Delivery of Transport Infrastructure Assets: Decison-Making Model to Ensure Value for Money

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Abstract

Transport infrastructure is pivotal for economic and social development. Over the past decade, Public-Private Partnerships (PPPs) have been widely adopted for its delivery in developing and developed economies due to increasingly limited public budgets. Therefore, deciding whether to use PPPs is a critical topic for governments and relies on an essential criterion that is referred to as value for money (V*f*M). However, the complexity of transport infrastructure projects renders current V*f*M-oriented decision-making tool (i.e. public sector comparator) to be a less-than-comprehensive assessment. Thus, a total of five case studies of transport PPPs in Australia are undertaken in this paper to interpret existing practice. The empirical evidences indicate that the V*f*M-based assessment being widely used is ineffective in capturing: (1) key stakeholders' (e.g. client and asset end-users) expectations and (2) the underlying dynamics of complexities of transport projects. Accordingly, a novel decision-making model that emphasizes asset service quality and usage is mathematically developed. Relevant implications for improving current practice have also been discussed. This research contributes to body of knowledge in

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terms of *ex-ante* evaluation of infrastructure projects and it is useful to enhance the effectiveness of government's decision-making about the employment of PPPs for transport assets.

***Keywords*: Transport infrastructure, PPPs, V*f*M assessment, decision making, case study

Introduction

Transport infrastructure describes the networks supporting people's socio-economic activities and benefits in an economy (Knowles *et al*., 2020). However, many governments are being subjected to an increasingly limited budget for infrastructure development; therefore, Public-Private Partnerships (PPPs) have been adopted worldwide to procure transport assets such as roads, rails and tunnels (Geddes and Reeves, 2017; Cui *et al*, 2019). For example, there have been 19 transport PPP projects initiated over the past decade across Australia (Department of Infrastructure and Regional Development, 2018). In the United Kingdom (UK), a total of 60 transport projects with the capital expenditure (CAPEX) over £7.5 billion (≈US$9.2 billion) have been procured through PPPs (HM Treasury, 2019). Essentially, PPPs are now an integral part of government's procurement strategy in many developed economies, such as Australia, Canada, New Zealand, UK and USA.

Despite the widespread use of PPPs, deciding effectively to choose PPPs has been being a challenge for governments. This decision-making process is currently relying on *ex-ante* evaluation that is based on a criterion in terms of value for money (V*f*M) (European Investment Bank - EIB, 2015). As stated by UK's HM Treasury (2006), PPPs can only be used if they can provide better V*f*M. Put simply, V*f*M assessment justifies the adoption of PPP schemes (Morallos *et al*., 2009). Fundamentally, it is viewed as an optimum combination among life-cycle cost, quality and end-user satisfaction (Office of Government Commerce, 2004). The studies undertaken by the National Audit Office (NAO) (2011) of the UK and Ross and Yan (2015) amplified that V*f*M assessment is conducted not only for saving government's budgets, but also enabling the assets to be better functioning the society.

Extant practice in assessing V*f*M for infrastructure projects, however, is primarily dependent upon cost estimate (Department of Transport, 2017; NSW Treasury, 2017). It is being criticised as an asymmetric comparison and manipulation, i.e. an evaluation based on a hypothetical cost comparison (Gopalkrishna and Karnam, 2015; Operal *et al*., 2017). The paucity of this assessment hinders the ability of governments to make informed decisions by overlooking non-financial issues (e.g. asset service quality and functionality), which are however critical for choosing an appropriate procurement method, particularly for transport projects (DeCorla-Souza *et al*., 2016). Nonetheless, limited attention has been paid to elaborating how to effectively capture such essential aspects for the policy decision makers (i.e. government) (Cui *et al*. 2018). Acknowledging this limitation, this study empirically and mathematically develops a novel choice model to supplement present practice in V*f*M-oriented decision-making for PPPs within the context of transport infrastructure.

Literature Review

PPPs are defined as long-term arrangements formed between public and private sectors with an aim of introducing private resources and/or expertise to deliver public assets and provide relevant services (EIB, 2004). Based on the commitment level of private entities to the projects, PPP contracts can be categorised as follows: (1) utility restructuring, corporatization and decentralization; (2) civil works and service contracts; (3) management and operation agreement; (4) leases; (5) concessions (e.g. build-operate-transfer (BOT), Design-Build-Operate (DBO) and design-build-finance-operate (DBFO)); (6) joint ventures; (7) partial and full divestiture; and (8) contract plans and performance contracts (World Bank, 2019). Fundamentally, transport infrastructure projects (i.e. roads, tunnels, urban transit systems) are developed under the concessional contracts, such as BOT, DBO and DBFO, owing to the complexities of the assets in terms of design, construction and operations (Babatunde and Perera, 2017; Zhang *et al*., 2018).

