The End of Megaproject Certainty: Post COVID-19 National Infrastructure Management

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Abstract. Uncertainty and its profound impact on the management of infrastructure project portfolios is introduced. The advent of COVID-19 is depicted as a defining event in the management of infrastructure. This study applies the Black Scholes option valuation model and real options analysis to determine value for money in front-end engineering for Australian megaprojects. The findings indicate that despite the fact all current Australian infrastructure projects examined had a positive net present value and a benefit to cost ratio greater than one, almost sixty percent of the planned expenditure was for projects for which real options analysis indicated the engineering as being poor value for money. The paper concludes with recommendations to manage the national portfolio of infrastructure projects as a pipeline of carefully chosen pre-engineered options, some of which are constructible projects and others being non-asset, demand management solutions.

Keywords: Black Scholes model · Decisions under uncertainty · Megaproject management · Project Portfolio management · Real options analysis · Real options theory

1 Introduction

More than two thousand years ago, Heraclitus postulated that change is the only constant. Think back to your childhood. For many of us, the only ways to communicate over distance were telegram, landline telephone or written letter. How different is communication now? The evidence for change is strong yet its likelihood is often neglected as a factor in major infrastructure decisions. Whilst change in demand for various services is a given, the degree and nature of that change is uncertain. Should the level of uncertainty in demand for services be a significant, or even the dominant factor, in relation to our design of infrastructure solutions? If so, how should decisions regarding major infrastructure to deliver services take uncertainty into account?

Over the last decade, the Queensland government made several attempts at defining a solution to public transport bottlenecks in the Brisbane rail network. Construction of the Cross-River Rail (CRR) project eventually started in September 2019 at an estimated cost of AUD 5.4 billion. Billed as a key to unlocking the public transport gridlock for Brisbane commuters, the project now appears misplaced against the backdrop of COVID-19. Many
Brisbane commuters, in consultation with their employers, have chosen to work from home. Some employers are seeing measurable improvements in workforce productivity of those working from home and the opportunity to reduce the cost of office rent. The result is a significant decline in the demand for public transport services in Brisbane. Nevertheless, the CRR construction is underway and scheduled for completion in 2024. Would another option be more appropriate at this juncture? Should the CRR project be delayed or even abandoned?

Decisions to invest in large-scale infrastructure assets are always made with the expectation of future returns, be they pecuniary, social, environmental or a combination. These decisions are complex and difficult to get right because they typically involve a partially or fully irreversible commitment of substantial capital sums in the face of significant uncertainty. This uncertainty is mainly with respect to future returns on the investment which is tied closely to the demand for services emanating from that infrastructure. Demand can be heavily influenced by the evolution of customer needs, the impact of disruptive technologies and even government policy changes.

Given the relentlessness of uncertainty and the continuing need for services to be prudently delivered through infrastructure assets, the authors see the need for a new paradigm of research into megaproject portfolio management at national level. To this point in time, infrastructure megaproject research has been focused mainly on aspects of singular megaprojects, such as stakeholder management, risk management, sustainability, complexity management or governance [1]. This study represents an exception to that general pattern by analyzing the management of a portfolio of nationally significant infrastructure megaprojects within an environment of uncertainty.

The COVID-19 pandemic has been a watershed event. The last comparable global pandemic was the Spanish influenza over 100 years ago. Infrastructure management, indeed the nature of infrastructure itself has changed so much in the intervening years. The Brisbane CRR project is but one infrastructure project. The advent of COVID-19 has called into question the soundness of a number of proposed projects and the process for prioritizing new infrastructure projects itself. Should the processes for infrastructure management be reassessed in the light of our knowledge of the effects of COVID-19?

This manuscript is organized into sections in order to convey the logical development of a framework for infrastructure megaproject portfolio management under uncertainty and the demonstration of that framework via an indicative study of Australia’s infrastructure megaproject portfolio.

Section one introduces the concept of uncertainty as it impacts megaprojects via a recent example and poses some questions about the management of a portfolio of national megaprojects. The second section provides the background theory and literature in relation to this study by outlining the theory with respect to framing and valuing infrastructure project options in the face of uncertainty. Section three establishes the design of this study, essentially an indicative analysis of megaproject real options using the Black Scholes option valuation model. It also details the sources of data used to develop and analyze project options and the assumptions made in carrying out the analysis. The fourth section presents the results and highlights findings with respect to the real options analysis at the project portfolio level. Section five discusses the results and section six recommends areas of future research. Section seven is the conclusion.
2 Background to This Study

Uncertainty in relation to infrastructure projects is to be expected and so there is a commensurate need for creating flexibility of choice and agility with respect to implementing the right solution in the prevailing circumstances. The managerial flexibility to enact the most applicable service delivery solution via infrastructure assets in a changing environment has considerable value [2, 3]. This section explores the theoretical framework for the valuation of different forms of flexibility in the delivery of services via infrastructure assets.

