.17	104.4	81.8	1105	130.4	935	:	:
Q3 2001	86.25 (s)	86.34	94.5	72.1	88.2	87.00 (e)	86.47	94.4	87.4	79.6	88.43	104.0	81.6	1094	132.7	945	:	114.2
Q2 2001	85.73 (s)	85.82	94.4	70.8	88.05	86.52 (e)	85.93	93.8	86.2	78.7	87.83	103.2	80.2	1075	131.3	960	:	:
Q1 2001	84.65 (s)	84.75	93.3	69.5	87.65	85.58	85.73	92.3	85.1	76.4	87.4	104.0	78.6	1065	130.3	990	98.7	115.5
Q4	83.42	83.51	94.2	65	86.38	84.97	85.1	91.2	83.9	73.7	85.7	104.3	77.7	1060	131.7	1020	:	:

2000	(s)					(e)												
Q3 2000	82.65 (s)	82.75	93.9	62.4	85.88	84.58 (e)	84.6	90.7	83.4	72.3	84.49	104.2	77.1	1039	130.4	1040	:	111.5
Q2 2000	82.36 (s)	82.49	93.8	59.9	85.36	84.09 (e)	84	89.33	82.7	73.2	83.47	104.3	76.7	1027	128.4	1057	:	:
Q1 2000	81.27 (s)	81.42	92.2	56.6	84.73	83.43 (e)	83.63	88.73	81.5	71.4	82.93	103.7	76.0	1013	126.3	1079	100.0	108.1
Q4 1999	80.20 (s)	80.33 (s)	:	:	82.73	82.21 (e)	82.51 (ei)	85.72 (eip)	80.5	71.1	81.85(ei)	103.1	74.6	1008	125.8	:	:	:
Q3 1999	79.68 (s)	79.81 (s)	:	:	82.36 (ei)	81.82 (e)	82.12 (ei)	85.24 (eip)	80	70.3	81.03(ei)	102.1	73.7	1000	124.3	:	:	105.8
Q2 1999	78.76 (s)	78.89 (s)	:	:	81.67 (ei)	81.10 (e)	81.78 (ei)	84.35 (eip)	79.6	68.6	80.76(ei)	101.3	73.3	987.762238	120.7	:	:	:
Q1 1999	77.84 (s)	77.97 (s)	:	:	81.27	80.27 (e)	81.18 (ei)	83.82 (eip)	78.9	66.9	80.47(ei)	100.4	72.3	990.384615	118.9	:	102.0	102.0
Q4 1998	76.90 (s)	77.02 (s)	:	:	80.52 (ei)	79.86 (e)	81.13 (ei)	83.45 (eip)	78.6	64.7	80.11(ei)	99.6	71.6	990.384615	119.4	:	:	:
Q3 1998	76.36 (s)	76.47 (s)	:	:	80.81 (ei)	80.11 (e)	80.81 (ei)	83.69 (eip)	78.2	62.7	79.19(ei)	98.7	70.4	991.258741	115.9	:	:	100.0
Q2 1998	76.07 (s)	76.19 (s)	:	:	80.88 (ei)	80.44 (e)	80.29 (ei)	83.48 (eip)	77.7	62.1	78.91(ei)	98.0	70.0	981.643357	114.3	:	:	:
Q1 1998	75.76 (s)	75.88 (s)	:	:	80.78 (ei)	80.35	79.96 (ei)	83.16 (eip)	76.8	61.7	77.59(ei)	97.0	69.2	973.776224	112.6	:	104.1	98.1
