

1 Cost Overruns in Transportation Infrastructure Projects: 2 Sowing the Seeds for a Probabilistic Theory of Causation

3
4 **Abstract:** Understanding the cause of cost overruns in transportation infrastructure projects has been a topic that has
5 received considerable attention from academics and the popular press. Despite studies providing the essential building
6 blocks and frameworks for cost overrun mitigation and containment, the problem still remains a pervasive issue for
7 Governments worldwide. The interdependency that exists between ‘causes’ that lead to cost overruns materializing
8 have largely been ignored when considering the likelihood and impact of their occurrence. The vast majority of the
9 cost overrun literature has tended to adopt a deterministic approach in examining the occurrence of the phenomenon;
10 in this paper a shift towards the adoption of pluralistic probabilistic approach to cost overrun causation is proposed.
11 The establishment of probabilistic theory incorporates the ability to consider the interdependencies of causes so to
12 provide Governments with a holistic understanding of the uncertainties and risks that may derail the delivery and
13 increase the cost of transportation infrastructure projects. This will further assist in the design of effective mitigation
14 and containment strategies that will ensure future transportation infrastructure projects meet their expected costs as
15 well as the need of taxpayers.

16
17 **Keywords:** Infrastructure, cost overrun, causal reasoning, probabilistic causation, mechanisms, dependencies
18

19 1. Introduction

20 Investment in transport infrastructure (e.g., roads, bridges, ports, railways) is required to meet the
21 growing needs of an increasing population, as well as to sustain a competitive advantage in the
22 global marketplace. For an economy to position itself to capitalize on growth and increased
23 investment due to a burgeoning population and increasing international demand for goods and
24 services, greater investment in transportation infrastructure is needed. In Australia, for example,
25 it has been forecasted that over the next two decades the number of trucks on its roads will increase
26 by 50%, rail freight by two-thirds and shipping containers through ports will double; international
27 and domestic travel through capital city airports will double; and technology will play a significant
28 role in meeting the needs of transport, while also improving safety (Australian Federal
29 Government, 2014a). Yet history explicitly indicates the capital expenditure (CAPEX) of
30 transportation infrastructure projects routinely overrun their initial cost estimates leaving asset
31 owners, financiers, contractors and the public dissatisfied (Flyvbjerg *et al.*, 2005; Flyvbjerg, 2007;
32 Love *et al.*, 2015). This is not an unusual situation for infrastructure projects, as it has been
33 observed that on average, 48% of them fail to meet their baseline time, cost and quality objectives

34 (Caravel Group, 2013). Well-known Australian projects that have attracted the attention of the
35 popular press due to cost overruns include the Melbourne's Southern Cross Railway Station,
36 Sydney Cross City Tunnel, Brisbane's RiverCity Motorway and the M7 Clem Jones Tunnel.

37

38 If the CAPEX of a project overruns, then the scope of works in others being considered or
39 undertaken by Government's may be reduced to accommodate the increased expenditure.
40 Moreover, contractors could face cash flow issues, liquidity and damage to their business image
41 while the public has to pay more when the taxpayer funds projects. This may also have a knock-
42 on effect on the funds available for maintaining and operating the asset. For Governments,
43 managing the cost performance of their portfolio of transportation infrastructure projects is
44 essential for ensuring the economic competitiveness and wealth for its constituents; it is a critical
45 metric, as it quantifies the cost efficiency of the work completed. Cost performance is generally
46 defined as the value of the work completed compared to the actual cost or progress made on the
47 project (Baccarini and Love, 2014). Thus, the ability to reliably estimate the final cost of
48 construction is vital for maintaining the planning and resourcing in other projects or those in the
49 pipeline. An issue that has been overlooked is the cost overrun that often materializes during the
50 operation and maintenance of the asset that is constructed. Often transportation projects are
51 delivered using Public Private Partnerships or variants thereof, though during operations and
52 maintenance the private sector will generally be responsible managing the asset.

53

54 Put simply, a cost overrun is traditionally defined as the ratio of the actual final costs of the project
55 to the estimate made at full funds authorization measured in escalation-adjusted terms (Morrow,
56 2011). In this instance, a cost overrun is treated as the margin between the authorized initial project
57 cost and the real final costs incurred after adjusting for expenditures due to escalation terms. While
58 not always the case, cost overruns are often accompanied by schedule overruns as well so that the
59 Government tends to be subjected to a 'double whammy'. The Edinburgh Trams project in
60 Scotland (discussed in more detail in Section 2.2 below) is an apt example. Cost and schedule
61 overruns are not mutually exclusive as they have similar causes though the strategies for mitigating
62 their consequences can be significantly different.

63

64 Despite the considerable amount of research that has been undertaken, cost overruns are a
65 pervasive problem (e.g. Vidalis and Najafi, 2004; Cantarelli *et al*, 2012a,b,c; Odeck *et al.*, 2015;
66 Love *et al.* 2015; Verjweij *et al.*, 2015). While such studies providing the essential building blocks
67 to better understand and provide a much-needed stimulus for theory that can be used to explain
68 cost overrun causation, they still remain a ubiquitous and on-going issue (e.g., Flyvbjerg *et al.*,
69 2002; Bordat *et al.*, 2004; Odeck, 2004; Flyvbjerg *et al.*, 2005; Flyvbjerg, 2007; Cantarelli *et al*,
70 2012a,b,c; Love *et al.*, 2015b). If cost overruns are to be mitigated, then there is a need to be able
71 to determine whether a set of events or propositions can be validated and their causal relationships
72 can be accepted as being true; at present, neither can be corroborated. With this in mind, this paper
73 briefly reviews the normative literature and proposes that research should focus on developing a
74 probabilistic theory of cost overrun causation.