2.1 Asset Management and the Delivery of Services via Infrastructure Assets

The relatively recent discipline of asset management provides an appropriate context for the delivery of services via infrastructure. Societal requirements for various services, such as power, water, transport, telecommunications or waste removal are provided via various forms of infrastructure assets. Hence, the ISO 55000 series of International Standards on Asset Management places the emphasis on the provision of value via infrastructure assets to an organization and its stakeholders. Therefore, the infrastructure assets are necessary but secondary to the provision of value to stakeholders.

2.2 Real Options Theory (ROT) and Its Application to Infrastructure Assets

In 1973 Fischer Black and Myron Scholes developed an elegant mathematical solution for the value of a financial option that became the basis for financial option pricing. A financial option is the right but not the obligation to buy or sell a financial asset at an agreed price and date. Financial option valuation is firmly established as the basis for the design of financial assets and their management plans, that have the flexibility to cope with market uncertainty. Such was the value of this contribution that Scholes and one of his colleagues, Robert Merton, were awarded the Nobel prize in economics in 1997. It is most likely that Black would have been a co-recipient had he not passed away in the intervening period.

Real options, as opposed to financial options, were first described by Professor Stewart Myers in 1976 who defined them as “opportunities to purchase real assets on possibly favorable terms” [4]. Since then, the development of Real Options Theory (ROT), fostered by numerous theoreticians and practitioners, has grown to the point where it is used to assist with decisions related to design options, configurations, construction timing, alternate uses and even retirement or abandonment of infrastructure assets.

Real options, can be used as the basis for decisions related to the design of real infrastructure assets or their management and are directly analogous to financial options. The analogous relationship, as interpreted by several well-cited authors, Luerhman [5], Smit and Trigeorgis [6], Leslie and Michaels [7], Martins et al. [8], is shown in Table 1.

The evaluation of real asset options using ROT requires an estimate of the six parameters in Table 1. Parameter 7, the real option time to expiry, is estimated from the time period for which contracts for the delivery of the asset remain valid. Technology life cycle [6, 7], contracts [6, 7] and competitive advantage [6] are mentioned as influencing factors for 7. Clearly, though, other forms of business risk should be considered. For
Table 1. Analogy between real and financial options.

| Symbol | Financial option variable | Real option variable Leslie and Michaels [7] | Real option variable Luerhman [5] | Real option variable Smit and Trigeorgis [6] | Real option variable Lint and Pennings cited in Martins et al. [8] |
|--------|----------------------------|---------------------------------------------|----------------------------------|---------------------------------------------|----------------------------------------------------------|
| $T$    | Time to expiry             | Time to expiry                              | Length of time the decision may be deferred | Length of deferral time                     | Time until the investment opportunity disappears          |
| $X$    | Exercise price             | Present value of fixed costs                | Expenditure required to acquire the project assets | Present value of investment outlays        | Costs of irreversible follow-on investment                |
| $\sigma$ | Uncertainty of stock price movements | Uncertainty of expected cash flows | Riskiness of the project assets | Volatility of project’s returns | Variability of growth in project value |
| $S$    | Stock price                | Present value of expected cash flows        | Present value of a projects operating assets to be acquired | Present value of expected cash flows        | Present value of expected cash flows                      |
| $r$    | Risk-free interest rate    | Risk-free interest rate                      | Time value of money               | Time value of money                        | Risk-free rate of return                                   |
| $\delta$ | Dividends                  | Value lost over duration of option          | –                                | –                                           | Value lost by waiting to invest                            |

For example, the fallout from COVID-19 has severely impacted the commercial viability of many Public Private Partnership infrastructure projects [8] resulting in an effective and premature expiry of option for those projects.

Parameter $X$ is the **cost estimate for the real underlying asset** in question. Parameter $r$, or **risk-free yield** is typically estimated using the yield of government bonds because they are considered as almost risk-free. There appears to be widespread agreement on the analogical representation of parameters $X$ and $r$.

Parameter $S$ is the **expected present value of cash flows** for the real underlying asset in question. The distinction between our definition and “present value of expected cash flows” [6–8] is that expected present value takes correlation between contributing cash flow streams into account. Further, we specifically advocate building in business risks to cash flow estimates such as the risk of pandemic and note a lack of attention to those issues by others.