Q4 1997	75.37 (s)	75.49 (s)	:	:	79.78 (ei)	79.94 (e)	82.46 (ei)	81.81 (eip)	76.4	60.2	77.20(ei)	95.9	69.3	972.027972	114.2	:	:	:
Q3 1997	74.92 (s)	75.05 (s)	:	:	79.44 (ei)	79.63 (e)	82.22 (ei)	81.71 (eip)	75.9	59.4	76.94(ei)	95.2	69.0	966.783217	113.9	:	:	95.7
Q2 1997	74.17 (s)	74.29 (s)	:	:	79.18 (ei)	79.00 (e)	81.05 (ei)	81.18 (eip)	75.4	58.4	76.69(ei)	94.1	68.1	964.160839	110.2	:	:	:
Q1 1997	73.56 (s)	73.69 (s)	:	:	79.09 (ei)	78.42	80.87 (ei)	80.84 (eip)	75	57.1	75.93(ei)	93.3	67.6	970.27972	108.0	:	107.4	93.6
Q4 1996	73.15 (s)	73.28 (s)	:	:	77.91 (ei)	78.25 (e)	80.68 (ei)	80.10 (eip)	74.4	57.2	75.48(ei)	92.0	67.3	974.65035	:	:	:	:
Q3 1996	72.61 (s)	72.74 (s)	:	:	77.75 (ei)	77.83 (e)	80.24 (ei)	79.99 (eip)	74.2	56.1	75.31(ei)	91.6	66.8	978.146853	:	:	:	91.1
Q2 1996	72.01 (s)	72.15 (s)	:	:	77.79 (ei)	77.56 (e)	78.93 (ei)	79.75 (eip)	73.7	55.2	75.26(ei)	:	66.2	982.517482	:	:	:	:
Q1 1996	71.51 (s)	71.66 (s)	:	:	77.75 (ei)	77.34 (e)	78.75 (ei)	79.65 (eip)	73.2	54	74.76(ei)	:	65.7	975.524476	:	:	107.8	89.8
Q4 1995	71.02 (s)	71.18 (s)	:	:	75.93 (ei)	77.01 (e)	78.73 (ei)	79.46 (eip)	72.3	54	74.59(ei)	:	65.6	971.153846	:	:	:	**:**
Q3 1995	70.97 (s)	71.13 (s)	:	:	76.01 (ei)	77.03 (e)	78.69 (ei)	79.57 (eip)	71.8	53.9	74.64(ei)	:	65.6	952.797203	:	:	:	**:**
Q2 1995	70.79 (s)	70.96 (s)	:	:	75.78 (ei)	77.03 (e)	78.35 (ei)	79.15 (eip)	71	54	74.64(ei)	:	65.2	951.048951	:	:	:	**:**
Q1 1995	70.27 (s)	70.44 (s)	:	:	75.00 (ei)	76.73 (e)	77.36 (ei)	78.67 (eip)	70.4	53.9	73.66(ei)	:	64.8	949.300699	:	:	109.7	**:**
Q4 1994	69.49 (s)	69.66 (s)	:	:	72.74 (ei)	75.51 (e)	76.81 (ei)	77.05 (eip)	68.6	54.6	72.74(ei)	:	64.4	953.671329	:	:	:	**:**
Q3 1994	69.23 (s)	69.40 (s)	:	:	72.26 (ei)	74.76 (e)	77.02 (ei)	76.82 (eip)	68	54.5	71.89(ei)	:	63.1	947.552448	:	:	:	**:**