75

76 **2.1 Cost Overruns: Points of Conjecture**

77 Reported cost overruns have been found to vary significantly between studies in various countries
78 ranging, for example, from -11 to 106% (Pickrell, 1990), -59% to 183% (Odeck, 2004), and -12%
79 and 70% (Love *et al.*, 2014). A primary reason for the disparity between studies is the ‘point of
80 reference’ from which the cost overrun is measured. Within the planning fraternity, cost overruns
81 have been generally determined as the difference between initial forecast and actual construction
82 costs (Cantarelli *et al.*, 2012a). Between the initial forecast of construction costs and the
83 commencement of construction, several estimates will be prepared and refined before being lodged
84 for approval. Odeck (2004) has however, suggested that the reference point for determining a cost
85 overrun should be at the detailed planning stage where design, specification and final cost are
86 determined. The use of the aforementioned different reference points provides varying results, in
87 the case of road projects for example, Flyvbjerg *et al.* (2002) provides a mean cost overrun of 20%
88 whereas Odeck (2004) revealed a more modest mean cost overrun of 7.9%. Using the budget at
89 the time of the decision to build as reference point, as advocated by Flyvbjerg *et al.* (2002), will
90 naturally lead to an overinflated cost overrun value, as the initial budget would not include the cost
91 the project’s new characteristics and changed scope that is included when project information has
92 become sufficiently detailed not to trigger any great variability (Allen Consulting and the
93 University of Melbourne, 2007).

94

95 Most large publicly funded projects tend to go through a long definition period after project
96 inception during which many changes to scope and accompanying costs occur. It would seem
97 misleading in some cases to make direct comparisons between the initial estimate at the ‘time of
98 decision-to-build’ and that at project completion, particularly if the estimate at the ‘time of
99 decision-to-build’ is only based only on a conceptual design (Love *et al.*, 2015b). As suggested by
100 Ahiaga-Dagbui and Smith (2014b), a more robust explanation of a cost overrun would need to
101 factor-in process and product, as well as changes to scope and specification. With changes in scope,
102 the fees of consultants may increase as well. Consequently, this may lead to the pre-construction
103 phase incurring significant *cost growth* (Ahiaga-Dagbui and Smith, 2014b). A point to also
104 consider is that there is often a tendency for Governments to anchor themselves to the initial budget
105 estimate and subsequently inform the public of the estimated cost of a project without providing
106 any form of *proviso*. The time between the establishment of the initial budget and the letting of
107 contracts for construction may be lengthy; prices of materials and labor can increase. Moreover,
108 as more information becomes readily available during the design process scope may change, which
109 can also lead to increases in cost.

110

111 2.2 *Schools of Thought on Cost Overrun Causation*

112 Two predominant schools-of-thought have emerged from the on-going discourse regarding the
113 sources of cost overruns (Ahiaga-Dagbui and Smith, 2014). These are the ‘Evolution Theorists’
114 who suggest that overruns are the result of changes in project scope and definition between
115 inception stage and eventual project completion (e.g., Odeyinka *et al.*, 2012). Sometimes scope
116 changes may account for up to 90% of what are traditionally called ‘overruns’ (Auditor General
117 of Western Australia, 2012). The other school-of-thought, is the ‘Psycho Strategists’ (i.e., which
118 is a combination of psychological contributors and business strategy) attribute overruns to
119 deception, planning fallacy and unjustifiable optimism in the setting of initial cost targets (e.g.,
120 Flyvbjerg *et al.*, 2002; Siemiatycki, 2009). Figure 1 combines these two approaches to provide an
121 overview of cost overrun causation (Figure 1).

122

123 There has been a widespread campaign by the ‘Psycho Strategists’ that *optimism bias* (i.e. the
124 underestimation of risks and overestimation of benefits) and *strategic misrepresentation* (i.e.
125 deception) can adequately explain why transportation infrastructure projects experience cost

126 overruns. While on face value there may be grounds for this argument, the evidence presented
127 lacks credibility and is unscientific; no proof of any causal relationship is provided (Love *et al.*,
128 2012; Love *et al.*, 2015a). Osland and Strand (2010) have been particularly critical of the research
129 presented in Flyvbjerg *et al.* (2002), as they conclude that they applied the logic of suspicion in
130 their claim that inaccurate cost forecasting is a result of optimism bias and strategic
131 misrepresentation. They specifically state, “Flyvbjerg and other proponents for the hermeneutics
132 of suspicion, the actors actually admitting telling lies can be seen as the tip of the iceberg. However,
133 it is also a perspective that would not be falsified if no examples of actors admitting lying were
134 found. On the contrary, it could easily be interpreted as a verification that they were lying also for
135 the researchers.” (Osland and Strand, 2010: p.81).

136

137 Contrastingly, in support of the ‘Psycho Strategists’, which focuses on specific planned actions,
138 Love *et al.* (2012) suggests that cost overruns arise as a result of a series of pathogenic influences,
139 which lay dormant within the project system as denoted in Figure 1. However, before such
140 influences become apparent, participants often remain unaware of the impact that particular
141 decisions, practices and procedures can have on project performance. Pathogens can arise because
142 of strategic decisions taken by senior management or key decision- makers. Such decisions may
143 be mistaken in the form of optimism bias, but they also may be deliberate in the form of strategic
144 misrepresentation or a political/economic decision; this is represented by the Psycho Strategist’s
145 ‘outside’ view presented in Figure 1. Latent conditions can lay dormant within a system for a
146 considerable period of time and thus become an integral part of everyday work practices.
147 Meanwhile once they combine with active failures, then omission errors can arise and their
148 consequences may be result in safety incidents and/or rework, which can contribute to an increase
149 in project costs (Figure 1).