Parameter $\sigma$, or the **volatility of expected cash flows** is, in many cases, estimated from the volatility of proxies such as relevant commodity or service prices and the
demand for those commodities or services. Again, \( \sigma \) is severely impacted by existential business risks such as pandemic risk as demonstrated in the movement of share market volatility associated with news of the COVID-19 pandemic. The estimation approach for \( \sigma \) is highly dependent on the project in question. We will discuss \( \sigma \) in detail as we estimate relevant parameters for the examples in this study in Sect. 3.2.

Parameter \( \delta \) or the **forgone rate of return** is equivalent to a dividend yield being paid on a share for which the option is yet to be converted. For real options, it must be estimated for each project on a case by case basis. We will examine this in detail for the projects under study in Sect. 3.2. Overall, we note agreement on this factor except that two \([5, 6]\) have omitted \( \delta \) as part of their analogy. In our opinion, ROT should consider \( \delta \) because a dividend-like return is present in many projects.

A complete discourse on ROT is unnecessary in this forum, however a review of its key principles is worthwhile. ROT is a branch of decision theory applied to investments in real assets under conditions of uncertainty. Techniques derived from ROT such as the family of real option valuation (ROV) techniques take into consideration the value of flexibility in the face of uncertainty, unlike net present valuation (NPV) and cost benefit analysis (CBA) methods calculated using discounted cash flow (DCF). Another downfall of NPV and CBA is that they are simply expected values. They fail to consider the probabilistic distribution of DCF into the future whereas ROV does. ROT is therefore considered superior to NPV and CBA.

ROVs can be classified as European, for which the option is exercised at the expiry date, or American, for which the option can be exercised at any time up to and including the expiry date. The Black Scholes option valuation model (BSOVM) for European options \([10]\), call option value \( C \) shown in Eq. (1) and put option value \( P \) in Eq. (2), can be used for both real and financial options. It has the advantages of being easy to calculate and precise but isn’t applicable in all instances (e.g. where value is lost over the duration of the option). \( N(d) \) is the cumulative normal distribution function.

\[
C = SN(d_1) - Xe^{-rT}N(d_2) \tag{1}
\]

\[
P = Xe^{-rT}N(-d_2) - SN(-d_1) \tag{2}
\]

where

\[
  d_1 = \frac{\ln\left(\frac{X}{S}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma \sqrt{T}}
\]

and

\[
  d_2 = d_1 - \sigma \sqrt{T}
\]

The assumptions associated with applying the Black Scholes option valuation model BSOVM are clearly articulated in their seminal work \([10]\) and many proponents of ROV have analyzed these assumptions in relation to the application of financial options valuation to ROV. A full discussion of the assumptions is not relevant here, however, some aspects of these assumptions are worthy of highlighting at this point.
The first of these is the assumption that the risk-free interest rate remains constant over the life of the option. We know this to be unrealistic from the behavior of bond markets. In the context of option valuation, the risk-free interest rate is usually approximated by the yield values of Government bonds. For this study, being about Australian projects for which the option life is expected to be no more than five years, it is appropriate to choose the Australian Government three-year bond yield as an approximation of the risk-free interest rate.

Another assumption is that the present value of expected cash flows for the underlying asset, over time, is in the form:

\[ S_t = S_0 \cdot \exp \left[ \left( r - \frac{\sigma^2}{2} \right) t + Z_t \sigma \right] \]  

(3)

Where \( r \) is a drift constant, which is actually assumed to be the same as the risk-free interest rate, \( \sigma \) is a volatility constant and the function \( Z_t \) is a standard geometric Brownian motion function. Whilst many real options researchers have implicitly agreed with this assumption through their steadfast application of option valuation models, several have highlighted the inconsistencies with the real world [11]. In summary the main issues are that:

- the value of \( S_t \) can never be negative yet in reality some projects have liabilities that cause the present value of expected cash flows to be negative.
- volatility \( \sigma \) is assumed to be constant and we know from experience this is almost never true.
- drift \( r \) is assumed to be constant and this is not consistent with the real world.

Davis [11] has addressed some of these issues via an approach that uses simple production capped business models under conditions of operating flexibility and no operating flexibility.

2.3 European and American Options

Recall the only difference between European and American options is that American options have the ability to be exercised at any time prior to maturity. Now, Merton [12] provided proof that the value of a European call option is higher than the value it would otherwise assume if it could be exercised immediately. Hence, rational investors never exercise American call options prior to maturity. An exception to this is possible under circumstances where a dividend is paid, remembering that dividends are payable only after an option has been exercised. For example, a toll road has a dividend yield, in this case the toll revenue, that is only realized when the road is operational, that is to say, only after the toll road design option has been “exercised”. It is, of course, essential that the BSOVM is only applied to cases where no dividend is paid, however BSOVM is efficient and accurate and is therefore preferred where applicable.