Q2 1994	68.82 (s)	68.98 (s)	:	:	72.04 (ei)	74.49 (e)	76.83 (ei)	76.82 (eip)	67.3	53.7	70.27(ei)	:	62.1	945.804196	:	:	:	:
Q1 1994	68.05 (s)	68.21 (s)	:	:	71.64	73.88 (e)	76.44 (ei)	76.58 (eip)	66.5	52.3	68.95(ei)	:	61.5	936.188811	:	:	114.0	:
Q4 1993	66.89 (s)	67.05 (s)	:	:	70.41 (ei)	72.91 (e)	74.50 (ei)	75.41 (eip)	66.5	51.5	68.75(ei)	:	61.1	928.321678	:	:	:	:
Q3 1993	66.36 (s)	66.52 (s)	:	:	70.17 (ei)	72.74 (e)	74.33 (ei)	75.41 (eip)	65.9	50.2	68.61(ei)	:	60.3	921.328671	:	:	:	:
Q2 1993	66.07 (s)	66.23 (s)	:	:	69.61 (ei)	72.44 (e)	74.11 (ei)	75.18 (eip)	66	50.1	68.58(ei)	:	59.7	920.454546	:	:	:	:
Q1 1993	65.21 (s)	65.37 (s)	:	:	69.26 (ei)	71.58 (e)	73.65 (ei)	74.26 (eip)	65.8	48.7	68.30(ei)	:	59.0	925.699301	:	:	120.8	:
Q4 1992	62.38 (s)	62.52 (s)	:	:	67.57 (ei)	:	72.61 (ei)	74.02 (eip)	66.1	43.09 (ei)	68.47(ei)	:	58.3	920.454546	:	:	:	:
Q3 1992	62.53 (s)	62.67 (s)	:	:	67.68 (ei)	:	72.31 (ei)	74.72 (eip)	66	43.53 (ei)	68.33(ei)	:	57.2	918.706294	:	:	:	:
Q2 1992	61.63 (s)	61.77 (s)	:	:	67.59 (ei)	:	72.15 (ei)	:	65.6	44.04 (ei)	68.22(ei)	:	56.7	914.335664	:	:	:	:
Q1 1992	61.43 (s)	61.57 (s)	:	:	67.07 (ei)	:	71.64 (ei)	:	65.3	44.44 (ei)	68.22(ei)	:	56.5	916.083916	:	:	126.0	:
Q4 1991	60.78 (s)	60.92 (s)	:	:	64.86 (ei)	:	70.87 (ei)	:	65.4	44.96 (ei)	68.19(ei)	:	56.1	909.090909	:	:	:	:
Q3 1991	60.75 (s)	60.89 (s)	:	:	65.00 (ei)	:	70.28 (ei)	:	65.3	45.26 (ei)	68.13(ei)	:	56.3	908.216783	:	:	:	:
Q2 1991	60.13 (s)	60.27 (s)	:	:	64.84 (ei)	:	67.82 (ei)	:	65.4	45.56 (ei)	67.94(ei)	:	55.8	910.839161	:	:	:	:
Q1 1991	59.55 (s)	59.69 (s)	:	:	64.45 (ei)	:	65.96 (ei)	:	65	45.82 (ei)	66.90(ei)	:	55.4	904.72028	:	:	125.1	:
Q4 1990	58.72 (s)	58.86 (s)	:	:	62.53 (ei)	:	65.21 (ei)	:	62.8	45.93 (ei)	66.17(ei)	:	55.7	905.594406	:	:	:	:
Q3 1990	58.27 (s)	58.41 (s)	:	:	62.27 (ei)	:	64.20 (ei)	:	62	45.83 (ei)	65.92(ei)	:	55.7	898.601399	:	:	:	:
Q2 1990	57.59 (s)	57.72 (s)	:	:	62.16 (ei)	:	63.02 (ei)	:	61	45.22 (ei)	65.78(ei)	:	55.4	891.608392	:	:	:	:
Q1 1990	56.72 (s)	56.85 (s)	:	:	61.55 (ei)	:	61.74 (ei)	:	60.2	44.61 (ei)	64.79(ei)	:	55.1	872.377622	:	:	115.0	:
1988	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	102.3	:
Data Source:	Euro Stat	Euro Stat	Euro Stat	Euro Stat	Euro Stat	Euro Stat	Euro Stat	Euro Stat	Euro Stat	Euro Stat	Euro Stat	Australian Bureau of Statistics	U.S. Census Bureau	Statistics New Zealand	Israel Central Bureau of Statistics	Davis Langdon & Seah	Japanese Statistics Bureau	Swiss Federal Office of Statistics