The extensive use of PPPs worldwide has led to a plethora of studies that have been performed to investigate PPPs within the following areas: (1) critical success factors; (2) concessionaire selection; (3) the roles and responsibilities of governments; (4) risk management; (5) time performance under different types of contracts; (6) project finance; and (7) PPP evaluation (Kwak *et al.*, 2008; Liu *et al.*, 2018a). Moreover, there has been an emerging research scheme over the past decade, focusing on procuring transport assets via PPPs (Table 1 below). These studies primarily concentrated on either the project's management of demand- and cost/finance-related risks or CSFs for transport PPPs. Essentially, transport PPPs in many countries or regions are subjected to a greater controversy (e.g. Australia, UK and EU) and, therefore, studies indicate that PPPs cannot be adopted without adding higher values to local transport systems (Klijn and Teisman, 2003; Koppenjan, 2005). Otherwise, the untenable decision-making at the inception stage will nourish underperformance, due to the uncertainties as a result of the long-term transport contracts that are normally up to 30 years (Macario *et al*., 2015; Ghahari *et al*., 2018; Ghahari *et al*., 2019).

The recurring schemes of PPPs above, spurred by calls to respond to a higher quality of asset service, have been recommended to be extended to V*f*M-oriented decision-making, as V*f*M is acknowledged as a strategic goal of PPPs but its assessment has received limited attention (Neto *et al*., 2016, Bao *et al*., 2018, Cui *et al*., 2018). Specifically, the extant literature lacks empirical research that attempts to expand the knowledge of PPP evaluation through development of new decision-making techniques, particularly in the context of transport infrastructure (Kweun *et al.*, 2018; Penyaler *et al.*, 2019). In making headway to address this problem, a novel model is developed to improve current V*f*M-based assessment of transport procurement through case studies of the Australian transport PPP projects.

Methodology

Case study approach has been applied in this study due to a wide acceptance that it is suitable for all stages of a research process, cascading down from the proposition of hypothesis to the generation of new knowledge (Flyvbjerg, 2006). The aim of this study is to explore 'how' to improve existing V*f*M-oriented assessment that is used for decision making of use of PPPs. To identify critical implications for a future improvement, a deep interpretation of and understanding for current practice (in assessing V*f*M) should not be ignored, and this is also referred to as the exploratory case study (Yin, 2014; Liu *et al.*, 2018b).

The case projects selected for this paper cover two types of transport infrastructure assets that have been frequently procured by using PPPs, including road and railways projects. They are based in New South Wales (NSW) and Victoria, which have been considered as leading and well-developed transport PPP markets in Australia (Infrastructure Partnerships Australia, 2016). The implications derived from case studies based on such mature PPP markets (i.e. NSW and Victoria, Australia) are significant and reliable for improving the V*f*M-oriented decision making of transport infrastructure procurement in developed economies (Liu *et al.*, 2018b). To minimise subjectivity, the objective data comprising relevant project documentations (e.g. contract summaries and service agreements) being available from the websites of the NSW

Treasury and Victoria Department of Treasury and Finance have been adopted for the case studies of this research.

Case Study and Application

This paper examines the practice by undertaking a case study of five Australian transport PPP projects. It includes the Cross City Tunnel, Lane Cove Tunnel, North West Rail Link, NSW, and the Peninsula Link and Metro Tunnel, Victoria.

NSW-based Projects

Background of the Case Projects

The Cross City Tunnel (CCT) project incorporates a 2.1km twin-tunnel toll road, which links Darling Harbour of Sydney CBD to Rushcutters Bay, NSW. It is under a 33-year DBFOM contract (design-build-operate-finance-operate-maintain) with a value of AU$680 million (≈US$418.73 million), running from December 2002 to December 2035. The CCT project is being operated by a private entity (Transurban) and engaged with a series of public-sector parties such as Minister for Roads, Treasury and NSW Roads and Marine Services (RMS) (project client). Similarly, the Lane Cove Tunnel (LCT) is a project based in NSW and is under the DBFOM contract (i.e. contract value: AU$1.1 billion≈US$677.35 million) valid from December 2003 to January 2037. The LCT is a 3.6km-long motorway in twin tunnels connecting Epping Road Bridge crossing to Gore Hill Freeway, Artarmon. This project is also being operated by Transurban with a partnership of such public-sector organizations as NSW Minister for Roads, Rail Corporation and RMS (project client). In addition to CCT and LCT, another NSW-based project being studied is the Sydney North West Rail Link (NWRL), where the relevant contract is associated with a total value of AU$3.7 billion (≈US$2.28 billion) and a term from September 2014 and April 2034. The NWRL is approximately 15.5 kilometres, which connects Cudgegong Road, Rouse Hill and Chatswood, and it incorporates a total of 8 new stations. This project encompasses three main contracts, including: (1) a D&C (design and construct) contract of the tunnel and station civil works package that has been awarded to the Thiess, John Holland and Dragados Joint Venture; (2) a D&C contract of the surface and viaduct civil works package to be delivered by Impregilo Salini Joint Venture; and (3) a PPP contract between the Transport for NSW (public authority) and NRT Pty Ltd for the operations, trains and systems package.