Clearly, models used for American options reflect a higher level of flexibility than European options and should be employed, where possible, when a dividend or income stream is a feature. Bjerksund and Stensland [13] have developed a convenient closed form approximation of the value of call and put American options.
2.4 Options to Defer, Stage, Scale, Grow, Abandon, Shut Down and Restart

ROT extends well beyond the calculation of a number to represent the expected value of options. It provides the theory to support the identification of options to create, expand, switch use or abandon an infrastructure asset and guides ongoing data collection that supports value creating decisions for the asset stakeholders. Value creation is the end result of a process that takes advantage of opportunities whilst simultaneously limiting downside risks created by uncertainty. Trigeorgis and Reuer [2] have categorized four stages to this process, namely:

(i) identification of the option, during which hidden or “shadow” options are discovered;
(ii) the acquisition or creation phase, during which the information, third party agreements and organization of necessary resources are completed.
(iii) management of the option during which the option is maintained, kept relevant during periods of change and even further enhanced if opportunities are presented, and
(iv) exercising of the option during which plans for enactment of the option are implemented and benefits are realized.

Trigeorgis and Reuer [2] have reported a deficit of research in the real options identification stage. Moreover, it appears that the application of ROV to infrastructure asset management is still in its early stages [8, 14–16].

Lander and Pinches [17] identified six types of real options: defer, stage, scale, switch, grow and abandon. Trigeorgis [18], identified a seventh option to shut down and restart. All have the potential to be applied to major infrastructure assets, although some apply to the operational phase whereas others apply to the design and construction phase. A review of the applicability to infrastructure projects as well as the components of value and cost for each option is given here.

The option to defer a project is postponement of commencement until more favorable conditions prevail. It can apply to commencement of design, construction or operation. The value of deferral is in the flexibility to choose a start date that aligns with advantageous conditions. An infrastructure project start date may be deferred if there is a significant reduction in expected cash flow such that the completed project is predicted to be cash flow negative. The potential cost of deferral is escalation of labor and materials. Another potential cost is obsolescence of the project design or part of the design whereby the investment already made is either entirely or partly lost.

The option to stage a project implies a plan for possible deferral at the completion of logical parts or stages of a project. The value of staging is the flexibility to restart each subsequent stage at a time that suits. Alternatively, staging can be viewed as a series of options each on the next stage of the project. This is known as a compound option. Project staging is often planned in such a way that there is no need for additional demobilization and remobilization, hence the cost of staging is often limited to the escalation of subsequent stages if there has been a delay between stages large enough to result in escalation.
The option to scale up or down is associated with flexibility of design such that the capacity of the infrastructure can be increased or decreased at any future time. The value of an option to scale down is the flexibility to deliver infrastructure to match a lesser demand and to potentially save construction and operating costs commensurate with that smaller scale. Alternatively, the value of an option to scale up is the flexibility to deliver infrastructure to match a greater demand if needed.

The option to switch is associated with an ability to change between two or more different modes of operating, two or more designs, two or more asset configurations. An example of two different operating modes is weekday and weekend public transport schedules. In this example, we can create an option to switch between two different schedules. Another form of this option is a switch between inputs. This type of switching option is often associated with production lines that have a capability to manufacture different but similar products using different raw materials, however, it could be applied to a power station with multi fuel capability. The value of the switching option is found in the flexibility of choice in operating mode enabling reduction in operating costs or risks or increased revenue from an additional product line or revenue stream. The cost of this option is the extra capital cost associated with the switchable design and the losses associated with switching.

The option to grow is associated with the early identification of an additional type of revenue. Hence the growth is in new revenue streams rather than the scale of a given revenue stream. The value of an option to grow is in the possible improvement of net present value of the entire project. The cost typically begins with research including experiments and is followed by design, construction, commissioning and operating costs associated with the output of that research.

Another type is the option to abandon. This option is not taken lightly but is sometimes exercised when it is clear that the project will not be successful and that long term and unabated financial loss is apparent. The value of abandonment is the recovery of unspent project funds and possibly the salvaging of resources dedicated to the project. The cost of abandonment is the cost of demobilization of resources deployed to the project site.

Finally, the option to stop and restart may be of interest in situations where a period of substantial decline in the revenue associated with a project manifests unexpectedly. The value of such an option is in the ability to mitigate or even completely prevent significant financial loss for stakeholders. The cost of stopping and restarting is the cost of demobilization and the subsequent remobilization of resources when the project starts again.

3 Design of This Study

This study applies an indicative ROA to project stage management for national infrastructure assets. The infrastructure assets analyzed under this study are Australian based megaprojects that are in the option definition, design or construction stage.

