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Cost performance of public infrastructure projects

The nemesis and nirvana of change-orders

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1 **Cost Performance of Public Infrastructure Projects: The** 2 **Nemesis and Nirvana of Change-Orders**

3
4 **Abstract:** The cost performance of a wide range of public sector infrastructure projects completed
5 by a contractor are analyzed and discussed. Changes-orders after a contract to construct an asset
6 was signed were, on average, found to contribute to a 23.75% increase in project costs. A positive
7 association between an increase in change orders and the contractor's margin was identified.
8 Taxpayers pay for this additional cost, while those charged with constructing assets are rewarded
9 with an increase in their margins. As the public sector embraces an era of digitization, there is a
10 need to improve the integration of design and construction activities and engender collaboration
11 to ensure assets can be delivered cost effectively and future-proofed. The research paper provides
12 empirical evidence for the public sector to re-consider the processes that are used to deliver their
13 infrastructure assets so as to reduce the propensity for cost overruns and enable future-proofing to
14 occur.

15
16 **Keywords:** Change-orders, public sector, cost performance, infrastructure, procurement.

23 **Introduction**

24 Cost overruns have been and continue to be the *bête noire* for the public sector in Australia (Love
25 *et al.*, 2015a; Love *et al.*, 2017a;b); this also is a problem worldwide (Flyvbjerg *et al.*, 2002;
26 Cantarelli *et al.*, 2012; Odeck, 2014). Cantarelli *et al.* (2012) has revealed that the size of the cost
27 overrun that can materialize (i.e., from the decision to build to a project’s practical completion)
28 varies by geographical region. Similarly, Flyvbjerg (2008) has declared that specific types of
29 transportation infrastructure projects (e.g., rail, roads, and bridges) display similar cost overrun
30 profiles, irrespective of their geographical location, the technology used, and contractual method
31 employed in their delivery.

32
33 A significant problem that has been consistently identified as a contributor to increasing an asset’s
34 construction costs is the quality of the contractual documentation that is produced (e.g., Jarkas,
35 2014). The errors and omissions that often materialize in contract documentation, for example,
36 typically do not come to light until construction has commenced, and can therefore result in
37 change-orders occurring (i.e. additional work and/or rework). Fundamentally, change-orders lead
38 to unintended consequences; in their basic form this is an increase in project costs for the public-
39 sector client, but for contractors it can result in increased margins. There has been a tendency to
40 overlook this dynamic, as data is not readily available due to commercial confidentiality. A
41 change-order is essentially a client’s written instruction (or their representative) to a contractor,
42 issued after the execution of a construction contract, which authorizes a change to the work being
43 undertaken and contract time and/or amount.

44

45

46 In this paper, the cost performance of a wide range of infrastructure projects (n=67) completed
47 between 2011 to 2014 are analyzed and discussed to illustrate the prevailing problem that confronts
48 the public sector when it opts to use traditional (design-bid-construct) procurement methods or
49 variants thereof to deliver their assets. The research presented in this paper provides much needed
50 empirical evidence for the public sector to re-consider the processes that are used to deliver their
51 infrastructure assets so as to reduce the propensity of cost overruns occurring and ensure better
52 value-for-money (VfM) to the taxpayer.

53

54 **Cost Performance**

55 For the public sector, managing the cost performance of their portfolio of projects is essential to
56 ensure taxpayers are being provided with an asset that is able to deliver VfM; this is a critical
57 metric, as it quantifies the cost efficiency of the work that is completed. Cost performance is
58 generally defined as the value of the work completed compared to the actual cost of progress made
59 on the project (Baccarini and Love, 2014). For the public sector, the ability to reliably predict the
60 final cost of construction of an infrastructure asset whilst ensuring it does not experience a cost
61 overrun is vital for the planning and resourcing of other projects or those in the pipeline. In this
62 case, a cost overrun is defined as the ratio of the actual final costs of the project to the estimate
63 made at *full funds authorization* measured in escalation-adjusted terms. Thus, a cost overrun is
64 treated as the margin between the authorized initial project cost and the real final costs incurred
65 after adjusting for expenditures due to escalation terms.

