

VfM-Oriented Decision-Making of Transport Infrastructure

PPPs: Moving Beyond Extant Praxis

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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 (VfM). However, the complexity of transport infrastructure projects renders current VfM-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 VfM-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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20 terms of *ex-ante* evaluation of infrastructure projects and it is useful to enhance the effectiveness
21 of government's decision-making about the employment of PPPs for transport assets.

22

23 **Keywords:** Transport infrastructure, PPPs, VfM assessment, decision making, case study

24

25 **Introduction**

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

37

38 Despite the widespread use of PPPs, deciding effectively to choose PPPs has been being a
39 challenge for governments. This decision-making process is currently relying on *ex-ante*
40 evaluation that is based on a criterion in terms of value for money (VfM) (European Investment
41 Bank - EIB, 2015). As stated by UK's HM Treasury (2006), PPPs can only be used if they can
42 provide better VfM. Put simply, VfM assessment justifies the adoption of PPP schemes
43 (Morallos *et al.*, 2009). Fundamentally, it is viewed as an optimum combination among life-
44 cycle cost, quality and end-user satisfaction (Office of Government Commerce, 2004). The

45 studies undertaken by the National Audit Office (NAO) (2011) of the UK and Ross and Yan
46 (2015) amplified that VfM assessment is conducted not only for saving government's budgets,
47 but also enabling the assets to be better functioning the society.

48

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

61

62 **Literature Review**

63 PPPs are defined as long-term arrangements formed between public and private sectors with an
64 aim of introducing private resources and/or expertise to deliver public assets and provide
65 relevant services (EIB, 2004). Based on the commitment level of private entities to the projects,
66 PPP contracts can be categorised as follows: (1) utility restructuring, corporatization and
67 decentralization; (2) civil works and service contracts; (3) management and operation
68 agreement; (4) leases; (5) concessions (e.g. build-operate-transfer (BOT), Design-Build-
69 Operate (DBO) and design-build-finance-operate (DBFO)); (6) joint ventures; (7) partial and

70 full divestiture; and (8) contract plans and performance contracts (World Bank, 2019).
71 Fundamentally, transport infrastructure projects (i.e. roads, tunnels, urban transit systems) are
72 developed under the concessional contracts, such as BOT, DBO and DBFO, owing to the
73 complexities of the assets in terms of design, construction and operations (Babatunde and
74 Perera, 2017; Zhang *et al.*, 2018).

75
76 The extensive use of PPPs worldwide has led to a plethora of studies that have been performed
77 to investigate PPPs within the following areas: (1) critical success factors; (2) concessionaire
78 selection; (3) the roles and responsibilities of governments; (4) risk management; (5) time
79 performance under different types of contracts; (6) project finance; and (7) PPP evaluation
80 (Kwak *et al.*, 2008; Liu *et al.*, 2018a). Moreover, there has been an emerging research scheme
81 over the past decade, focusing on procuring transport assets via PPPs (Table 1 below). These
82 studies primarily concentrated on either the project's management of demand- and cost/finance-
83 related risks or CSFs for transport PPPs. Essentially, transport PPPs in many countries or
84 regions are subjected to a greater controversy (e.g. Australia, UK and EU) and, therefore,
85 studies indicate that PPPs cannot be adopted without adding higher values to local transport
86 systems (Klijn and Teisman, 2003; Koppenjan, 2005). Otherwise, the untenable decision-
87 making at the inception stage will nourish underperformance, due to the uncertainties as a result
88 of the long-term transport contracts that are normally up to 30 years (Macario *et al.*, 2015;
89 Ghahari *et al.*, 2018; Ghahari *et al.*, 2019).

90
91 The recurring schemes of PPPs above, spurred by calls to respond to a higher quality of asset
92 service, have been recommended to be extended to VfM-oriented decision-making, as VfM is
93 acknowledged as a strategic goal of PPPs but its assessment has received limited attention (Neto
94 *et al.*, 2016, Bao *et al.*, 2018, Cui *et al.*, 2018). Specifically, the extant literature lacks empirical

95 research that attempts to expand the knowledge of PPP evaluation through development of new
96 decision-making techniques, particularly in the context of transport infrastructure (Kweun *et*
97 *al.*, 2018; Penyalder *et al.*, 2019). In making headway to address this problem, a novel model is
98 developed to improve current VfM-based assessment of transport procurement through case
99 studies of the Australian transport PPP projects.