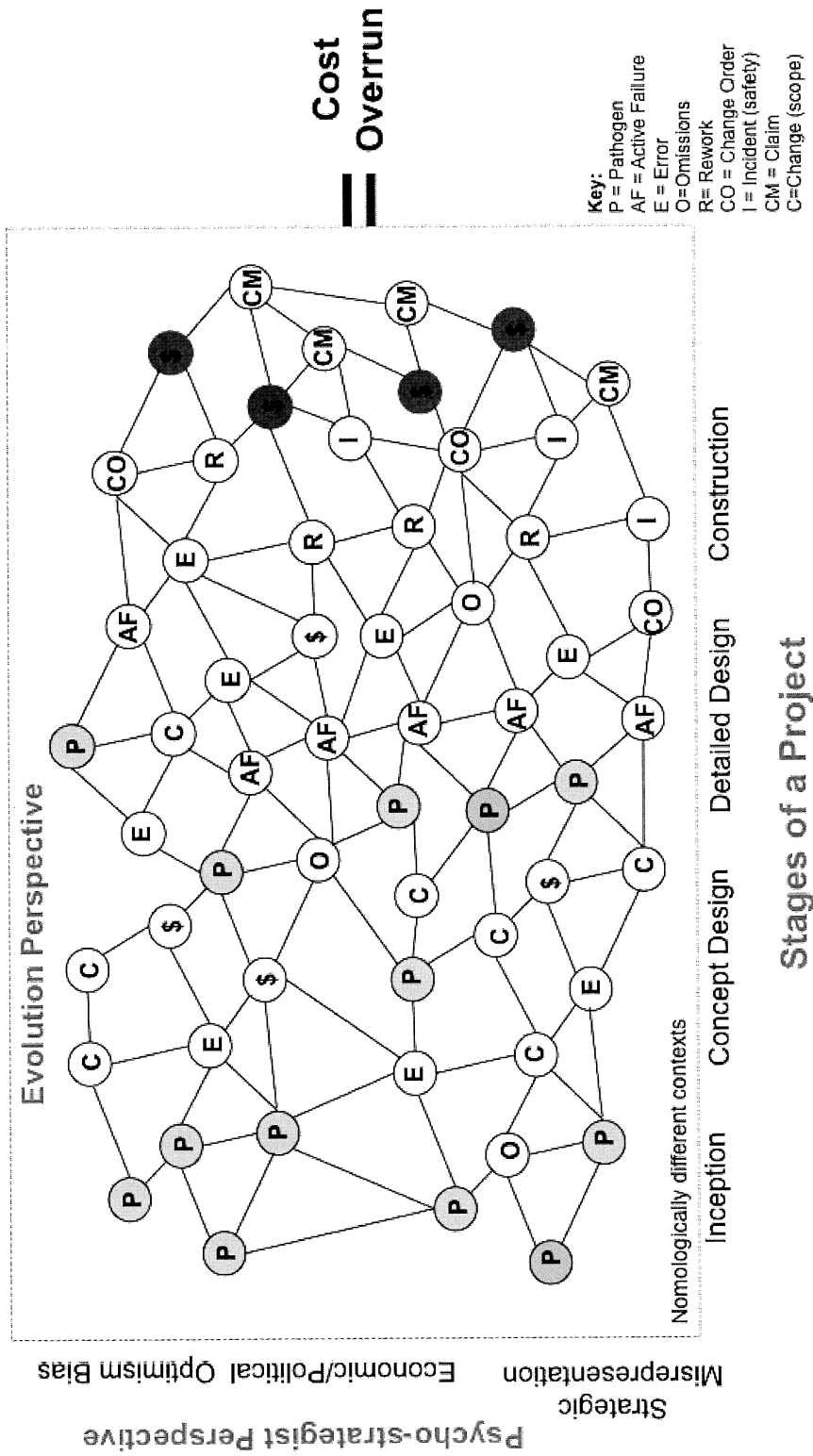
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151 Active failures are essentially unsafe acts (or those of an inappropriate nature) that are committed
152 by people who are in direct contact with a system. Such acts take the form of errors, which include:
153 slips, lapses, mistakes and procedural violations. Active failures are often difficult to foresee. As
154 a result, simply reacting to the event that has occurred cannot eliminate them. Accordingly, this
155 school of thought is widely supported by authors such as Odeck (2004) and Odeyinka *et al* (2012).
156 Essentially, Love *et al.* (2012) and Ahiaga-Dagbui and Smith (2014) conclude from their research

157 that cost overruns are not really a case of ‘projects not going according to plan (budget)’, but ‘plans
158 not going according to project’.

159
160 While Love *et al.* (2012) have been critical of the research promulgated by Flyvbjerg (2002), in
161 recent works, Love *et al.* (2015a) acknowledges that political, economic, psychological and
162 managerial factors may influence the generation of pathogenic influences (i.e. latent conditions)
163 that may arise in projects. Subsequently, Love *et al.* (2015a) have advocated for a ‘balanced
164 approach’ that focuses on how process and technological innovations can be used to improve the
165 cost performance of infrastructure projects. Fundamentally, understanding ‘why’ and ‘how’
166 projects overrun, from both ‘Psycho Strategist’ and ‘Evolution Theorists’ perspectives, is pivotal
167 to reducing their impact and occurrence; Figure 1 provides an overview of cost overrun causation
168 (Figure 1). The absence of theory has hindered the development of a ‘balanced approach’, which
169 can explain and be used to reliably predict cost overruns. Noteworthy cost overruns do not only
170 materialize due to change orders, and rework as identified in Figure 1, but also due to safety
171 incidents that may occur as a result of these events. For example, Love *et al.* (2015b,c) revealed
172 that when a rework event occurred during construction, the propensity for safety incidents to
173 materialize significantly increased, as well as project costs.

174
175 In an attempt to predict the occurrence of a cost overrun for road projects, Love *et al.* (2014)
176 ascertained using a ‘best fit’ probability distribution from an empirical distribution, and revealed
177 that a continuous *Generalised Logistic Probability Density Function* was the most appropriate to
178 use; though, a major shortcoming of this work is that the sample size was small and limited to 50
179 projects. The determination of the ‘best fit’ probability distribution provides a reliable estimate of
180 risk and ensures the effectiveness of the decision-making process (Love *et al.*, 2014b). If an
181 inappropriate probability distribution is selected, it will be misaligned with the nature of the data
182 and therefore produce inappropriate results rendering any form of risk analysis undertaken to be
183 inaccurate and unreliable. Evidence of this can be seen when a *Normal Distribution* (based upon
184 the original works of Flyvbjerg *et al.*, 2002) was assumed for predicting the cost contingency for
185 the Edinburgh Tram System in the United Kingdom. The project was originally estimated to cost
186 £320 million, which included a risk contingency based-estimate.