Practice of the Case Projects in VfM-Oriented Assessment for Asset Procurement

During the decision-making stage of procurement selection, the three PPP projects introduced above had undergone a V*f*M-oriented assessment performed by the NSW state government. As stated in the 'Summaries of Contract Change' of the CCT projects, the NSW RMS's V*f*M assessment was primarily underpinned by (NSW Government, 2008, p.4):

> "*… a 'comparative value' assessment against a 'public sector comparator' (PSC) – a hypothetical, risk-adjusted estimate of the net present cost of delivering the project, to the same level and standard of service, using the most efficient likely form of delivery able to be financed by the public sector …*"

Essentially, the 'Updated Summary of Contracts' of the LCT has a statement that is same as above, indicating that the project's V*f*M assessment that rationalises the use of PPP is a cost-focused comparison depending on the PSC. A detailed statement (shown as below) about the V*f*M assessment can be retrieved in the footnote of the LCT contract summary (NSW Government, 2010, p.8):

> “.. *For a ‘public sector comparator’ based on the most efficient likely form of delivery of the Lane Cove Tunnel project able to be financed by the public sector, the estimated net present value of the normalised risk-adjusted financial cost of the project to the RMS, using 10 September 2003 interest rates, was $193.2 million (≈US$123 million). In contrast, the delivery of the project by the private sector, in accordance with the rights, obligations and risk allocations described in this report, was expected to result in a significant net financial benefit to the RMS, with the financial costs of the project to the RMS being outweighed by a substantive transfer of risks to the private sector* ...”

In the NWRL project, which is a more recent project passing the financial close in September 2014, its V*f*M assessment also hinges on the PSC. The official ‘Contract Summary’ of the NWRL has statements presented as follows (Transport NSW, 2014, pp.12-13).

> “*... the 'Public Sector Comparator' (PSC) provides a hypothetical estimate of the risk adjusted cost of the project if it (i.e. NWRL) were to be designed, built and operated by the State. To develop the estimate, the PSC was based on a reference project developed by the State, consistent with the Specified Performance Requirements ...*”

> “*... the present value of the OTS PPP was evaluated using a discount rate that included a systematic risk premium of 1.40%, in accordance with NSW Treasury policies on the assessment of complying proposals ...*”

To provide more detailed information, Table 2 summarises the PSC-based V*f*M assessment of the NWRL project. It is noted that the NSW state government’s decision making for employing PPPs to the NWRL project was based on ‘financial benefit’.

In summary, the V*f*M assessments of the three NSW-based transport PPP projects interpreted above are the PSC-based estimate. They were mainly focused on cost savings to be generated from the involvement of private-sector entities.

Victoria-based Projects

Background of the Case Projects

As introduced above, a total of two transport PPPs based in the state of Victoria, Australia, have also been undertaken in this research, involving the *Peninsula Link* (PL) and *Melbourne Metro Tunnel* (MMT) projects. The Peninsula Link is a four-lane 27-kilometre motorway that connects the Frankston Freeway to the Mornington Peninsula Freeway at Mount Martha, Victoria. This project with a contract value of AU$849 million (≈US$523 million) ran through the financial close in February 2010. The 27-year contract to be expired in December 2037 has been signed off by the Linking Melbourne Authority (i.e. project client) and the Southern Way consortium, a private *Special Purpose Vehicle* (SPV) responsible for designing, building, financing, operating and maintaining the asset. Regarding the MMT project, it has been initiated to deliver the twin tunnels under Melbourne CBD and relevant five new underground stations. The 31-year contract to September 2048 possesses a total value up to AU$6 billion (≈US$3.8 billion) and includes the parties such as the *Rail Project Victoria* (i.e. public authority and project client) and a private SPV (e.g. Lendlease Engineering, John Holland, Bouygues Construction and Capella Capital). Based on the awarded contract, the SPV handles the asset's design, construction, finance, operations and maintenance.

Practice of the Case Projects in VfM-Oriented Assessment for Asset Procurement

The V*f*M assessment of the PL project is PSC-based, concentrating on the life-cycle cost savings to be yielded by the private SPV. A statement extracted from the project's 'Contract

Summary' supports this identification, and it is shown below (Linking Melbourne Authority, 2010, p.5):

> "*The Government's Partnerships Victoria framework seeks to identify and implement the most efficient form of infrastructure delivery. The concept of value for money goes beyond the selection of the cheapest solution, focusing on the overall value of each delivery option … The analysis considered quantifiable elements (i.e. items that can be quantified in dollar terms) by using the public sector comparator.*"

> "*… The PSC includes amounts to cover the design and construction costs, lifecycle asset replacement costs and the maintenance and facilities management costs during the 25 year operating phase of the Project …*"

Similar to the PL project, the V*f*M assessment practice of the MMT project also depended on the PSC, and this can be reflected by the statement same as above in relevant contract summary (Melbourne Metro Rail Authority, 2018). Tables 3 reports the cost information produced by the PSC-based V*f*M assessments of the two projects.

Shortcomings of Extant Practice in VfM Assessment

It can be identified from the data presented above that the decision-making process for the use of PPP in the selected case projects is focused on saving costs. However, V*f*M assessment is conducted for a purpose of not only enabling cost saving, but also examining whether the concerns of the key stakeholders can be better satisfied, especially those of the clients and asset end-users (Department for Transport, 2017). This perspective is supported by the viewpoints stated in the official documents of the case projects. For example, as reflected in the contract summaries, public interest such as a higher service quality to be provided by the assets to better meet the public's transport demand (usage) has been emphasised by local communities (NSW Government, 2008; 2010; Linking Melbourne Authority, 2010; Melbourne Metro Rail Authority, 2018). Nevertheless, the PSC-based quantitative assessment adopted by NSW and Victorian state governments is unable to capture the aforementioned aspects.