Table 8 Inflation Factors

Country Name	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990
Australia	100.00%	104.94%	104.39%	105.09%	104.87%	104.09%	103.26%	102.70%	103.15%	104.71%	102.56%	100.11%	101.28%	101.17%	102.18%	101.73%	101.21%	100.94%	101.17%	103.15%	107.10%
Canada	102.94%	98.07%	104.11%	103.19%	102.67%	103.31%	103.19%	103.28%	101.09%	101.12%	104.13%	101.75%	99.57%	101.20%	101.62%	102.26%	101.15%	101.44%	101.32%	102.95%	103.18%
Chile	114.37%	102.87%	100.24%	105.45%	112.42%	107.55%	107.48%	106.23%	104.17%	103.79%	104.56%	102.43%	101.93%	104.27%	102.73%	110.42%	113.73%	111.75%	112.89%	122.44%	122.46%
China	106.60%	99.41%	107.80%	107.60%	103.79%	103.93%	106.91%	102.61%	100.58%	102.05%	102.06%	98.75%	99.14%	101.51%	106.44%	113.74%	120.61%	115.12%	108.24%	106.85%	105.84%
Denmark	103.42%	100.36%	103.85%	102.28%	102.12%	102.88%	102.33%	101.65%	102.30%	102.50%	103.00%	101.68%	101.19%	101.99%	102.01%	101.26%	101.53%	100.67%	101.68%	102.68%	102.83%
France	100.81%	100.47%	102.54%	102.59%	102.14%	101.91%	101.67%	102.00%	102.22%	102.01%	101.57%	100.18%	101.03%	100.91%	101.46%	101.24%	101.13%	101.75%	101.93%	102.65%	102.76%
Germany	100.60%	101.17%	100.77%	101.63%	100.31%	100.62%	101.07%	101.10%	101.43%	101.13%	99.33%	100.19%	100.59%	100.26%	100.64%	102.01%	102.49%	103.98%	105.40%	103.09%	103.40%
Greece	101.71%	102.79%	104.72%	103.54%	102.52%	102.81%	102.95%	103.92%	103.40%	103.12%	103.40%	103.03%	105.20%	106.78%	107.34%	109.79%	111.18%	114.43%	114.80%	119.79%	120.69%
Hong Kong	100.49%	99.38%	101.46%	102.93%	99.71%	99.94%	96.46%	93.85%	96.54%	98.11%	96.36%	95.54%	100.78%	105.68%	105.76%	104.13%	106.47%	108.70%	109.93%	109.05%	107.50%
India	110.50%	107.54%	106.69%	105.75%	106.41%	104.18%	108.70%	103.56%	103.80%	103.03%	103.53%	103.80%	107.98%	106.46%	107.55%	109.08%	110.00%	109.81%	108.97%	113.73%	110.68%
Ireland	100.37%	95.97%	98.54%	101.10%	103.74%	102.52%	101.98%	102.78%	104.53%	105.52%	105.77%	103.86%	106.61%	103.86%	102.16%	103.03%	101.69%	105.18%	102.81%	101.80%	99.27%
Israel	101.06%	105.15%	101.38%	100.24%	102.04%	100.84%	99.99%	99.63%	104.15%	101.79%	101.56%	106.32%	107.11%	108.07%	110.06%	120.61%	112.70%	109.28%	113.54%	118.32%	115.90%
Italy	100.61%	102.27%	102.76%	102.57%	101.84%	102.06%	102.63%	103.12%	103.26%	102.96%	101.91%	101.78%	102.62%	102.56%	104.81%	104.97%	103.55%	103.91%	104.40%	107.54%	108.39%
Japan	97.84%	99.63%	98.99%	99.26%	99.10%	98.77%	98.92%	98.40%	98.45%	98.77%	98.27%	98.70%	99.97%	100.53%	99.37%	99.50%	100.12%	100.44%	101.59%	102.61%	102.63%
South Korea	103.73%	103.43%	102.91%	102.08%	99.86%	100.65%	103.03%	103.56%	103.23%	103.86%	105.01%	99.90%	105.82%	104.62%	105.12%	107.39%	107.84%	106.35%	107.62%	110.66%	110.52%
Laos	109.45%	97.65%	108.97%	107.28%	112.78%	101.90%	110.38%	115.73%	110.65%	108.60%	125.10%	227.97%	184.50%	119.35%	113.73%	119.69%	107.70%	111.18%	105.99%	112.97%	137.91%