Psycho-strategist Perspective
Strategic
Misrepresentation Economic/Political Optimism Bias

Figure 1. Current view(s) of cost overruns in transportation infrastructure projects

190 Taking all the available distributional information into account, by considering a reference class
191 of comparable rail projects (e.g. London Docklands Light Rail); the reference class estimated an
192 80th percentile value of £400 million (Auditor General for Scotland and Accounts Commission,
193 2011). The project was completed three years late in the summer of 2014 at a reported construction
194 cost of £776 million (City of Edinburgh Council, 2014). Considering claims and contractual
195 disputes, which partly occurred due to errors and omissions in contract documentation, a revised
196 estimated final cost of over £1 billion has been forecasted, including £228 million interest
197 payments on a 30-year loan to cover the funding shortfall.

198

199 Despite the use of an inappropriate probability distribution, Reference Class Forecasting (RCF),
200 propagated by Flyvbjerg and Cowi (2004), has a number of other limitations such lack of large
201 heterogeneous samples, scarcity of project types, and an over reliance on the dependence of
202 singular causal factors to derive the estimated uplift (Liu and Napier, 2009; Liu *et al.*, 2010; Love
203 *et al.* 2015d). The interdependency that prevails between causal variables and subsequent coupling
204 of risks that materialise are negated under this approach. Thus, the accuracy and reliability of RCF
205 to be able to assess a risk of a cost overrun (using a percentage up-lift), which is added to estimate
206 as a risk contingency is questionable, especially considering the example of the Edinburgh Tram
207 System project. Surprisingly, this limitation has not been identified in the extant literature, yet
208 RCF is being used and advocated by several governments throughout Europe. It is suggested that
209 if RCF is solely relied upon to determine the issues over and above the estimated ‘contingency for
210 transportation projects, then Government’s will continue to inaccurately forecast construction
211 costs.

212

213 2.3 *Moving from Independent to Interdependent Causes*

214 There has been a proclivity for studies to explain the cause of cost overruns as ‘independent’ rather
215 ‘interdependent’ causal influences within the transportation literature (e.g., Cantarelli, 2010;
216 Verjweij *et al.*, 2015). While such studies have attempted to provide a context to explain ‘why’
217 and ‘how’ cost overruns arose, the views of those participants involved in the chain of events that
218 lead to their occurrence are generally limited to specific points in time. Thus, the determination of
219 causation is narrowly and superficially defined, which potentially leads to an innate *bias* being
220 reported (Ahiaga-Dagbui *et al.*, 2015). Furthermore, researchers have sought to pinpoint a single

221 'root cause' for a cost overrun and then suggest that an intervention to change and/or prevents its
222 occurrence (e.g. Rosenfeld, 2014). However, 'the root cause' often represents the place in a point
223 of time where a researcher decided to complete their investigation (Dekker, 2006). The use of the
224 singular, independent-cause identification approaches have led to inappropriate risk assessments
225 for cost overrun to be developed; the interdependency between causal variables has not been
226 effectively considered and accommodated. Cost overruns seldom occur as a result of a stand-alone
227 cause. Even though they may superficially appear to be different, the causes of poor performance
228 in infrastructure projects are interwoven and form a complex network. There is therefore a need to
229 move beyond simply developing lists or ranks of independent factors to understanding dynamic
230 connections between various causal factors and how they materialise during the course of a project
231 (Ahiaga-Dagbui, *et al.*, 2015; Love *et al.*, 2016). Failure to adequately understand and
232 accommodate this inherent interdependency can lead to the development of sub-optimal solutions
233 for mitigating cost overruns; for example RCF does not accommodate the coupling of risks that
234 can contribute to increasing a project's cost.

235

236 Techniques such as System Dynamics (SD) have been used extensively to model the
237 interdependencies between causal variables of cost overruns (e.g., Reichelt and Lynies, 1999; Eden
238 *et al.* 2005; Parvan *et al.*, 2015). The causal loop diagrams that emerge are invariably derived from
239 interview data whereby memory and judgment are relied upon to give an account of what
240 transpired. Thus, conditional statements are used to create an association or determine an influence
241 and while plausible, the issue of causation remains an unaddressed issue (Love *et al.*, 2016).
242 Moreover, a lack of real-life industry data to create and simulate the dynamic nature of cost
243 overruns using stock-flows also diminishes the accuracy, validity and reliability of SD models
244 (Tombesi, 2000). Considering that cost overruns have become an innate feature of transportation
245 infrastructure projects, it is now time to remedy this issue and develop a cost overrun theory of
246 causation that recognizes the interdependency that prevails within causal claims.

247

248 **3. Toward a Probabilistic Theory of Causation**

249 The development of such a theory should be able to explain and predict the occurrence of cost
250 overruns thus accommodate risk and uncertainty that can emerge in projects. However, in the case
251 of potential 'unknown, unknown' causes (also referred to as Black Swans) cannot be predicted

252 using Bayesian decision theory (Feduzi and Runde, 2014). According to Feduzi and Runde (2014)
253 the problem of uncovering ‘unknown unknowns is connected with the practicalities of ‘state space
254 construction’; that is, “the activities of generating, evaluating and a then accepting or rejecting
255 candidate hypotheses about how the world might turn out” (p.281). Prior to the introduction a way
256 forward in the development of a theory for cost overrun causation, it should be acknowledged that
257 there are many competing theories of causation in the philosophical and wider literature, but in
258 this paper probabilistic causation is the focus as it can characterize the relationship between cause
259 (*C*) and effect (*E*) using the tools of probability theory; causes change the probabilities of their
260 effects. Under the auspices of a probabilistic theory decision-makers could be confronted with
261 alternatives involving risk and may invariably need to rely on the use of probabilities rather than
262 heuristics when making a prediction of a cost overrun. This is supported by Kahneman and
263 Tversky (1982) who have distinguished between two modes of judgement during decision-making
264 under uncertainty: (1) a singular mode that generates an “inside view”, which is subjective in
265 nature and based on heuristics and biases; (2) a distributional mode that generates an “outside
266 view” based on aleatory sides of probability (p.518).