Whilst considering the design of this study, there is an important distinction made between:
• analysis for the purpose of infrastructure asset investment, that essentially treats the infrastructure asset project as a black box by evaluating opportunities to invest in options relating to that infrastructure asset as a whole; and
• analysis for the purpose of project and portfolio managers seeking to evaluate managerial flexibility created via options within the infrastructure asset projects.

It is essentially the difference between real options “on” projects as opposed to those “in” projects [19]. This study is exclusively centered on the latter. Hence the study converges on the intersection between ROA, Asset Management and Project Management.

In addition to this, the perspective offered by this study of real options “in” projects is intended for those working at a national level on the portfolio of national infrastructure projects. Hence the study is designed to extract data from Australia’s megaprojects and to perform ROA as strategic guidance for those responsible for national megaproject portfolio management.

3.1 Framing and Estimating the Cost of Megaproject Options

Framing a real option involves determining ways in which managerial flexibility can be introduced. One type of option that applies to all engineered projects is an option for flexibility of timing. Flexibility in project timing is gained by carrying out the design and locking in contractual arrangement with those suppliers and contractors that deliver a functioning asset.

An indicative cost of preparing the megaproject design plus the preparation and execution of the necessary contracts for megaproject procurement, construction and commissioning is estimated using the following formula. This is designated “the acquisition cost for the right to construct the project” ($C_a$) and it is derived from the estimated P50 project capital cost ($C_{P50}$), a project specific engineering complexity factor ($\mu$) and a project specific contracts complexity factor ($\rho$) as follows:

$$C_a = (\mu + \rho)C_{P50}$$  \hspace{1cm} (4)

The engineering complexity factor ($\mu$) varies considerably from project to project and is largely a function of the design effort required in each project which in turn depends on the number of individual design elements, the number of standard design elements within the overall project and the level of design interdependency between individual design elements. Likewise, the contract complexity factor depends on the existence of standing agreements with suppliers, the existence of industry accepted standardized contract forms and the level of interdependency between individual contracts.

The nature of the project is also a factor, for example, the engineering complexity and contract complexity factors in relation to the design and procurement of nuclear power generation plants are quite different from those for highway projects. For the purpose of this study $\mu$ is estimated at 0.15 and $\rho$ is estimated at 0.05.

3.2 Estimating the Value of Real Options

The first step is to correctly frame the option of interest. The option of interest is the option to carry out engineering design and execute procurement contracts required to
deliver the project. We will subsequently call this the front-end engineering option (FEE option). The FEE option value is calculated using the BSOVM closed form Eq. (1). This concept was previously explored and utilized in 2010 in the context of the renewal of water utility assets [20].

The approach to estimating each of the six parameters used to value the real option defined above is examined individually here.

**Parameter T: Time to real option expiry** is the time period for which contracts for the delivery of the project remain valid. It is within the control of the project management team up to a point. Suppliers and contractors may be inclined to resist longer term contracts without an escalation clause and other types of risk protection. The project design may become obsolete or partially obsolete after several years. We have assumed a value of 5 years for all infrastructure projects in this study.

**Parameter X: Cost estimate for the real underlying asset** is derived directly from the P50 project cost estimates in the business plans of each respective project. It is subject to uncertainty to the extent not covered by contracts for the delivery of the project.

**Parameter r: Risk-free yield.** In the model, the current yield of three-year Australian government bonds is used as a proxy. The return for three-year Australian government bonds as at the 8th of September 2020 is 0.273%.

**Parameter S: Expected present value of cash flows** is derived from the business case, being the expected net present value for each project. It is subject to a significant level of uncertainty.

**Parameter o: Volatility of expected cash flows.** This is a particularly difficult parameter to estimate although there are some proxies that can be used. The current share market volatility index provides some guidance because infrastructure companies such as Sydney Airport, a proxy for the proposed Western Sydney airport, and Transurban, a proxy for some toll roads are traded on the stock exchange. The current volatility index as of the 8th of September 2020 is 30.75% so a value of 30% is used.

**Parameter δ: Forgone rate of return.** This, too, is difficult to estimate. The forgone rate of return is equivalent to a dividend yield being paid on a share for which the option is yet to be converted. Shareholders are paid a dividend; option holders are not. Hence the value lost by an option holder is the dividend not received. It is almost impossible to determine the expected dividend on an asset that has yet to be built. However, we can say with surety that many public transport assets, a substantial proportion of the megaprojects of this study, only continue to operate under government subsidy and hence a dividend is not appropriate. Many of the highway and motorway projects in this study have no toll and will therefore have no associated dividend. Toll road projects expecting to charge a toll will likely have significantly reduced traffic volumes because of pandemic conditions. The planned Western Sydney airport is also likely to have significantly reduced usage and is not likely to be in a situation to pay a dividend for many years. In the understanding that this is study is indicative rather than definitive, an estimate of zero lost value would seem fitting.