66

67 Deloitte Access Economics (2014), for example, have revealed that on average, completed
68 economic infrastructure projects in Australia experience a cost overrun of 6.5% in excess of their

69 initial estimate. Moreover, projects in excess of AU\$1 billion have been found to experience an
70 average cost overrun of 12.7%. Higher values have been reported in Flyvbjerg *et al.* (2002) who
71 examined the cost overruns of 258 transportation projects and revealed a mean cost overrun of
72 32.8% from the budget established at the decision to build to the completion of construction.
73 Contrastingly, Love (2002) found that cost overruns from the final tender sum to completion of
74 construction for a sample 169 projects to possess a mean cost overrun of 12.6%. Terrill and
75 Danks's (2016) comprehensive analysis of 836 transportation infrastructure projects valued in
76 excess of AU\$20 million revealed that 90% of the total increase in costs incurred in Australia can
77 be explained by 17% of projects that exceed their cost by more than 50%. In addition, Terrill and
78 Danks (2016) revealed that 24% of projects exceeded the cost announced by the incumbent
79 Government, and 9% were delivered under their publicized budget.

80
81 The disparity between the reported magnitude of cost overruns that have been experienced arises
82 due to the 'point of reference' from where they are determined in a project's development process
83 (Siemiatycki, 2009; Love *et al.* 2016). A review of the literature reveals cost overruns have been
84 typically determined between the: (1) initial forecasted budget (i.e. base estimate) and actual
85 construction cost (Cantarelli *et al.* 2012); (2) detailed planning stage and actual construction costs
86 (Odeck, 2004); and (3) establishment of a contract value and actual construction costs (Love *et al.*,
87 2015b).

88
89 These differences, in part, arise as there is a tendency for public infrastructure projects to engage
90 in a lengthy 'definition' period after the decision-to-build and a base estimate has been established.
91 Needless to say, such a protracted period can result in projects being susceptible to experiencing

92 change-orders, which can lead to cost increases being incurred (Allen Consulting and the
93 University of Melbourne, 2007). With this in mind, it is suggested that it is misleading to make
94 direct comparisons between the base estimate at the time of the decision-to-build and actual
95 construction costs, as the estimate that is initially prepared is typically based upon a conceptual
96 design. As noted in Figure 1, the accuracy of an estimate improves as more information becomes
97 available (e.g., scope is defined and users' requirements are identified). In Figure 1, Ashworth's
98 (2008) percentage range for each type of estimate that is produced during the design development
99 phase of a project is presented (p.251).

100

101 At this juncture, it is important to mention that the Royal Institution of Chartered Surveyors (RICS)
102 under the auspices of the 'New Rules of Measurement' advocate that all estimates are expressed
103 as a single figure (RICS, 2012). The use of such a precise figure is failing the basic tests of validity:
104 accuracy and precision (Newton, 2012). The inadequacies of the traditional estimating process are
105 camouflaged by the use of deterministic percentage additions that take the form of a contingency,
106 which cater for an increase in a project's cost due to: (1) variability (i.e. random uncertainty); (2)
107 risk events; and (3) unforeseeable situations (Baccarini and Love, 2014). In stark contrast to the
108 deterministic approach, it has been suggested the application of a probabilistic approach to
109 determining a construction cost contingency based upon empirical analysis of a wide range of
110 infrastructure projects should be applied (e.g. Baccarini and Love, 2014).