267
268 In contrast to popular belief within the transportation infrastructure literature, it should be
269 acknowledged that probability theory might not be sufficient in this case to assist with predicting
270 cost overruns. According to Gigerenzer and Hoffrage (1995) and Gigerenzer and Todd (1999)
271 people can use smart heuristics, that is, rules of thumb to make decisions when minimal
272 information is provided to them. Gigerenzer and Hoffrage (1995) have proffered that heuristics
273 should not lead decision-makers to conceive of human thinking as riddled with irrational cognitive
274 biases, but rather to consider rationality as an adaptive tool that is not identical to the rules of
275 formal logic or probability calculus. Yet, the use of probability calculus has become a norm when
276 conducting risk analysis for infrastructure projects (e.g., Flyvbjerg and Cowi, 2004; Signor *et al.*,
277 2015); an alternative is to use frequency formats that they are expressed as Bayesian algorithms,
278 which have been identified as being computationally simpler to calculate (Gigerenzer and
279 Hoffrage, 1995). A thorough discussion of decision making under uncertainty using the laws of
280 probabilities (e.g., Kahneman and Tversky, 1979;1982) or bounded rationality by employing
281 heuristics (e.g., Gigerenzer and Murray, 1987; Kruger *et al.*, 1987; Gigerenzer and Reinhard, 2002)

282 is outside the scope of this paper. However, probability and heuristics *via* the use of frequencies
283 can be incorporated within a theory of probabilistic causation and used to predict a cost overrun.

284

285 3.1 *Simpson's Paradox: From Statistical to Causal Reasoning*

286 A caveat, however, is that if frequency data is used, then possible emergence of *Simpson's Paradox*
287 needs to borne in mind (Simpson, 1951; Pearl, 2009). It refers to a phenomenon whereby the
288 association between a pair of variables (X, Y) reverses sign upon conditioning of a third variable
289 (Z), regardless of the value Z takes when data is divided into subpopulations, each representing a
290 specific value of the third variable (Z) (Pearl, 2014:p.8). The phenomenon appears as sign reversal
291 between the associations measured in the disaggregated subpopulations relative to the aggregated
292 data, which describes the population as whole.

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294 Path analysis and structural equation methods have been used extensively for analyzing causal
295 systems that have direct and indirect effects on other variables, but are also prone to experiencing
296 Simpson's Paradox (Kock, 2015). A simple example, derived from Kock (2015), is used to
297 demonstrate this phenomenon for public sector clients and the like within the context of variables
298 that have been found to contribute to cost overruns in the transportation projects. It is assumed
299 that data from 500 road projects is collected for two variables: 'degree of quality assurance of the
300 cost estimate' provided by an external consultant to government (X) (Odeck *et al.*, 2015) and the
301 extent of a cost overrun (Z). In Figure 2a a two variable path model representing this relationship
302 is presented. As this path model contains only two variables, then $p_{zx} = r_{zx} = 0.5$; where p_{zx} and r_{zx}
303 denote the path coefficient and the correlation between the two variables. In Figure 2b an
304 additional variable is introduced which is directed at Z : the degree of errors contained in the Bill
305 of Quantities (BoQ) (Y). The BoQ can be used to ensure the accuracy of the cost estimate prior
306 to the commencement of construction; hence the link $X \rightarrow Y$. The addition of the new variable led
307 to the path coefficient p_{zx} for the link between variables 'degree of quality assurance of the cost
308 estimate' (X) and 'cost overrun' (Z) to assume a negative value (-0.2), in contrast with the positive
309 correlation r_{zx} (0.5). This sign reversal characterizes Simpson's Paradox in a path model (Kock,
310 2015).

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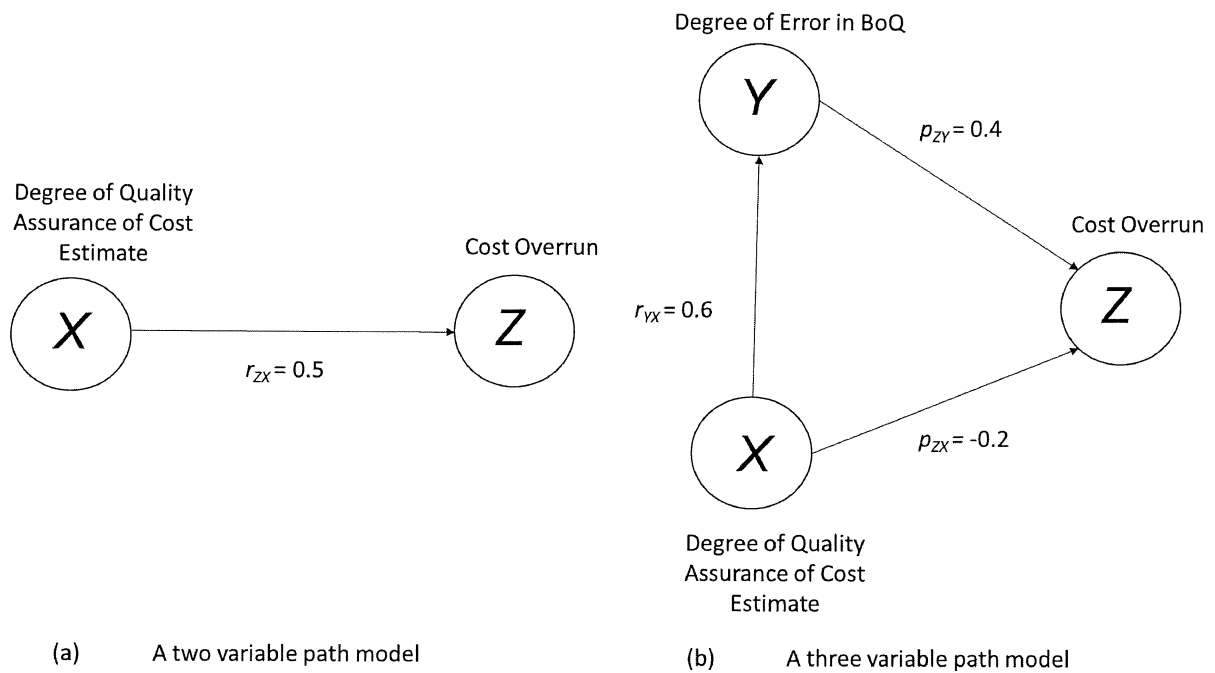