The BSOPVM shown earlier in Eq. (1) is used to calculate the option values associated with engineering design and contract execution. As previously stated, the BSOVM is a European option valuation model and applies to projects for which no dividend is payable.
3.3 Analysis

As the prime step of the analysis, the FEE option value is compared to the FEE option cost for all of the megaprojects. Value for money is evident when the FEE option value exceeds the FEE option cost. Hence a decision to carry out the engineering for such a project is in the interests of the project customers because they would be receiving value for money. The option ratio is used as a numerical indicator of projects that are “in the money”. The option ratio formula ($R_o$) is shown in Eq. (5).

$$R_o = \frac{C}{C_a}$$

The final part of the analysis is a comparison of option ratios across the entire portfolio of Australian infrastructure megaprojects to determine the portfolio of projects for which front end engineering is recommended.

4 Results

This section presents the results obtained from the option ratio analysis using data for current Australian infrastructure megaprojects extracted from Infrastructure Australia’s Infrastructure Priority List “High Priority Projects” and “Priority Projects”. The results also include an analysis of the Brisbane CRR project (never included on the infrastructure priority list but promoted by the Queensland Government) but exclude the Perth Metronet Morley to Ellenbrook project for which the capital cost estimate was unavailable.

The analysis showed that projects 1 to 13, on Table 2, had an option ratio significantly greater than unity. These are the projects on Australia’s infrastructure list for which the FEE represents value for money, in that the cost of the FEE is significantly less than the theoretical value represented by the BSOVM. The P50 capital cost estimate for these projects is AUD 19.6 billion. Hence the analysis indicated that the FEE for just over thirty percent of estimated capital expenditure on Australia’s infrastructure projects represented value for money.

Similarly, projects 16 to 28 inclusive had an option ratio significantly less than unity. The analysis indicated that the projects on Australia’s infrastructure list representing poor value for money, in that the cost of the FEE is significantly higher than the theoretical value represented by the BSOVM, was an estimated AUD 38.8 billion worth of projects. Hence the FEE for just under sixty percent of the planned expenditure on Australia’s infrastructure projects represented poor value for money by this analysis.

The remainder, that is projects 14 and 15, had an option ratio of close to unity. Given the uncertainties involved, the analysis showed that these projects may or may not represent value for money. This is approximately ten percent of planned infrastructure expenditure.

Overall, the analysis has shown that despite the fact that all projects on Table 2 had a positive net present value and a benefit to cost ratio greater than one, almost sixty percent of the planned expenditure was for projects that had option ratios significantly less than unity and therefore indicated the FEE represented poor value for money.

Note, the analysis undertaken here was indicative in nature, mainly because of difficulties in reliably estimating the unpredictability of expected cash flows ($\sigma$) but also
Table 2. Australian Infrastructure Projects Key Data [21] and ROA Results