More importantly, the PSC assessment failed in examining the impact of introducing private sectors on asset usage over the project's dynamic lifecycle. Nonetheless, enhancing asset usage through an improved service quality has been the government's (client) expectation on the use of PPPs for transport infrastructure, regardless of in the user-charge or availability-based PPPs. For instance, the selected CCT and LCT projects in NSW are the user-charge PPPs, where the demand risk (i.e. asset usage) is transferred to the private-sector entities. Despite the transferred demand risk, the client (i.e. NSW state government) of the two projects expects the involved private SPVs to significantly improve the quality of the services so as to boost the usage of the tunnels. This is because the aim of these two projects is to alleviate commuting problems through a reduced congestion (NSW Government, 2008; 2010), and an enhanced usage of the tunnels can diminish the traffic volume of other congested roads, then relieving the local traffic pressure. Furthermore, facilitating the usage of the assets (i.e. tunnels) can lead to a higher toll revenue of the State government, as there has been an additional-profit-sharing mechanism established by the government for the CCT and LCT projects. Put simply, the NSW state government can share agreed certain percentages of extra toll revenue that is above the projected profits yielded from the operations of the assets. Table 4 indicates the details of the profit-sharing mechanism inserted into the projects.

Apart from the CCT and LCT, other three case projects (e.g. NWRL, Peninsula Link and Melbourne Metro Tunnel) are classified as the availability-based PPPs, where public authorities retain the demand risk (i.e. asset usage). As a result, the projects' clients have a strong expectation on an enhanced asset usage to be achieved by the private SPVs' contribution to improving the quality asset services, as this can enable a satisfactory revenue for the state governments as well. An Australia-based PPP research undertaken by Liu *et al.* (2018a) echoes this point of view by contending that 'asset profitability' is critical for the success of the availability-based PPPs. Notably, the KPIs presented in the contract summaries of the NWRL and Metro tunnel projects can also reinforce the aforementioned perspective, i.e. Table 5, in which the service-quality-related KPIs account for 68.5% of the total KPIs of the projects.

Based on the demonstration about the selected case projects above, the shortcomings of extant practice in V*f*M-oriented assessment performed by the governments for the decision making of employment of PPPs can be illustrated as Figure 1. It is noted that the existing widely-used quantitative V*f*M assessment in the context of transport infrastructure procurement substantially neglects the relationship between two critical aspects relevant to key stakeholders' expectations (e.g. client and asset end-users), i.e., improved service quality and enhanced asset usage (after introducing private sector into the asset procurement). Hence, a new method is needed to supplement extant V*f*M assessment for the decision making of PPP option.

Model Propagation to Supplement Extant Practice in PPP V*f*M Assessment

V*f*M in terms of governments' selection of an appropriate procurement method for transport infrastructure is an economic concept, which describes maximizing values for taxpayers by: (1) saving costs from public money and/or (2) enriching asset service to better satisfy the public's transport demand (i.e. an improved functionality) throughout the project's dynamic life-cycle

(Macário *et al.*, 2015; Department for Transport, 2017). This definition enables an ideal environment to apply the Dynamic Discrete Choice Model (DDCM), which is developed based on the Random Utility Maximization (RUM) theory. It is widely accepted that DDCM is beneficial for an 'economic agent' to efficiently make a proper choice that can maximise the value to satisfy key stakeholders over a period of time (McFadden, 1978; Heckman, 1981).

According to Cirillo and Xu (2011), "DDCM describes the behaviour of a forward-looking economic agent who chooses between multiple alternatives over time" (p.473). Essentially, it has been widely applied in decision-making research within the context of transport sector, for example, choice modelling of travel and direction, transport policy and strategy. This type of research can be found in recent studies undertaken by Le Pira *et al.* (2017), Haghani and Sarvi (2018), Hasnine and Habib (2018), Liu and Cirillo (2018) and Qin *et al.* (2019). Mathematically, DDCM can be represented as Equation (1) below:

$$V\left(x_{n0}\right)=\max_{\{d_{nt}\}_{t=1}^{T}} E\left(\sum_{t^{'}=t}^{T}\sum_{i=1}^{J}\beta^{t^{'}-t}\left(d_{nt}=i\right)U_{nit}\left(x_{nt},\varepsilon_{nit}\right)\right) \tag{1}$$

where x_{nt} represents state variables, x_{n0} is the agent's initial condition; d_{nt} is n's decision among J discrete alternatives; U_{nit} stands for the flow utility; and T denotes the time horizon.

It is extrapolated that the choice to be made by the government is between PPPs and traditional procurement method, i.e. Equation (2). There is also another assumption made for this study that: (1) political issues (i.e. politician's bias against PPPs) are excluded; and (2) tendering process is competitive and impartial. These two assumptions are represented as Equations (3) and (4).

$$j=\begin{cases}1, & \text{PPPs;}\\ 0, & \text{traditional procurement method}\end{cases} \tag{2}$$

$$j = \sum_{q=1}^{n} f_{ijt}^{n}, \; i = 1, \; f_{i1t}{}^{1} = f_{i0t}{}^{1} \tag{3}$$

$$AR = MR = P \tag{4}$$

where f_{ijt}^{n} are all the factors that i considers at time t when making the decision j, and 1 means the political or managerial bias. Moreover, *AR* in Equation (4) is private-sector entity's average revenue; *MR* is its marginal revenue, and *P* is the bidding price.