Figure 2. Path model demonstrating Simpson's Paradox

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Attempts to address Simpson's Paradox had been widespread, which led Lindley and Novick (1981) to conclude that there was no statistical criterion that could be used to forewarn someone from drawing the wrong conclusions or indicating which data represented the correct answer. Acknowledging the need to combat this problem, Pearl (1993) has shown that this statistical irregularity has causal roots and that the determination of the correct answer is insensitive to temporal information. Thus, Pearl (2009; 2014) used *causal reasoning* (i.e., ability to identify causality: the relationship between a cause and its effect, $C \rightarrow E$) to legitimize the cause-effect relationship through the use of graphical condition referred to as 'back door' (i.e., non-causal path between two variables). Pearl (2009; 2014) trace causal paths using a Directed Acyclic Graph (DAG), which is used to assure that spurious paths are intercepted by the third variable; in doing so, Pearl (2014) has announced that Simpson's Paradox is now resolved using causal reasoning. Pearl (2014) points out that Simpson's Paradox "is a reminder of how easy it is to fall into a web of paradoxical conclusions when relying solely on intuition, unaided by rigorous statistical methods (p.8)

330 *3.2 Probabilistic Causation*

331 Causality (also referred to as causation) governs the relationship between events and as such has
332 been at the heart of philosophy since Aristotle. A plethora of theories of causality have evolved
333 (e.g., Hume, 1896; Russell, 1913; Gasking, 1955; Lewis, 1973; McDermott, 1995; Ramachandran,
334 1997; Nordoff, 1999). According to Williamson (2009) philosophical theories of causation can be
335 categorized according to the way they answer a range of questions such as: (a) Are causal relations
336 single-case or generic? (b) Is there a physical connection between the cause and effect or is it a
337 feature of an individual's epistemic state? And (c) Does the theory in question attempt to
338 understand actual or potential causality?

339

340 The philosophy of causation, however, has been typically dominated by advocates of a causal
341 mechanical view (e.g., Salmon, 1984, Salmon, 2000), those that take a counterfactual stand, which
342 have been based primarily upon the work of Lewis (1973), and dualists, who seek to combine both
343 the aforementioned perspectives (e.g., Hall, 2004). These theoretical viewpoints have tended to
344 conceptually analyse causal claims in an everyday language and the metaphysical issues of
345 causation (Weber, 2009). Yet, to analyse how causation functions in science requires the use of a
346 probabilistic approach (Weber, 2009).

347

348 Fundamentally, probabilistic theories of causality aim to characterise or analyse causality in terms
349 of probabilistic dependencies. Such theories try to provide probabilistic criteria for determining
350 whether *A* causes *B* maintaining that causality just is the corresponding pattern of probabilistic
351 relationship (Williamson, 2009). A wealth of probabilistic theories have been proposed over the
352 last century, with the most notable philosophers laying its foundations being Reichenbach (1923),
353 Good (1959), Suppes (1970), Humphreys (1989) and Eells (1991). According to Williamson
354 (2009) probabilistic theories that have been developed focus on the following key elements: "(a)
355 changing a cause makes a difference to its effects, and (b) this difference –making shows up in
356 probabilistic dependencies" (p.187). In addition, proponents of probabilistic theories have also
357 maintained that probabilistic dependencies characterise the causal relation; that is, "provide the
358 necessary and sufficient condition for causal connection of the form: *C* causes *E* if and only if
359 appropriate probabilistic dependencies obtain" (Williamson, 2009:p.187).

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361 A detailed critique of the probabilistic theories of causation can be found in Williamson (2009),
362 Weber (2009) and with additional limitations regarding counterfactuals and pre-emption being
363 addressed in Noordorf (1999). However, the specific limitations are briefly presented and brought
364 to the fore, which include the discounting of mechanistic evidence and context unanimity. For
365 example, Suppres (1970) assumed genuine probabilistic causes are prima facie (i.e., a first
366 appearance) and not spurious. A prima facie cause is defined when (Suppres, 1970; p.12):

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368 The event B_t is a prima facie cause of event A_t , if and only if:

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370 $t' < t$

371 $P(B_{t'}) > 0$

372 $P(A_t|B_{t'}) > P(A_t)$

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374 Furthermore, spurious causes are defined as:

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376 An event $B_{t'}$ is a spurious cause in the sense of A_t , if and only if, B_t is a prima facie cause of A_t and
377 there is a $t'' < t'$ and an event $C_{t''}$ such that:

378

379 $P(B_{t'}C_{t''}) > 0,$

380 $P(A_t|B_{t'}C_{t''}) > P(A_t|C_{t''}),$

381 $P(A_t|B_{t'}C_{t''}) \geq P(A_t|B_{t'})$

382

383 Suppres (1971) answers the question “What do probabilistic chains mean?” and reveals that
384 presence and absence of statistical relevance relations in the real world. For policy makers, such
385 as Government, they would be supplied with causal knowledge and with no explicit link between
386 causation and policy, as it refers to the real world and not the hypothetical that they like to create.

387 In addition, mechanistic evidence is discounted when probabilistic evidence is introduced. Here
388 specific information (probabilistic dependencies) is used to define the meaning of causation
389 (Weber, 2009).