100

101 **Methodology**

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

109

110 The case projects selected for this paper cover two types of transport infrastructure assets that
111 have been frequently procured by using PPPs, including road and railways projects. They are
112 based in New South Wales (NSW) and Victoria, which have been considered as leading and
113 well-developed transport PPP markets in Australia (Infrastructure Partnerships Australia,
114 2016). The implications derived from case studies based on such mature PPP markets (i.e. NSW
115 and Victoria, Australia) are significant and reliable for improving the VfM-oriented decision
116 making of transport infrastructure procurement in developed economies (Liu *et al.*, 2018b). To
117 minimise subjectivity, the objective data comprising relevant project documentations (e.g.
118 contract summaries and service agreements) being available from the websites of the NSW

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

121

122 **Case Study and Application**

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

126

127 **NSW-based Projects**

128 *Background of the Case Projects*

129 The Cross City Tunnel (CCT) project incorporates a 2.1km twin-tunnel toll road, which links
130 Darling Harbour of Sydney CBD to Rushcutters Bay, NSW. It is under a 33-year DBFOM
131 contract (design-build-operate-finance-operate-maintain) with a value of AU\$680 million
132 (\approx US\$418.73 million), running from December 2002 to December 2035. The CCT project is
133 being operated by a private entity (Transurban) and engaged with a series of public-sector
134 parties such as Minister for Roads, Treasury and NSW Roads and Marine Services (RMS)
135 (project client). Similarly, the Lane Cove Tunnel (LCT) is a project based in NSW and is under
136 the DBFOM contract (i.e. contract value: AU\$1.1 billion \approx US\$677.35 million) valid from
137 December 2003 to January 2037. The LCT is a 3.6km-long motorway in twin tunnels
138 connecting Epping Road Bridge crossing to Gore Hill Freeway, Artarmon. This project is also
139 being operated by Transurban with a partnership of such public-sector organizations as NSW
140 Minister for Roads, Rail Corporation and RMS (project client). In addition to CCT and LCT,
141 another NSW-based project being studied is the Sydney North West Rail Link (NWRL), where
142 the relevant contract is associated with a total value of AU\$3.7 billion (\approx US\$2.28 billion) and
143 a term from September 2014 and April 2034. The NWRL is approximately 15.5 kilometres,

144 which connects Cudgegong Road, Rouse Hill and Chatswood, and it incorporates a total of 8
145 new stations. This project encompasses three main contracts, including: (1) a D&C (design and
146 construct) contract of the tunnel and station civil works package that has been awarded to the
147 Thiess, John Holland and Dragados Joint Venture; (2) a D&C contract of the surface and
148 viaduct civil works package to be delivered by Impregilo Salini Joint Venture; and (3) a PPP
149 contract between the Transport for NSW (public authority) and NRT Pty Ltd for the operations,
150 trains and systems package.

151

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

153 During the decision-making stage of procurement selection, the three PPP projects introduced
154 above had undergone a VfM-oriented assessment performed by the NSW state government. As
155 stated in the ‘Summaries of Contract Change’ of the CCT projects, the NSW RMS’s VfM
156 assessment was primarily underpinned by (NSW Government, 2008, p.4):

157

158 “... a ‘comparative value’ assessment against a ‘public sector comparator’ (PSC) – a
159 hypothetical, risk-adjusted estimate of the net present cost of delivering the project, to the
160 same level and standard of service, using the most efficient likely form of delivery able to
161 be financed by the public sector ...”

162

163 Essentially, the ‘Updated Summary of Contracts’ of the LCT has a statement that is same as
164 above, indicating that the project’s VfM assessment that rationalises the use of PPP is a cost-
165 focused comparison depending on the PSC. A detailed statement (shown as below) about the
166 VfM assessment can be retrieved in the footnote of the LCT contract summary (NSW
167 Government, 2010, p.8):

168

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

177
178 In the NWRL project, which is a more recent project passing the financial close in September
179 2014, its VfM assessment also hinges on the PSC. The official ‘Contract Summary’ of the
180 NWRL has statements presented as follows (Transport NSW, 2014, pp.12-13).