Based on the assumptions represented in Equations (2), (3) and (4), a binomial logit decision-making model indicated as Equation (5) can be developed from Equation (1) to modelling the selection of PPPs in terms of private sectors' contribution to asset usage through an improved service quality.

$$u_{ijt} = \mathrm{Logit}\left(\frac{\mathrm{P}_{ijt}}{1 - \mathrm{P}_{ijt}}\right) = \alpha + \alpha_1^{x_{ijt}^{o}} x_{ijt}^{o} + \zeta_{ijt} \tag{5}$$

where u_{ijt} denotes the utility government i can gain from the decision j (j=1: PPPs are favoured; j=0: traditional procurement method is preferred) at time t; P stands for probability; α is a constant; $\alpha_1^{x_{ijt}^{o}}$ is the coefficient that stipulates functionality x_{ijt}^{o}'s impact on u_{ijt}; and ζ_{ijt} is a random vector depending on i, j, t, specifying the effects of unobservable dynamic issues on the economic agent's decision-making.

To further develop Equation (5), x_{jt}^{o} can be expanded by inserting an 'impact factor' (x_o) and an initial traffic volume ($TVOL_{kqm}$) or passenger ridership ($PTRA_{kqm}$). Practically, traffic volume or ridership has been widely as a proximity variable to forecast asset usage (i.e. transport demand) to estimate the relationship between private-sector-provided service and asset usage (i.e. traffic volume/passenger ridership) (Department for Transport, 2017). x_o is simulated through a process of adapting the Bayesian Networks (BN) (which is demonstrated below) with an input variable of service quality (x_s). In other words, x_{ijt}^{o} in Equation (5) is a variable comprising: (1) service quality (x_s); (2) transport demand represented by traffic volume or passenger ridership ($TVOL_{kqm}/PTRA_{kqm}$); and (3) an impact factor (x_o) mathematically representing the causal relationship between x_s and $TVOL_{kqm}/PTRA_{kqm}$. Noteworthy, the *Service Quality Dimensions*, a theory that is built on the Expectancy-Disconfirmation Paradigm, suggests that customer (asset end-users in infrastructure service) satisfaction that represents the 'gap' between their expectations (expected service) and perceptions (perspective service) is a 'parameter' significant for assessing the quality of a service (Parasuraman *et al*., 1988). Thus, the service quality (x_s) can be viewed as end-user satisfaction, which has been acknowledged as being an important KPI of the service provided by transport systems (Mouwen, 2015; Yuan *et al.*, 2018).

As previously described, BN has been deployed to underpin the development of a mathematical model to estimate x_o. BN is based on probability and graph theories and is powerful in dealing with conditional independencies among a group of variables, in which let G=(E, F) be a directed acyclic graph and then X=(X_e), e∈E be a set of random variables indexed by E; therefore, a BN joint conditional probability can be rewritten as:

$$p(x) = \prod_{e \in E} p(x_e / x_{pa(e)}) \tag{6}$$

where $pa(e)$ is the set of parents of e; E is a vertex and F is a single edge. Thus, it is effective in identifying uncertain and complex relationships between variables within the engineering context (Jordan, 1998). Compared with regression models, BN is more robust in capturing causal interrelationship between variables using past data and thus is suitable for forward-looking decision making such as impact simulation (Li *et al.*, 2017; Namazian *et al*., 2019).

The BN-based modelling in this study is developed with an assumption proposed by Sun *et al.* (2006), who postulate that factors determining the observed variable are independent of each other. Thus, let (s, o) be a partition of the node indices of the BN, so that it converts to disjointed subsets, and then let (x_s, x_o) be a partition of the corresponding variables. Accordingly, the marginal probability of x_s can be written as:

$$p(x_s) = \sum_{x_o} p(x_s, x_o) \tag{7}$$

Consequently, the conditional probability $p(x_o|x_s)$ derived from BN can be reformulated as:

$$p(x_o \mid x_s) = \frac{p(x_o, x_s)}{p(x_s)} = \frac{p(x_o, x_s)}{\sum_{x_o} p(x_s, x_o)} \tag{8}$$

With a reference to the Gaussian mixture model (Sun *et al.*, 2006) and a lemma proved in Rao (1973), Equation (8) can be further represented as below.

$$p(x_o \mid x_s) = \sum_{l=1}^{M} \beta_l G(x_o; \mu_{lo|s}, \Sigma_{lo|s}) \tag{9}$$

where $G(x_o; \mu_{lo|s}, \Sigma_{lo|s})$ is a multidimensional normal density function with mean $\mu_{lo|s}$ and covariance matrix $\Sigma_{lo|s}$;

$$\beta_l = \frac{\alpha_l G(x_s; \mu_{ls}, \Sigma_{lss})}{\sum_{j=1}^{M} \alpha_j G(x_s; \mu_{js}, \Sigma_{jss})}$$

$$\mu_{lo|s} = \mu_{lo} - \Sigma_{los} \Sigma_{lss}^{-1} (\mu_{ls} - x_s)$$

$$\Sigma_{lo|s} = \Sigma_{loo} - \Sigma_{los} \Sigma_{lss}^{-1} \Sigma_{lso} \tag{10}$$