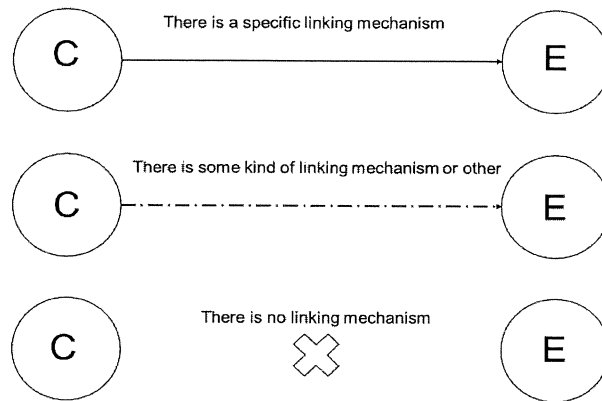
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391 Eells (1991) also defines causation in terms of positive statistical relevance, and thus faced a
392 similar problem to Suppes (1971). However, Eells (1991) introduced the concept of *context*
393 *unanimity* whereby a cause must raise the probability of its effect in *every* background context.
394 Thus Eells (1991) states: “X is a *positive causal factor* for Y if and only if, for each *i*, $Pr(Y|K_i \& X)$
395 $> Pr(Y|K_i \& \sim X)$. Negative causal factorhood and neutrality are defined by changing the “always
396 rises” (>) idea to “always lowers” (<) and “always leaves unchanged” (=), respectively. The idea
397 that the inequality or equality must hold for each of the background contexts K_i (p.86). The
398 characteristic property of causes here is unable to be reversed (from positive to negative) or
399 overpowered (from positive or negative to casually neutral) in a subpopulation. Bearing this in
400 mind Governments (who are policy-makers), for example, are only concerned with average
401 effects of cost overruns on their projects, not the causes in the sense of context unanimity. In
402 summary, governments would be interested in likelihood of a project experiencing a cost overrun
403 and not necessarily the specific causes that would potentially arise.

404

405 To establish a causal claim, there is a need for mutual support of both mechanisms and
406 dependencies (Russo and Williamson, 2007); this view is referred to by Weber (2009) as *evidential*
407 *pluralism*. It has been proposed by Russo and Williamson (2007) that to establish a causal claim
408 two things are required: (1) a cause makes a difference to the effect, and (2) that there is a
409 mechanism from cause to effect. In the case of being able to establish a causal claim for cost
410 overruns, the evidence-based medicine can be drawn upon, whereby both mechanistic (bottom-up
411 evidence) and probabilistic evidence is required to substantiate a causal claim. Glennan (1996)
412 states a mechanism underlying behaviour is a complex system, which produces that behaviour by
413 the interaction of a number of parts to direct causal laws (p.52). The inclusion of such a mechanism
414 in a theory of probabilistic causation for cost overruns is deemed to be necessary as it can
415 accommodate the social system and subsequent interactions that invariably prevail within project
416 environments used to deliver transportation infrastructure. Sources of evidence of mechanisms
417 may include direct observation, experiments, statistical analysis, documentary sources, simulation,
418 and experience (Clarke *et al.*, 2014). Figure 3 categorizes of evidence of mechanisms linking an
419 assumed cause (*C*) with effect (*E*) are presented (Clarke *et al.*, 2014).

420



(Adapted from Russo, 2014)

421
422
423
424
425

Figure 3. Categories of evidence of mechanism

426 In the first instance, the evidence of mechanism explicitly indicates that provided is relevant. For
427 example, it has been widely demonstrated that there is a correlation between change orders and
428 cost increases in projects (e.g., Bordat *et al.*, 2004); this is not to say that such statistical analysis
429 should be solely relied upon, but it can provide a high degree of confidence that $C \rightarrow E$. In the
430 second instance, presented in Figure 2, there is an initial reason to believe that $C \rightarrow E$, for example
431 a drawing error contributes to a change order but whether error was created by an architect or
432 structural engineer is difficult to determine as it could appear on both sets of drawings that were
433 created. Interrogation of correspondence and documentation would reveal why and how the cause
434 originated. Such a process, however, should not be about apportioning blame but understanding
435 why it occurred and assessing the likelihood it would occur again, even if an intervention strategy
436 were introduced. In the final example evidence of mechanism is self-explanatory, there is no
437 mechanism, but it is important to acknowledge as it can be used to define the space of possible
438 mechanisms of action and the likely causal relations between C and E .

439

440 Ultimately, whether a causal claim is accepted or not is dependent on the quality of evidence that
441 can be accumulated and underlying reasoning between causal connections. Commencing the
442 evidence gathering process from a tactical level (i.e., bottom-up) can provide assumptions and
443 insights about the rational/or non-rational decision-making that determine the behaviour of people
444 that lead to events where a cost increase was incurred. The established assumptions can be used
445 to infer causal relations on the higher level (i.e. operational).

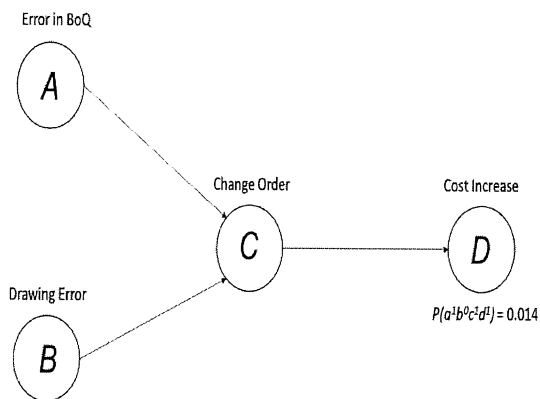
446 **4. Future Research**

447 Probabilistic causal inferences about cost overruns can be acquired from a combination of
448 assumptions, experiments and data. But, the challenge for researchers addressing this pervasive
449 and complex problem has been the lack of a formal language that can be used to explicate,
450 determine, and predict their occurrence. Causal graphical models have been advocated as a
451 formalism for learning and reasoning about causal relationships (e.g. Pearl, 2009). Such models
452 are often referred to as Bayesian Networks (BN) and provide a means of specifying the causal
453 relationships that hold among a set of variables. A central feature of BN is the DAG that provides
454 an intuitive representation for the causal structure relating to a set of variables. An example of
455 DAG and a simple example of how a cost increase arises due to result of errors in BoQ and
456 drawings, which lead to a change order is presented in Figure 4. In this instance both mechanisms
457 and dependencies could be used to construct a DAG, but the nature of relationships is not defined;
458 they can be deterministic or probabilistic. Moreover, multiple causes of an effect can act
459 independently or strongly interact.