| ID | Project                                                                 | Capital cost (P50) $m | NPV $m  | Benefit cost ratio | Option ratio |
|----|-------------------------------------------------------------------------|------------------------|---------|--------------------|--------------|
| 1  | M4 Motorway upgrade Paramatta to Lapstone: New South Wales (NSW)        | 7921                   | 2640    | 5.30               | 16.20        |
| 2  | Bruce Highway: Maroochydore Interchange                                 | 2861                   | 529     | 3.21               | 7.32         |
| 3  | University of Tasmania: North Transformation                            | 2791                   | 483     | 2.41               | 6.59         |
| 4  | Bindoon Bypass: Western Australia                                       | 2611                   | 462     | 3.40               | 6.26         |
| 5  | Bruce Highway: Deception Bay Interchange Queensland                     | 1451                   | 234     | 3.03               | 5.89         |
| 6  | Brisbane Metro: Inner City Public Transport                             | 8771                   | 1235    | 2.40               | 4.62         |
| 7  | Inland Rail: Melbourne to Brisbane                                      | 9,890                  | 13928   | 2.62               | 4.62         |
| 8  | Nowra Bridge: Princes Highway NSW                                       | 221                    | 268     | 2.20               | 3.50         |
| 9  | Port Botany Rail Line: Sydney                                          | 379                    | 430     | 2.68               | 3.06         |
| 10 | Western Sydney Airport: Badgerys Creek                                  | 5,000                  | 5441    | 1.90               | 2.82         |
| 11 | Myalup-Wellington water project: Western Australia                      | 394                    | 388     | 1.60               | 2.28         |
| 12 | University of Tasmania: Technology precinct                              | 400                    | 364     | 1.95               | 1.92         |
| 13 | M80 Ring Road Upgrade: Melbourne                                        | 687                    | 553     | 2.00               | 1.45         |
| 14 | Bruce Highway: Caboolture-Bribie Island Road to Steve Irwin Way Queensland (Qld) | 5841                   | 422     | 1.91               | 1.11         |
| 15 | Eyre Infrastructure project: South Australia                            | 6,000                  | 3800    | 1.30               | 0.79         |
| 16 | Perth Metronet: High Capacity Signaling                                 | 1,157                  | 688     | 2.60               | 0.66         |
| 17 | M12 Motorway: Western Sydney                                            | 1,888                  | 1171    | 1.80               | 0.57         |
| 18 | Beerburrum to Nambour Rail Upgrade Qld                                   | 541                    | 262     | 1.50               | 0.36         |
| 19 | Peak Downs Highway Realignment Qld                                      | 145                    | 67      | 1.50               | 0.32         |
| 20 | Sydney Rail: More Trains, More Services: Stage 2                        | 2,023                  | 890     | 1.38               | 0.27         |
| 21 | M1 Pacific Motorway, Varsity Lakes to Tugun Qld                         | 9661                   | 419     | 1.67               | 0.26         |
| 22 | Brisbane Cross River Rail                                              | 5,400                  | 1877    | 1.41               | 0.12         |
| 23 | Sydney Metro: City and southwest                                        | 8,680                  | 2775    | 1.30               | 0.09         |
| 24 | M1 Motorway: Eight Mile Plains to Daisy Hill Qld                        | 7101                   | 213     | 1.40               | 0.07         |
| 25 | Bruce Highway: Cooroy to Curra Qld                                      | 1,005                  | 274     | 1.36               | 0.05         |
| 26 | North East Link: Melbourne                                             | 14,6641                | 2187    | 1.30               | 0.003        |
| 27 | Gold Coast Light Rail: Stage 3A Qld                                     | 6581                   | 56      | 1.10               | 0.0001       |
| 28 | Bruce Highway: Cairns southern access Qld                               | 1,005                  | 49      | 1.14               | 0.000003     |
|    | Total                                                                   | 65,037                 |         |                    |              |

Notes: (1) P50 Capital cost estimated from the P90 capital cost or other sources because the value lost over the duration of the option ($\delta$) has been assumed to be zero for all cases. However, it is worth noting that many ROA researchers have reported the same difficulty [11]. A more rigorous study would include confidence levels for the option ratios calculated.

5 Discussion

The option ratio analysis methodology employed here reveals a new way to analyze megaprojects and megaproject portfolios. It shows whether or not the FEE is worth
doing from a rational “value for money” perspective and in full cognizance of uncertainty. For those megaprojects with option ratios much less than one, projects which could be labelled “out of the money” in options trading parlance, there is no rational argument for carrying out the FEE. If the FEE options for the out of the money projects were offered on the options exchange, it is likely that they would not trade. Interestingly, all of the projects in Table 2 have positive Net Present Value and a Benefit to Cost Ratio greater than 1. This would indicate to a rational investor that they are worth doing. However, since these measures don’t take uncertainty into account, there is a reasonable argument to be skeptical about the inclusion of any of the projects on the list.

Should the option ratio be used to screen new project options? If so, should the projects that pass the option ratio test be scheduled to carry out FEE? This idea holds significant merit when viewed from the perspective of impending recessions. Economic recessions happen on a regular basis in most countries and the catch cry is usually for the government of the day to immediately implement “shovel ready” projects in order to generate jobs. Wouldn’t it be good to have a portfolio of worthy projects that are ready to go?

So, Australia’s portfolio of infrastructure projects appears to be lacking in value for money. This is not to say, with the advent of further uncertainty, that those projects will remain so. However, there appears to be a real need for a larger and more diverse portfolio of valuable projects, possibly smaller scale and distributed, that offer a literal smorgasbord of possibilities.

Examining the current portfolio leads us to note another aspect, that the current infrastructure project list appears to be heavily weighted towards transport sector projects (see Fig. 1). One argument that could be posited is that such a one-sided portfolio is not ideal as an insurance against uncertainty especially if it were to materialize in the form of a disruptive technology. For example, disruptive drone transport systems are...
possibly not far over the horizon. How inappropriate would that render our proposed infrastructure projects? For that matter, how many of the projects now appear premature or inappropriate now that the pandemic has arrived? We have already discussed the Brisbane CRR project, however, there is a total of AUD 19.3 billion in public transport projects spread across Australia that is similarly placed. The AUD 5 billion Western Sydney Airport possibly should be postponed due to the longer-term outlook with respect to air travel. Many of the roads and highways were intended to service city or city fringe traffic needs during peak hour. The M12 Motorway project in Western Sydney was intended to service yet to be developed suburbs that will be left undeveloped for many years due to the now expected population decline.