Malaysia	105.09%	93.10%	110.34%	104.97%	103.88%	104.63%	106.01%	103.30%	103.13%	98.42%	108.86%	100.05%	108.50%	103.48%	103.68%	103.63%	103.94%	103.99%	102.41%	103.58%	103.81%
Mexico	104.37%	103.96%	106.33%	105.63%	106.69%	104.54%	109.07%	118.95%	106.96%	105.88%	112.10%	115.09%	115.39%	117.69%	130.74%	137.87%	108.47%	109.49%	114.41%	123.25%	128.13%
Netherlands	101.31%	99.60%	102.13%	101.85%	101.77%	102.43%	100.73%	102.18%	103.83%	105.10%	104.12%	101.78%	101.91%	102.64%	101.30%	102.06%	102.06%	101.60%	102.50%	103.12%	101.56%
New Zealand	100.00%	101.69%	103.40%	104.94%	104.24%	102.24%	103.17%	102.48%	100.22%	103.78%	102.99%	100.80%	101.40%	101.95%	101.35%	101.96%	101.87%	101.65%	101.96%	101.11%	102.46%
Norway	106.72%	94.45%	109.74%	102.39%	108.52%	108.65%	105.29%	102.97%	98.23%	101.73%	115.65%	106.62%	99.23%	102.80%	104.18%	103.04%	99.79%	102.29%	99.28%	102.18%	103.82%
Puerto Rico	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	105.35%	103.06%	101.47%	106.36%	101.33%	103.91%	102.77%	103.18%	101.89%	102.58%	103.12%	104.32%
Qatar	100.00%	81.74%	109.26%	105.31%	118.52%	126.28%	111.38%	117.44%	103.06%	95.57%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Singapore	99.48%	100.29%	98.79%	106.40%	101.76%	102.06%	104.31%	98.47%	99.09%	97.84%	103.61%	95.20%	98.58%	101.20%	100.95%	102.83%	103.53%	103.45%	101.41%	104.14%	104.38%
South Africa	108.06%	107.16%	108.90%	108.06%	106.53%	105.44%	106.37%	105.55%	110.75%	107.67%	108.81%	107.07%	107.71%	108.11%	108.09%	110.25%	109.59%	113.09%	114.57%	115.73%	115.52%
Spain	100.97%	100.60%	102.40%	103.34%	104.12%	104.29%	104.02%	104.14%	104.31%	104.20%	103.45%	102.63%	102.48%	102.38%	103.46%	104.93%	103.88%	104.54%	106.71%	106.94%	107.33%
Sri Lanka	107.27%	105.88%	116.33%	114.03%	111.28%	110.42%	108.80%	105.15%	111.81%	113.66%	107.28%	104.16%	109.21%	108.92%	110.82%	109.30%	109.77%	109.88%	109.40%	110.62%	120.06%
Sweden	101.22%	101.82%	103.14%	102.76%	101.94%	100.89%	100.31%	101.77%	101.53%	102.37%	101.42%	100.90%	100.53%	101.52%	100.82%	103.72%	102.63%	103.24%	100.98%	108.98%	108.72%
Switzerland	100.07%	100.16%	102.44%	102.49%	102.06%	100.11%	100.57%	101.00%	100.47%	100.80%	101.13%	100.61%	100.29%	99.87%	100.19%	100.73%	101.27%	102.38%	102.02%	105.43%	104.60%
United Kingdom	102.94%	101.45%	102.97%	102.99%	103.05%	102.03%	102.52%	103.07%	103.10%	102.12%	101.19%	102.10%	102.22%	102.79%	103.62%	102.68%	101.58%	102.88%	103.76%	106.46%	107.73%
United States	100.81%	101.82%	102.18%	102.94%	103.25%	103.34%	102.83%	102.16%	101.62%	102.27%	102.16%	101.47%	101.32%	101.93%	101.77%	102.33%	102.04%	102.19%	102.11%	103.40%	103.79%
Venezuela, RB	146.68%	108.29%	130.46%	113.53%	117.90%	129.60%	133.95%	134.93%	133.02%	108.00%	129.45%	126.19%	118.89%	138.42%	215.52%	151.76%	162.89%	131.65%	128.24%	121.45%	141.74%
Vietnam	111.86%	106.03%	122.14%	108.24%	107.27%	108.19%	108.18%	106.69%	103.94%	101.95%	103.41%	105.73%	108.84%	106.60%	108.70%	117.04%	116.95%	117.41%	132.63%	172.55%	142.10%