111

112 Generally, the construction contingency percentages applied to public infrastructure projects have
113 been unable to accommodate increases in cost that are incurred. For example, Baccarini and Love
114 (2014) analysis of 228 water infrastructure projects revealed that the mean percentage addition

115 was 8.46% of their contract value, but the construction contingency requirement for the final cost
116 was 13.58%; a shortfall in contingency in the region of 5%. The magnitude of this percentage
117 addition, while evidently inaccurate, can vary with the nature of the project and the type of
118 procurement method adopted. For example, in the case of a greenfield project that is being
119 delivered via a traditional procurement method (e.g., Construct Only), the design and
120 specifications (including drawings and Bills of Quantities (BoQ)) for a project are supposed to be
121 complete at the award of a tender and thus a construction contingency between 2% and 5% is often
122 provided. As a result, there is a perception that a high degree of cost certainty will ensue, but in
123 reality this is fallacy, as complete drawings and BoQs are seldom available when a project goes to
124 tender. As previously mentioned, they invariably contain errors and omissions, which can lead to
125 change-orders and rework and increased construction costs (Love *et al.*, 2012).

126

127 Brownfield projects can be considered to be higher risk ventures than greenfield sites (e.g., due to
128 geotechnical uncertainties, contaminated soil and neighboring structures). Thus, in the case of
129 Brownfields projects, a public sector client may opt to use a non-traditional procurement route
130 (e.g. Design and Construct) and transfer the associated risks for the development to a single-entity
131 as well as be provided with a Guaranteed Maximum Price, for the works. Any changes in the scope
132 of work under this form of contractual arrangement, however, will require a client to pay a
133 premium for any changes that are required. It is, therefore, necessary to have a sufficient
134 contingency allowance in place should the need for amendments arise (De Marco *et al.*, 2015).

135

136

137 ***Explanations for Deviations in Cost Performance***

138 The literature is replete with explanations as to ‘how’ and ‘why’ the cost performance of public
139 sector infrastructure projects deviates from their expected outturn cost (e.g., Pickrell, 1992; Bordat
140 *et al.* 2004; Odeck, 2004; Siemiatycki, 2009; Odeck *et al.*, 2015). According to Love *et al.* (2016)
141 two schools of thought have emerged explaining deviations in the cost performance of
142 infrastructure projects: (1) ‘Evolution Theorists’, who have suggested that cost deviations
143 materialize as a result of changes in scope and definition between a project’s inception and
144 completion. The Office of the Auditor General in Western Australia (2012), for example, revealed
145 that changes in scope were the primary culprit that had contributed to cost overruns occurring in
146 their major capital projects. Next are (2) ‘Psycho Strategists’ who have advocated that projects
147 experience cost overruns due to deception, planning fallacy and unjustifiable optimism bias in
148 establishing the initial cost targets (Flyvbjerg *et al.* 2002; Siemiatycki, 2009). According to
149 Flyvbjerg (2003) those responsible for determining the budget for an infrastructure project are
150 often subjected to applying Machiavelli’s formula to ensure it is given approval to proceed: costs
151 are underestimated (-), revenues are over estimated (+), environmental impacts undervalued (-)
152 and development effects are overvalued (+) (p.43).

153

154 Often estimators/planners only consider the information that is made available to them for the
155 particular project they are involved with delivering; such a focus is referred to as having an ‘inside
156 view’ (Flyvbjerg *et al.*, 2005). In particular, Kahneman and Lovallo (1993) observed that “the
157 inside view is overwhelmingly preferred in intuitive forecasting. The natural way to think about a
158 problem is to bring to bear all one knows about it, with special attention to its unique features”
159 (p.26). Contrastingly, an ‘outside view’ recognizes that projects of a similar nature should be used
160 as a reference point when assessing a project (Kahneman and Lovallo, 1993). By adopting an

161 'outside view' Flyvbjerg (2008) suggests that a more realistic forecast of cost can be acquired and
162 thereby reduce the propensity for optimism bias to arise.