And, an optimal forecasting of x_o after the calculation of minimum mean square error equals to:

$$x_o = E(x_o \mid x_s) = \int x_o p(x_o \mid x_s) dx_o$$

$$= \sum_{l=1}^{M} \beta_l \int x_o G(x_o; \mu_{lo|s}, \Sigma_{lo|s}) dx_o = \sum_{l=1}^{M} \beta_l \mu_{lo|s} \tag{11}$$

Finally, x_o is integrated into the annual average daily traffic (AADT) forecasting method (US Department of Transportation, 2018) to forecast x^o_{ijt}, being represented as:

$$x^o_{jt2} = \frac{1}{12}\sum_{m=1}^{12}\left[\frac{1}{7}\sum_{q=1}^{7}\left(\frac{1}{n_{qm}}\sum_{k=1}^{n_{qm}} TVOL_{kqm}\right)\right](1+\sum_{l=1}^{M}\beta_l\mu_{lo|s}) \qquad (12)$$

If the project intervention is that of transport where passenger ridership rather than traffic volume is applied (i.e. urban transit systems and airlines), Equation (12) can be rewritten as Equation (13).

$$x^o_{jt2} = \frac{1}{12}\sum_{m=1}^{12}\left[\frac{1}{7}\sum_{q=1}^{7}\left(\frac{1}{n_{qm}}\sum_{k=1}^{n_{qm}} PTRA_{kqm}\right)\right](1+\sum_{l=1}^{M}\beta_l\mu_{lo|s}) \qquad (13)$$

where $TVOL_{kqm}$ and $PTRA_{kqm}$ are the daily traffic volume and passenger ridership for k^{th} occurrence of the q^{th} day (1 to 7) of week within the m^{th} month (1 to 12) respectively; k is occurrences of day q in month m for which traffic data are available; and n_{qm} is number of occurrences of day q in month m for which traffic data is available.

To integrate the elements presented from Equations (7) to (13) into Equation (5), a decision-making model therefore can be finalized as Equation (14) or (15) as follows.

$$u_{ijt} = \mathrm{Logit}\left(\frac{\mathrm{P}_{ijt}}{1-\mathrm{P}_{ijt}}\right) = \alpha + \alpha_1^{x^o_{ijt}}\,\frac{1}{12}\sum_{m=1}^{12}\left[\frac{1}{7}\sum_{q=1}^{7}\left(\frac{1}{n_{qm}}\sum_{k=1}^{n_{qm}} TVOL_{kqm}\right)\right](1+\sum_{l=1}^{M}\beta_l\mu_{lo|s}) + \zeta_{ijt} \qquad (14)$$

$$u_{ijt} = \mathrm{Logit}\left(\frac{P_{ijt}}{1-P_{ijt}}\right) = \alpha + \alpha_1^{x^o_{ijt}}\,\frac{1}{12}\sum_{m=1}^{12}\left[\frac{1}{7}\sum_{q=1}^{7}\left(\frac{1}{n_{qm}}\sum_{k=1}^{n_{qm}} PTRA_{kqm}\right)\right](1+\sum_{l=1}^{M}\beta_l\mu_{lo|s}) + \zeta_{ijt} \qquad (15)$$

The final decision of an ‘economic agent’ (i.e., a public authority embarking on PPPs) is based on the result to be generated from Equations (14) and (15). In alignment with the RUM theory, if u and v (u and $v \in j$) exist and Equation (16) is enabled, an alternative procurement method u will be deemed to be more effective than the other option.

$$D_{ijt} = P(u_{iut} > u_{ivt}, \forall u \neq v) \quad (16)$$

Discussion and Comparisons

A new decision-making model has been developed as Equations (14) and (15) to supplement the current V*f*M-oriented decision-making practice for the procurement selection of transport infrastructure. The developed model possesses dynamic attributes, which consider the impact of introducing private-sector entity on asset usage throughout the project's lifecycle. It is capable of essentially addressing: (1) end-users' demand for quality service; and (2) the client's expectation on boosting asset usage through an improved quality of service to increase revenue within the context of PPPs. These two critical issues, essentially, have been ignored in PSC and cost-benefit analysis (CBA), which dominate in current V*f*M assessment practice. Moreover, the developed model involves ζ_{ijt} that can capture the impact of future unobservable variables, which are also being overlooked by PSC and CBA (e.g. change of technology in asset maintenance and management). This random vector can be estimated in practice by using a dummy variable to be determined according to actual situations of projects.

As manifested by the mathematical process above, the application of the developed model would be to consider inputting asset end-user satisfaction in addition to a forecasted traffic volume or passenger ridership. This can be achieved by using the data collected from the customer survey of similarly awarded transport projects under the governments as proximities. Notably, the model is also suitable for the governments with limited data of similar types of PPP projects. This is attributed to DDCM, which is a discrete model based on the probability concept of '1-*P*'. In other words, the decision makers can input relevant data of similar transport projects that were delivered via traditional procurement method to decide whether to choose PPPs by adopting the result obtained from the following simple equation: 'P_{PPPs}=1-P_t' (i.e. P_t

is the probability of use of traditional procurement method). This feature facilitates the decision-making process of the governments by simplifying their current process, as the decision makers do not need to identify hypothetical costs and relevant benefits for comparison (i.e. PSC/CBA).