7.9 Appendix H: Countries in Tunnel Costs Database

Table 9 Countries in Tunnel Costs Database by Region

ANZ	Europe	The Americas	Asia
Australia	Denmark	Canada	China
New Zealand	France	Chile	India
	Germany	Ecuador	Israel
	Greece	Mexico	Japan
	Ireland	Puerto Rico	Laos
	Italy	United States of America	Malaysia
	Netherlands	Venezuela	Qatar
	Norway		Singapore
	Spain		South Africa
	Sweden		South Korea
	Switzerland		Sri Lanka
	United Kingdom		Taiwan
			United Arab Emirates
			Vietnam

7.10 Appendix I: Supplementary Data

Data is available from AECOM.

7.10.1 Comparison with British Tunnelling Society Data

Figure 27: Comparison between Cost/m and Tunnel OD

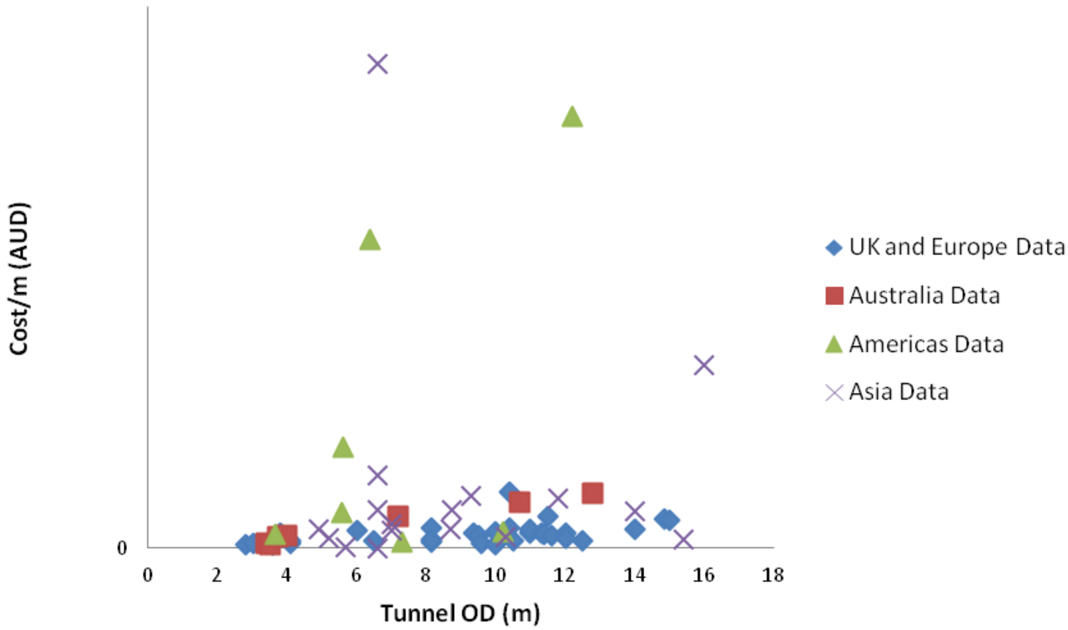


Figure 28: Comparison between Cost/m and Length

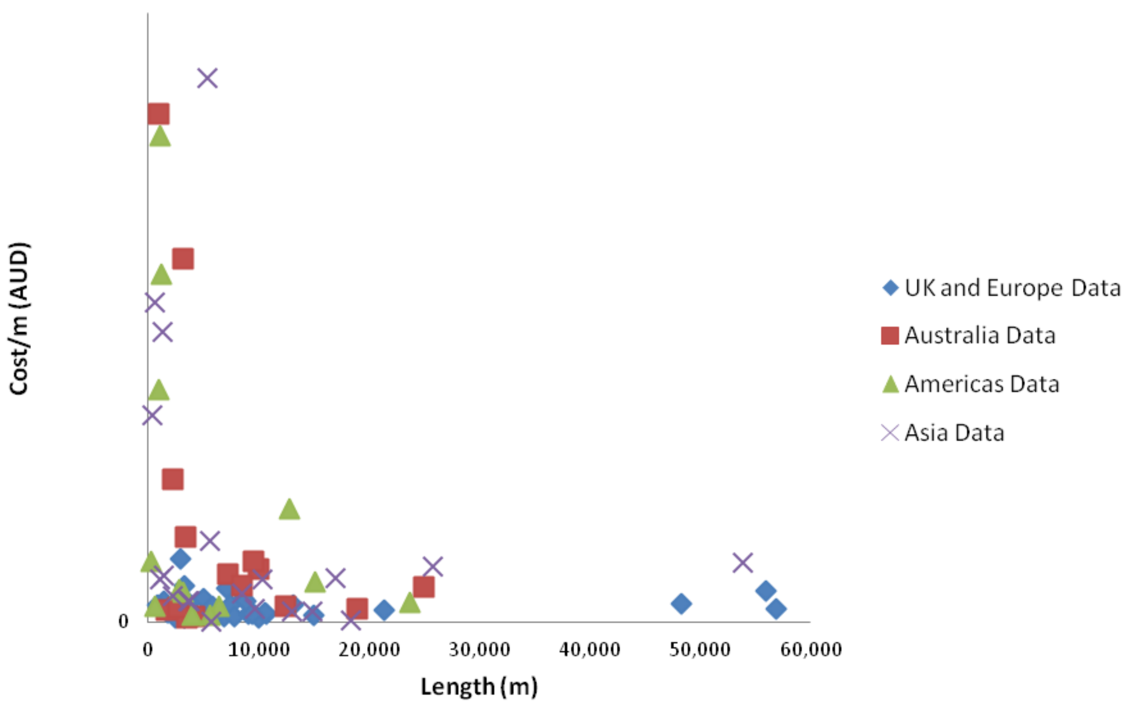
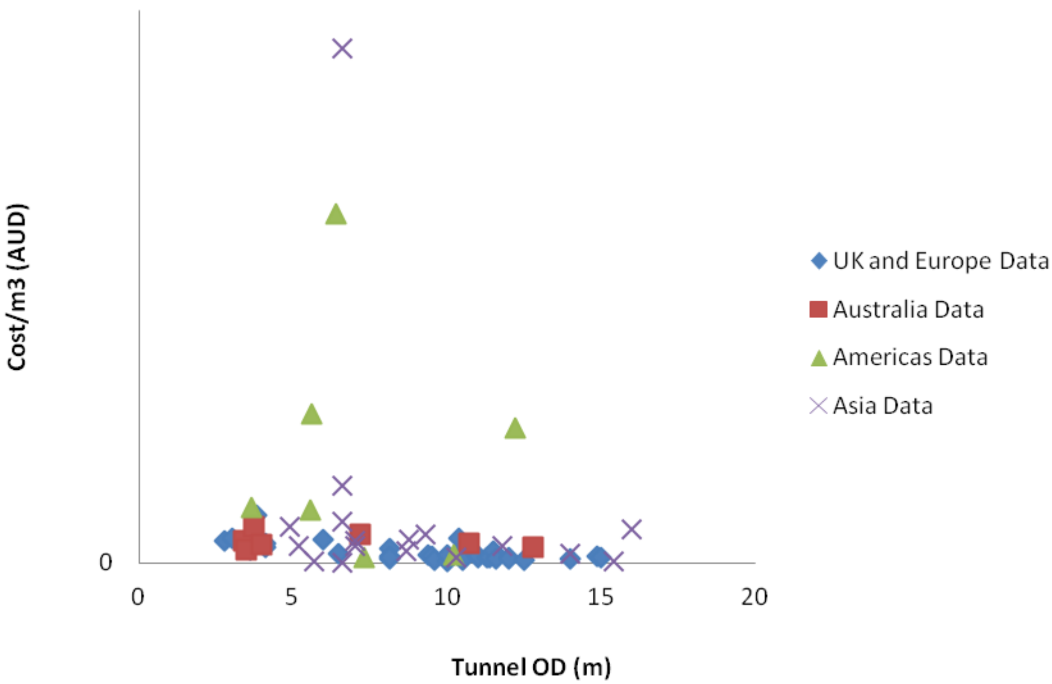


Figure 29: Comparison between Cost/m^3 and Tunnel OD



7.11 Appendix J: Monthly Labour Rates by Country