460

461 Determining the nature relationship between variables to establish a causal claim is an issue that
462 needs to be considered when developing a theory for cost overrun causation; essentially this is an
463 epistemological issue, which can be addressed through evidence of mechanisms (Clarke *et al.*,
464 2014). Another consideration to be borne in mind when establishing a causal claim is
465 methodological; that is, the evidence-gathering methods to be used. Consideration of the type of
466 information and how it is collected needs to be made with specific emphasis being placed on
467 establishing causal claims within a project. A major limitation of previous cost overrun research
468 that has examined causation in transportation infrastructure projects has been its emphasis on the
469 creation of causal claims from heterogeneous samples.

470



Here there are four two-valued variables, A, B, C, D . A BN can be formed by taking the DAG of and specifying the probability distribution of each variable conditional on its parents:

$$P(a^1) = 0.2, P(a^0) = 0.8$$

$$P(b^1) = 0.7, P(b^0) = 0.3$$

$$P(c^1|a^1 b^1) = 0.4, P(c^0|a^1 b^1) = 0.6$$

$$P(c^1|a^0 b^1) = 0.5, P(c^0|a^0 b^1) = 0.5$$

$$P(c^1|a^1 b^0) = 0.2, P(c^0|a^1 b^0) = 0.8$$

$$P(c^1|a^0 b^0) = 0.3, P(c^0|a^0 b^0) = 0.7$$

$$P(d^1|c^1) = 0.8, P(d^0|c^1) = 0.2$$

$$P(d^1|c^0) = 0.6, P(d^0|c^0) = 0.4$$

In this instance,

$$P(a^1 b^0 c^1 d^1) = P(a^1)P(b^0)P(c^1|a^1 b^0)P(d^1|c^1) = 0.0144$$

471

Figure 4. Hypothetical example of a DAG for a cost increase

472

473 This aggregation of data has resulted in a high degree of causal ambiguity and limited
474 understanding about causal inferences of cost overruns within the extant transportation literature.

475 Future research therefore should place emphasis on deconstructing what is already known about
476 the causal nature of cost overruns to arrive at point where the ‘noise’ within the data is reduced
477 and causal reasoning can be applied. From a practical perspective, this poses a major challenge,

478 as more often than not access is restricted to organizations and participants within a project due to

479 commercially sensitive reasons. The challenge here is for researchers to actively engage with

480 government and organizations to ensure that they are able to capture the ‘practice’ that contributes

481 to cost overruns. To understand the nomological context of cost overruns that may prevail, it is

482 suggested that ‘sensemaking’ (e.g., Wieck *et al.*, 1988, 1993; 1995; Goh *et al.*, 2012) form the

483 epistemological underpinning used to derive causal inferences. Here ‘sensemaking’ can be used

484 as process to ensure evidence of mechanism, as people can provide meaning to experience through

485 the ‘practice’ used to deliver projects. Notwithstanding, there are several broad philosophical

486 questions that need to be explored about their causal reasoning of cost overruns.

487

488 Drawing on the work of Claveau (2013:p.122) the following questions are proposed: (1) What are
489 the meaning of causal chains? Here the inferential relationships between events are determined.
490 (2) How can causal chains be supported by evidence? This is necessary considering the multiple
491 parties involved in a project and the complexity of relationships that exist. (3) How are causal
492 beliefs affected by new information (e.g., with the advent of BIM, how will beliefs be influenced)?
493 Once a causal chain is established and new information is made available, will the underlying
494 dynamics of it change? Addressing such questions will provide the seeding for the development
495 of a theory for cost overrun causation.

496

497 **5. Conclusion**

498 Transportation infrastructure is pivotal to improving an economy's productivity and society's over
499 all well-being. Thus, when cost overruns are experienced this has a direct negative impact on the
500 economy, and the taxpayer. Unfortunately cost overruns are a norm rather than an exception;
501 despite the accumulated knowledge that has sought to explain and predict their occurrence, there
502 remains limited understanding about their causal nature. To make decisions and implement risk
503 mitigation strategies to contain and reduce the likelihood of a cost overrun being experienced,
504 requires diagnosis – to determine its probable causes. Research undertaken to date has not been
505 able to effectively undertake this task regardless of the well-intentioned studies that have been
506 conducted.

507

508 Hindering this process of knowledge creation has been the absence of 'theory' and an
509 epistemological lens that can enable 'practice' to be captured, dissected and put together to develop
510 causal claims. In addressing this issue, this paper has suggested that there is a need re-examine
511 cost overrun from the perspective of pluralistic probabilistic causation so that it can be explained,
512 predicted and managed. In particular, it has been promulgated that the use of pluralistic approach
513 that considers mutual support of both mechanisms and dependencies is required so that 'practice'
514 that arises during the delivery of transportation infrastructure projects can be realized and used to
515 construct causal graphical models. Such models provide a formalism for learning and reasoning
516 about causal relationships that contribute to cost overruns. It is recognized that the establishment
517 of such causal relationships will be an arduous process considering the multitude of organizations
518 involved in delivering transportation infrastructure projects. If, however, headway is to be made

519 in tackling the cost overrun phenomena, then there is a need to acknowledge, understand, and
520 become immersed in practice rather than cherry picking from it using epistemological and
521 methodological approaches that are unable to accommodate for the creation of the situational
522 awareness required to develop the basis for causal claims.

523

524 This paper has not sought to provide a solution but instead sow the seeds for the development of a
525 theory of probabilistic causation for cost overruns in transportation infrastructure. A wealth of
526 research will be required to develop such a theory, but the authors hope that this paper provides a
527 way forward in this fertile area for Governments to consider in the future policy-making.

528

529 **Acknowledgment**

530 The authors would like to acknowledge the financial support provided by the *Australian Research*
531 *Council* (DP160102882). The authors would like to thank the anonymous reviewers for their
532 constructive comments, which have helped improve the quality of this manuscript.

533

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