Conclusions

Transport infrastructure assets are proved to be a solid pillar to the social and economic development in an economy. Within an era of austerity, private sectors' ingenuity and resources are increasingly being adopted to procure them worldwide. However, the salient V*f*M assessment that rationalises the use of PPPs during governments' decision-making process remains controversial. Despite a considerable amount of research that has been conducted for PPPs, empirical development of an approach to supplement current V*f*M-based assessment has received limited attention.

A total of five case studies of the Australian transport PPPs, therefore, have been undertaken by using the objective data that were collected from the official documentations of the projects. The empirical findings are twofold. First, extant practice in V*f*M-oriented decision making about whether to choose PPPs or not to procure transport assets is a cost-focused estimate. Second, existing V*f*M assessment failed in dynamically capturing non-financial aspects that are pivotal for both asset end-users and project client (i.e. government), such as quality asset service and an enhanced asset usage. Accordingly, a new decision-making model that is underpinned by the DDCM and BN has been developed to supplement existing V*f*M-oriented decision-making practice. The developed model is robust in addressing the private sectors' impacts in terms of service quality and life-cycle asset usage.

The study presented in this paper sheds light on a significant knowledge void by providing governments embarking on PPPs with a novel tool to select an appropriate method to procure their transport infrastructure assets. It significantly contributes to body of knowledge of infrastructure procurement, particularly within the context of transport PPPs. The developed model is also practical, as it supplements current practice and enables V*f*M assessment to be placed into a wider context with 'non-cost' perspectives. Put simply, the application of the model will ensure higher value for the key stakeholders of transport infrastructure projects. Future research will focus on identifying a more comprehensive model encompassing all underlying dynamics of PPP V*f*M. As this paper is an exploratory case study, model validation using quantitative modelling will be conducted against actual project data.

Data Availability Statement

Some or all data, models, or code generated or used during the study are available in a repository online in accordance with funder data retention policies. All URLs are available at:

(1) https://www.dtf.vic.gov.au/sites/default/files/2018-01/The-Peninsula-Link-Project-Summary.pdf;

(2) http://nswtreasury.prod.acquia-sites.com/sites/default/files/2017-02/Cross_City_Tunnel _contracts_summary_2008_update_lowres.pdf;

(3) https://www.dtf.vic.gov.au/sites/default/files/2018-02/Metro%20Tunnel%20PPP%20Project%20Summary%20-%2021%20February%202018.pdf;

(4) http://nswtreasury.prod.acquia-sites.com/sites/default/files/2017-02/Lane_Cove_Tunnel_contracts_summary_09August2010.pdf;

(5) http://nswtreasury.prod.acquiasites.com/sites/default/files/2017-02/NWRL_OTS_PPP_Contract_Summary_Dec_2014.pdf.

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Tables

Table 1. Key research into transport PPPs

Authors	**Research Themes**	**Level**
Phang (2007)	Cost-related risk assessment	Urban rail
Jain *et al.* (2008)	Finance-related governance	Urban rail
de Jong *et al.* (2010)	Cost/Finance	Metropolitan subways
Yuan *et al.* (2010)	CSFs	Metropolitan transport systems
Gross and Garvin (2011)	Cost-related risk management	Toll road
Chang (2013)	Cost/finance	Metro
Liu and Wilkinson (2013)	CSFs	Metro
Chang (2014)	Finance	Metro
Carpintero and Petersen (2014)	Risk sharing and cost effectiveness	Light rail
de Albornoz and Soliño (2015)	Finance	Entire transport sector
Hong (2016)	Cost management	Urban rail
Liao (2016)	CSFs (economic perspective)	Metro
Zhang and Soomro (2016)	CSFs	Entire transport sector
Ke *et al.* (2017)	CSFs	Urban rail
Chang and Phang (2017)	Cost-related management (recovery ratio/land value)	Urban rail
Engel *et al.* (2018)	Demand risk management	Airport
Feng *et al.* (2018)	Demand risk management	Road
Yuan *et al.* (2018)	Management of the finance-related issue of the project	Bridge

Table 2. PSC-based V*f*M assessment of the NWRL project

Cost Category	**PSC (NPC $m)**	**PPP (NPC $m)**	**Cost Savings (NPC $m)**	**Cost Savings (%)**
D&C cost	2,911.9	2,893.7	(-18.2)	(0.5%)
O&M cost	1,178.1	872.7	(-305.4)	(8.1%)
Total costs	4090.0	3,766.4	(-323.6)	(8.6%)
Transferred risk	488.8	Include above	-	-
Total NPC	**4,578.8**	**3,766.4**	**(-812.4)**	**(21.6%)**

(Source: Transport for NSW, 2014)