181
182 “... the ‘Public Sector Comparator’ (PSC) provides a hypothetical estimate of the risk
183 adjusted cost of the project if it (i.e. NWRL) were to be designed, built and operated by
184 the State. To develop the estimate, the PSC was based on a reference project developed
185 by the State, consistent with the Specified Performance Requirements ...”

186
187 “... the present value of the OTS PPP was evaluated using a discount rate that included
188 a systematic risk premium of 1.40%, in accordance with NSW Treasury policies on the
189 assessment of complying proposals ...”

190
191 To provide more detailed information, Table 2 summarises the PSC-based VfM assessment of
192 the NWRL project. It is noted that the NSW state government’s decision making for employing
193 PPPs to the NWRL project was based on ‘financial benefit’.

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

197

198 **Victoria-based Projects**

199 *Background of the Case Projects*

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

215

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

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

219 Summary' supports this identification, and it is shown below (Linking Melbourne Authority,
220 2010, p.5):

221

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

227

228 *“... The PSC includes amounts to cover the design and construction costs, lifecycle asset*
229 *replacement costs and the maintenance and facilities management costs during the 25*
230 *year operating phase of the Project ...”*

231

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

236

237 *Shortcomings of Extant Practice in VfM Assessment*

238 It can be identified from the data presented above that the decision-making process for the use
239 of PPP in the selected case projects is focused on saving costs. However, VfM assessment is
240 conducted for a purpose of not only enabling cost saving, but also examining whether the
241 concerns of the key stakeholders can be better satisfied, especially those of the clients and asset
242 end-users (Department for Transport, 2017). This perspective is supported by the viewpoints
243 stated in the official documents of the case projects. For example, as reflected in the contract

244 summaries, public interest such as a higher service quality to be provided by the assets to better
245 meet the public's transport demand (usage) has been emphasised by local communities (NSW
246 Government, 2008; 2010; Linking Melbourne Authority, 2010; Melbourne Metro Rail
247 Authority, 2018). Nevertheless, the PSC-based quantitative assessment adopted by NSW and
248 Victorian state governments is unable to capture the aforementioned aspects.

249

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

267

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

278

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

287

288 **Model Propagation to Supplement Extant Practice in PPP VfM Assessment**

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

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

298

299 According to Cirillo and Xu (2011), “DDCM describes the behaviour of a forward-looking
 300 economic agent who chooses between multiple alternatives over time” (p.473). Essentially, it
 301 has been widely applied in decision-making research within the context of transport sector, for
 302 example, choice modelling of travel and direction, transport policy and strategy. This type of
 303 research can be found in recent studies undertaken by Le Pira *et al.* (2017), Haghani and Sarvi
 304 (2018), Hasnine and Habib (2018), Liu and Cirillo (2018) and Qin *et al.* (2019).

305 Mathematically, DDCM can be represented as Equation (1) below:

$$306 \quad V(x_{n0}) = \max_{\{d_{nt}\}_{t=1}^T} E \left(\sum_{t=1}^T \sum_{i=1}^J \beta^{i-t} (d_{nt} = i) U_{nit}(x_{nt}, \varepsilon_{nit}) \right) \quad (1)$$

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

309

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

$$315 \quad j = \begin{cases} 1, & \text{PPPs;} \\ 0, & \text{traditional procurement method} \end{cases} \quad (2)$$

316
$$j = \sum_{q=1}^n f_{ijt}^n, i = 1, f_{i1t} = f_{i0t} \quad (3)$$

317
$$AR=MR=P \quad (4)$$

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

321
 322 Based on the assumptions represented in Equations (2), (3) and (4), a binomial logit decision-
 323 making model indicated as Equation (5) can be developed from Equation (1) to modelling the
 324 selection of PPPs in terms of private sectors' contribution to asset usage through an improved
 325 service quality.