Meanwhile, a broad and diverse array of infrastructure project types such as health and aged care facilities, justice and emergency services such as fire services infrastructure, hospitals, affordable housing, telecommunications, energy, water, wastewater, seaport infrastructure and coastal protection infrastructure should be included as options available for development and early deployment in the face of uncertain need. Project options should not overlook carefully designed demand management projects such as those needed for rationing of power, water, food, transport, hospital infrastructure and other forms of health facilities if necessary.

Of course, evaluation of infrastructure megaproject options can and should extend well beyond a financial analysis. Such projects have numerous stakeholders and multiple objectives. Often the objectives of one stakeholder oppose that of another. This is the complex realm of Multi Criteria Decision Analysis (MCDA) which is highly applicable to megaproject decisions, including those relating to megaproject options. Typically, the impact of a range of project options is considered in relation to socio-economic, environmental and financial objectives [20, 23] framed from the perspective of key stakeholders and their values.

In the case of the Brisbane CRR project the key stakeholders are Queensland Rail which is the owner/operator of the proposed CRR service, the passengers using the service, individual residents near to the railway service, the local community, the state and the nation. Some of the objectives important to stakeholders include establishing high levels of health and safety, jobs for community members, minimization of greenhouse gas emissions, the minimizing the cost of train fares (in the case of passengers) and maximizing revenue (in the case of the service operator).

Some of the options with the Brisbane CRR project are to:

1. stage the project by simply doing the engineering and then completing the project as a second stage remembering that before the commencement of each stage there is the option to delay.
2. Abandon the CRR project altogether.
3. Switch between different operation modes such as a peak hour demand management model that provides fare price incentives for off peak services.

It is possible to construct an overall utility model through the results of a value trade-off survey involving members of each key stakeholder group. Hence, the option that maximizes utility is preferred. An approach that combines real option problem structuring and MCDA has been successfully attempted before for smaller scale asset
renewal in the water utility industry [20, 23] but it appears that none have applied this approach to megaproject option decisions [24].

Now for some answers to questions posed in the beginning of this paper. Should the level of uncertainty in demand for services be a significant, or even the dominant factor, in relation to our design of solutions in response to demand for those services? It seems that uncertainty in the demand for services should be considered and this is supported by the results shown in Table 2.

It is interesting to note that the Brisbane CRR project is one of the projects for which the option ratio is very much less than 1. The questions in relation to this project were: Would another option be more appropriate at this juncture? Should the CRR project be delayed or even abandoned? It is pretty clear, given the option ratio is 0.12, that another option could better serve the travelling public. Perhaps a demand management option is more appropriate. And, yes, the Brisbane CRR project, which is currently underway, possibly should be delayed immediately or even abandoned. A hybrid MCDA ROA study in relation to these options could potentially save significant public money.

6 Recommendations

Several recommendations are offered for future research consideration:

- Apply a stochastic approach to the FEE option ratio calculation.
- Determine the confidence level for the option ratio figures. Indeed, develop a methodology for so doing.
- Collect data on the success, or otherwise, of projects to determine if the option ratio is a predictor of success. Indeed, carry out a longitudinal study based around the predictors of success for megaprojects.
- Carry out some further studies into megaprojects around options for abandonment, delay, switching and other pertinent options. Indeed, establish an international collaborative group for the expansion of a knowledge base in this area.
- Apply hybrid ROA MCDA decision processes to managing infrastructure megaprojects and their associated options.

7 Conclusion

There is serious inadequacy in Australia’s preparedness with respect to its pipeline of proposed infrastructure projects. A significant proportion, sixty percent, of the proposed projects are not robust in the face of uncertainty when we use the Black Scholes option valuation model to test the value of engineering for that infrastructure against its estimated cost. Further to this, the proposed infrastructure project list also appears overly biased towards transport projects. There is not enough flexibility to cope with change.

We believe the COVID-19 pandemic has, through its unique pervasiveness, revealed weaknesses in the way Australia manages its portfolio of infrastructure projects. Traditional infrastructure projects in which a project passes through a long planning period before being delivered in exact accordance with that plan may no longer apply, given our uncertain and complex world. In fact, there appears to be a gap in the body of knowledge
with respect to the management of a portfolio of infrastructure projects at a national level under conditions of uncertainty.

We advise a pipeline of carefully chosen pre-engineered options, some of which are constructible projects and others being non-asset, demand management solutions as the preferred portfolio of infrastructure projects. A flexible and diverse portfolio of “shovel ready” nationally distributed, project plans and solutions are necessitated as is a readiness to defer, stage, scale, grow, abandon, shut down and restart infrastructure projects as required.

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