Table 3. PSC-based V*f*M assessment of the PL and MMT project

No.	Public Sector Comparator ($m)	SPV's risk adjusted proposal ($m)	Estimated Savings ($m)	Estimated Savings (%)
PL	858	849	9	1%
MMT	5327.8	5240.4	87.4	1.6%

(Source: Linking Melbourne Authority, 2010 and Melbourne Metro Rail Authority, 2018)

Table 4. Additional profit sharing mechanism of the CCT and LCT projects

Portion of the Actual Toll Revenue	**The Client's share of the Portion**
up to 110%	0%
110% to 120%	10%
120% to 130%	20%
130% to 140%	30%
140% to 150%	40%
more than 150%	50%

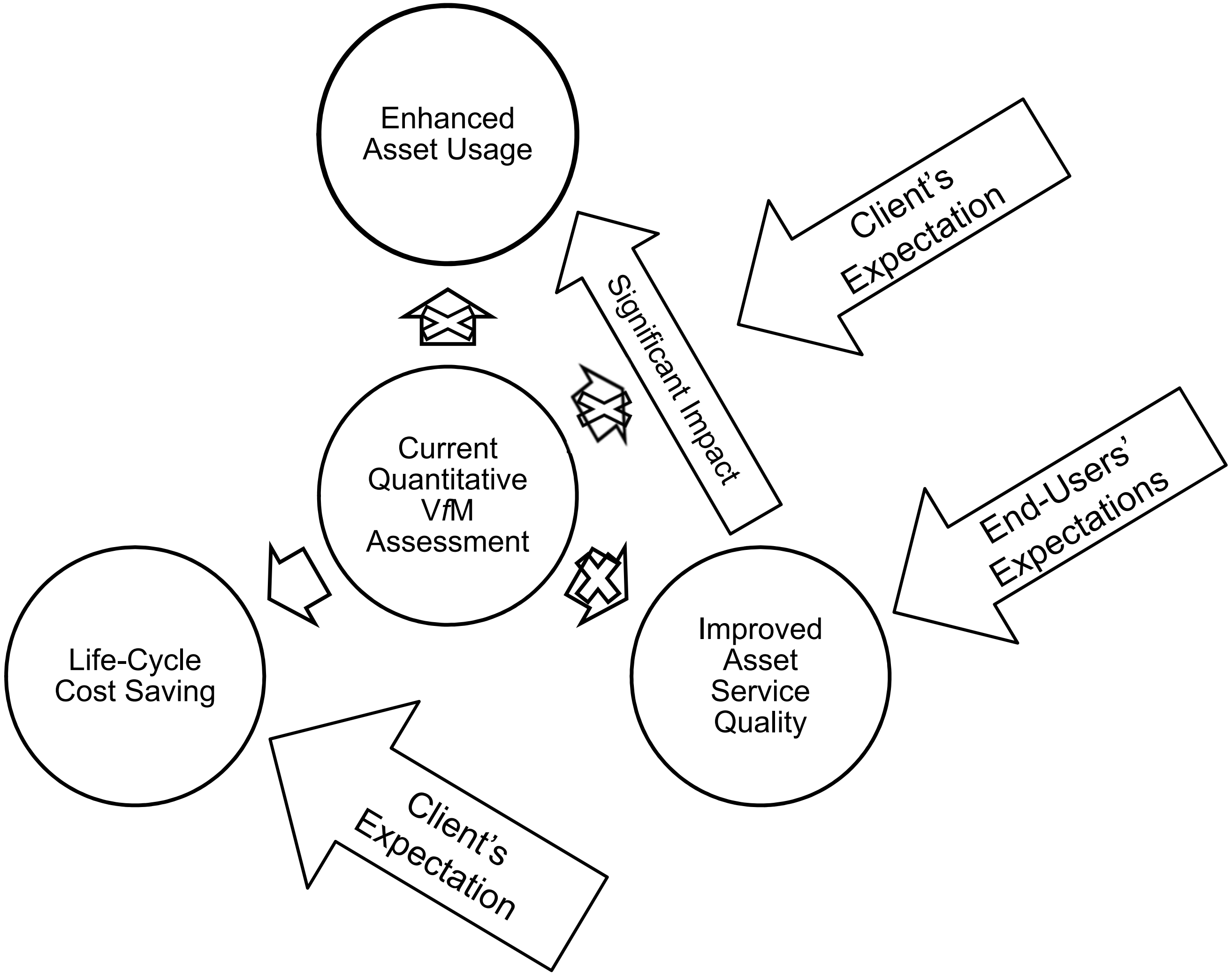
(Sources: NSW Government, 2010, p.44)

Table 5. Summary of the KPIs being adopted by the selected case rail projects

Service Quality KPIs	KPI Weighting
Train cleanliness	22.5%
Station cleanliness, condition and graffiti	6%
Public areas and rail corridor cleanliness, condition and graffiti	8%
Customer information during service disruptions	2%
Gate management	6%
Customer satisfaction survey	20%
Complaints management	4%
Total	**68.5%**

(Sources: Transport for NSW, 2014; Melbourne Metro Rail Authority, 2018)

Figure 1



Enhanced Asset Usage
Significant Impact
Client's Expectation
Current Quantitative VfM Assessment
End-Users' Expectations
Life-Cycle Cost Saving
Improved Asset Service Quality
Client's Expectation