326
$$u_{ijt} = \text{Logit}\left(\frac{P_{ijt}}{1-P_{ijt}}\right) = \alpha + \alpha_1^{x_{ijt}^o} x_{ijt}^o + \zeta_{ijt} \quad (5)$$

327 where u_{ijt} denotes the utility government i can gain from the decision j ($j=1$: PPPs are favoured;
 328 $j=0$: traditional procurement method is preferred) at time t ; P stands for probability; α is a
 329 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
 330 random vector depending on i, j, t , specifying the effects of unobservable dynamic issues on
 331 the economic agent's decision-making.

332
 333 To further develop Equation (5), x_{ijt}^o can be expanded by inserting an 'impact factor' (x_o) and
 334 an initial traffic volume ($TVOL_{kqm}$) or passenger ridership ($PTRA_{kqm}$). Practically, traffic volume
 335 or ridership has been widely as a proximity variable to forecast asset usage (i.e. transport
 336 demand) to estimate the relationship between private-sector-provided service and asset usage
 337 (i.e. traffic volume/passenger ridership) (Department for Transport, 2017). x_o is simulated
 338 through a process of adapting the Bayesian Networks (BN) (which is demonstrated below) with

339 an input variable of service quality (x_s). In other words, x_{ij}^o in Equation (5) is a variable
340 comprising: (1) service quality (x_s); (2) transport demand represented by traffic volume or
341 passenger ridership ($TVOL_{kqm}/PTR A_{kqm}$); and (3) an impact factor (x_o) mathematically
342 representing the causal relationship between x_s and $TVOL_{kqm}/PTR A_{kqm}$. Noteworthy, the *Service*
343 *Quality Dimensions*, a theory that is built on the Expectancy-Disconfirmation Paradigm,
344 suggests that customer (asset end-users in infrastructure service) satisfaction that represents the
345 ‘gap’ between their expectations (expected service) and perceptions (perspective service) is a
346 ‘parameter’ significant for assessing the quality of a service (Parasuraman *et al.*, 1988). Thus,
347 the service quality (x_s) can be viewed as end-user satisfaction, which has been acknowledged
348 as being an important KPI of the service provided by transport systems (Mouwen, 2015; Yuan
349 *et al.*, 2018).

350

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

$$356 \quad p(x) = \prod_{e \in E} P(x_e / x_{pa(e)}) \quad (6)$$

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

362

363 The BN-based modelling in this study is developed with an assumption proposed by Sun *et al.*
 364 (2006), who postulate that factors determining the observed variable are independent of each
 365 other. Thus, let (s, o) be a partition of the node indices of the BN, so that it converts to disjointed
 366 subsets, and then let (x_s, x_o) be a partition of the corresponding variables. Accordingly, the
 367 marginal probability of x_s can be written as:

$$368 \quad p(x_s) = \sum_{x_o} p(x_s, x_o) \quad (7)$$

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

$$370 \quad p(x_o | x_s) = \frac{p(x_o, x_s)}{p(x_s)} = \frac{p(x_o, x_s)}{\sum_{x_o} p(x_s, x_o)} \quad (8)$$

371 With a reference to the Gaussian mixture model (Sun *et al.*, 2006) and a lemma proved in Rao
 372 (1973), Equation (8) can be further represented as below.

$$373 \quad p(x_o | x_s) = \sum_{l=1}^M \beta_l G(x_o; \mu_{lo|s}, \sum_{lo|s}) \quad (9)$$

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

$$376 \quad \beta_l = \frac{\alpha_l G(x_s; \mu_{ls}, \sum_{lss})}{\sum_{j=1}^M \alpha_j G(x_s; \mu_{js}, \sum_{jss})}$$

$$377 \quad \mu_{lo|s} = \mu_{lo} - \sum_{los} \sum_{lss}^{-1} (\mu_{ls} - x_s)$$

$$378 \quad \sum_{lo|s} = \sum_{loo} - \sum_{los} \sum_{lss}^{-1} \sum_{lso} \quad (10)$$

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

$$380 \quad x_o = E(x_o | x_s) = \int x_o p(x_o | x_s) dx_o$$

$$381 \quad = \sum_{l=1}^M \beta_l \int x_o G(x_o; \mu_{lo|s}, \sum_{lo|s}) dx_o = \sum_{l=1}^M \beta_l \mu_{lo|s} \quad (11)$$