Table 10 Average Wages by Country and Profession

	Wages by Profession (2005 AUD)	
Country	Profession	Wage AUD
USA	Construction	3398.735
U.K.	Construction	3601.291
AUS	Construction	3238.269
Italy	Construction	2125.525
N.Z.	Construction	2278.1
Taiwan	Construction	1419.209
Mexico	Construction	449.8326
China	Construction	160.4666
USA	Engineer	6195.063
U.K.	Engineer	5557.143
AUS	Engineer	4356.274
Italy	Engineer	3311.925
N.Z.	Engineer	0
Taiwan	Engineer	2866.039
Mexico	Engineer	1421.839
China	Engineer	331.4556
USA	Mining	3543.418
U.K.	Mining	3819.631
AUS	Mining	5052.067
Italy	Mining	1627.026
N.Z.	Mining	N/A
Taiwan	Mining	1203.5
Mexico	Mining	484.0304
China	Mining	190.7185

Table 11 Average Wages by Country

	Average Wages (2005 AUD)	
Country	Profession	Wage AUD
USA	Average	4379.072
U.K.	Average	4326.022
AUS	Average	4215.537
Italy	Average	2354.825
N.Z.	Average	2278.1
Taiwan	Average	1829.582
Mexico	Average	785.2341
China	Average	227.5469