163

164 In theory, the proposition that has been proposed by Flyvbjerg (2008) is plausible, however, in
165 practice a different reality exists (Love *et al.*, 2016). For example, Perth Arena's initial budget
166 estimate was established based on square meter rate with reference to Melbourne Park's Multi-
167 Purpose Venue (formerly known as Vodafone Stadium and with a construction cost of AU\$65
168 million in 2000). The initial estimate was AU\$165 million, which then increased to AU\$343 within
169 two years, and with a final completion cost in excess of AU\$550 million (Office of the Auditor
170 General, 2010). According to Love *et al.* (2016) both 'inside' and 'outside' views need to be
171 adopted to adequately explain the causal nature of cost overruns. However, the research presented
172 in this paper does not seek to explain 'why', but bring to the fore 'how' cost overruns occur by
173 illustrating the direct financial consequences of poorly managed public infrastructure projects. At
174 the time a project's contract is signed, cost certainty should be affirmed, unless a form of cost-plus
175 agreement is otherwise agreed.

176

177 **Illustrative Case Study**

178 Most research studies that have examined the cost performance of infrastructure projects have
179 tended to rely upon heterogeneous datasets (e.g., Flyvbjerg *et al.*, 2002; Cantarelli *et al.*, 2012).
180 Such datasets are loosely connected and thus there is a propensity for them to possess a
181 considerable amount of 'noise', as a morass of missing information is adequately needed to explain
182 the nature of a project's cost performance (e.g. by way of an asset owners' aims and objectives,
183 planning requirements, contractors, project teams, technologies, and contractual arrangements).

184 Instead, this research sought to obtain an ameliorated understanding of the impact of change-orders
185 on the public sector and contractors financial performance.

186

187 To illustrate how the cost performance of infrastructure projects varies and provide an insight to
188 the problem that confronts the public sector, a case study is used (Fry *et al.*, 1999). Typically, an
189 illustrative case study is used to describe an event; they utilize one or two instances to demonstrate
190 the reality of a situation (e.g., change-orders and margin). In this instance, the case study provides
191 a platform to demonstrate that the cost performance of public sector projects has been mismanaged.
192 The case study serves to make the ‘unfamiliar, familiar’, and provide a common language for the
193 nature of infrastructure projects’ cost performance. A homogenous dataset (i.e. in terms of
194 processes, technologies, procedures and processes) from a contractor who completed a wide range
195 of infrastructure projects between 2011 to 2014 are examined where their final accounts had been
196 completed; that is, the final payment made to the contractor on completion of the works described
197 in the contract and payments owing being made at the end of the defects liability period (typically,
198 6-12 months after handover). Selecting only those projects that had their final accounts completed
199 enabled an accurate assessment of their cost to be determined. No project sampled was subjected
200 to open tendering, and several were delivered within a Building Information Modelling (BIM)
201 environment. Individual names, locations, and the Level of Development (LOD) specification of
202 projects are withheld and the data aggregated for reasons of commercial confidentiality.

203

204

205

206 **Analysis and Findings**

207 Cost data from 67 completed infrastructure projects were provided, which included their
208 procurement method, original contract value (OCV), final contract value, contractor's margin, total
209 of client approved change-orders, and final contractor's margin. Table 1 provides a summary of
210 the types and procurement methods for the 67 infrastructure projects that were constructed
211 throughout Australia within the study period (Table 1). 'Building' (n=16, 24%) (e.g., hospitals,
212 schools and civic assets) and 'Rail' (n=16, 24%) and 'Civil' (n=22, 33%) (i.e., miscellaneous
213 works such as dam upgrades and earthworks) were the most popular types of projects that were
214 constructed. A variety of procurement methods were selected by the public sector to deliver their
215 assets (Table 1); 65 (44%) were traditional 'Construct Only' lump sum contracts and the remainder
216 being non-traditional methods with the most popular form being 'Design and Construct',
217 (n=13,19%). Tables 2 and 3 provide an overview of the cost performance parameters of projects
218 and a breakdown by their type, respectively.