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

$$384 \quad x_{jt2}^o = \frac{1}{12} \sum_{m=1}^{12} \left[\frac{1}{7} \sum_{q=1}^7 \left(\frac{1}{n_{qm}} \sum_{k=1}^{n_{qm}} TVOL_{kqm} \right) \right] \left(1 + \sum_{l=1}^M \beta_l \mu_{lols} \right) \quad (12)$$

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

$$388 \quad x_{jt2}^o = \frac{1}{12} \sum_{m=1}^{12} \left[\frac{1}{7} \sum_{q=1}^7 \left(\frac{1}{n_{qm}} \sum_{k=1}^{n_{qm}} PTR_{kqm} \right) \right] \left(1 + \sum_{l=1}^M \beta_l \mu_{lols} \right) \quad (13)$$

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

393

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

$$396 \quad u_{ijt} = \text{Logit} \left(\frac{P_{ijt}}{1 - P_{ijt}} \right) = \alpha + \alpha_1 x_{ijt}^o \frac{1}{12} \sum_{m=1}^{12} \left[\frac{1}{7} \sum_{q=1}^7 \left(\frac{1}{n_{qm}} \sum_{k=1}^{n_{qm}} TVOL_{kqm} \right) \right] \left(1 + \sum_{l=1}^M \beta_l \mu_{lols} \right) + \zeta_{ijt} \quad (14)$$

$$397 \quad u_{ijt} = \text{Logit} \left(\frac{P_{ijt}}{1 - P_{ijt}} \right) = \alpha + \alpha_1 x_{ijt}^o \frac{1}{12} \sum_{m=1}^{12} \left[\frac{1}{7} \sum_{q=1}^7 \left(\frac{1}{n_{qm}} \sum_{k=1}^{n_{qm}} PTR_{kqm} \right) \right] \left(1 + \sum_{l=1}^M \beta_l \mu_{lols} \right) + \zeta_{ijt} \quad (15)$$

398

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

403
$$D_{ijt} = P(u_{iut} > u_{ivt}, \forall u \neq v) \tag{16}$$

404

405 **Discussion and Comparisons**

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

418

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

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

431

432 **Conclusions**

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

440

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

451

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

462

463 **Data Availability Statement**

464 Some or all data, models, or code generated or used during the study are available in a
465 repository online in accordance with funder data retention policies. All URLs are available at:
466 (1) <https://www.dtf.vic.gov.au/sites/default/files/2018-01/The-Peninsula-Link-Project-Summary.pdf>;
467
468 (2) http://nswtreasury.prod.acquia-sites.com/sites/default/files/2017-02/Cross_City_Tunnel_contracts_summary_2008_update_lowres.pdf;
469
470 (3) <https://www.dtf.vic.gov.au/sites/default/files/2018-02/Metro%20Tunnel%20PPP%20Project%20Summary%20-%202021%20February%202018.pdf>;
471
472 (4) http://nswtreasury.prod.acquia-sites.com/sites/default/files/2017-02/Lane_Cove_Tunnel_contracts_summary_09August2010.pdf;
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474 (5) http://nswtreasury.prod.acquiasites.com/sites/default/files/2017-02/NWRL_OTS_PPP_Contract_Summary_Dec_2014.pdf.

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1 **Tables**

2 Table 1. Key research into transport PPPs

Authors	Research Themes	Level
Phang (2007)	Cost-related risk assessment	Urban rail
Jain <i>et al.</i> (2008)	Finance-related governance	Urban rail
de Jong <i>et al.</i> (2010)	Cost/Finance	Metropolitan subways
Yuan <i>et al.</i> (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 <i>et al.</i> (2017)	CSFs	Urban rail
Chang and Phang (2017)	Cost-related management (recovery ratio/land value)	Urban rail
Engel <i>et al.</i> (2018)	Demand risk management	Airport
Feng <i>et al.</i> (2018)	Demand risk management	Road
Yuan <i>et al.</i> (2018)	Management of the finance-related issue of the project	Bridge

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4

5

6

Table 2. PSC-based VfM 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%)

7 (Source: Transport for NSW, 2014)

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Table 3. PSC-based V_fM 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%

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

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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%

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

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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%

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

Figure 1