219

220 ***Cost Performance***

221 The value of the contracts that had been awarded by the public sector varied, though a significant
222 proportion were less than AU\$100 million (n=55, 82%) as denoted in Figure 2. The contract value
223 of the projects ranged from approximately AU\$1.8 million to AU\$318 million, with a mean of
224 AU\$48 million (Table 2). More specifically, 'Civil', (43%) 'Building' (25%) and 'Rail' (20%)
225 project types accounted for a majority of the contractor's turnover from 2011 to 2014 (Table 3).

226

227 It can be seen that the cost performance of projects ranged from -42.88% to + 270.93% of budget
228 with a mean cost overrun of 23.75% as a proportion of the OCV. This finding is in stark contrast
229 to Love (2002) who reported a mean cost overrun of 12.6% of the OCV, with 48% being

230 attributable to change-orders and the remaining 52% being due to rework. All projects that utilized
231 BIM to a minimum of LOD 300 experienced cost increases; in this instance specific model
232 elements are demonstrated as specific assemblies accurate in terms of quantity, size, shape,
233 location and orientation.

234

235 A total of 67% (n=45) of projects incurred a cost overrun of less than 25% of the OCV and 9%
236 (n=6) experienced a cost underrun. A *Grubbs* test was used to detect outliers from a Normal
237 Distribution with the tested data being the minimum and maximum values (Grubbs, 1950). The
238 result is a probability that belongs to the core population being examined. The test is based on the
239 difference between the mean of the sample the most extreme data considering the standard
240 deviation is considered. So, if the data is approximately normally distributed, then outliers are
241 required to have Z-scores ± 3 . Outliers possessing a Z-score in the range ± 2 to 3 can be considered
242 to be ‘borderline’ outliers. As denoted in Figure 3, two projects were identified as being
243 ‘borderline’ with Z-scores being between +2 and +3 and two outright outliers being in excess of
244 +4. Considering these Z-scores, the ‘best fit’ distribution was determined. Considering the outliers
245 that were present, a Normal Distribution was not deemed to be the ‘best fit’ distribution’ for the
246 data.

247

248 The ‘best fit’ probability distribution for ‘cost performance’ was examined so that probability of
249 cost deviations (i.e., underruns and overrun) could be determined at the point of contract award
250 (Love *et al.*, 2013); the computation of such a distribution is both pertinent to the public sector and
251 contractors as part of formulating a risk management strategy for their projects. A caveat, however,
252 needs to be made here; the data’s homogeneity would likely provide a more accurate assessment

253 of risk for the contractor, but could provide public sector clients with ‘ballpark’ probabilities to
254 formulate future construction contingencies. ‘Underruns’ and ‘overruns’ should be separated when
255 examining cost performance, but considering the limited number of projects that were below the
256 agreed contract value it was decided to combine them together in this case.

257

258 Using the ‘Goodness of Fit’ Kolmogorov-Smirnov (D), and Anderson-Darling (A^2) tests it was
259 revealed that *Generalized Extreme Value* (GEV) distribution with parameters $k = 0.51$, $\sigma = 11.98$,
260 $\mu = 4.43$ was identified as the ‘best fit’ solution for examining the cost performance for the sample
261 of projects. The Kolmogorov-Smirnov (K-S) test revealed a D statistic of 0.13204 with a P -value
262 of 0.17669. The Anderson-Darling (A-D) statistic A^2 was revealed to be 5.2189. The K-S test
263 accepted the Null Hypothesis (i.e., H_0 where it is assumed that there is no difference in parameters)
264 for the sample distribution’s ‘best fit’ at the critical nominated α values of 0.2, and at 0.01 for the
265 A-D test. The resulting GEV probability density function (PDF) is expressed as:

266

$$267 \quad f(x) = \begin{cases} \frac{1}{\sigma} \exp(-(1 + kz)^{-\frac{1}{k}}) (1 + kz)^{-1-\frac{1}{k}} & k \neq 0 \\ \frac{1}{\sigma} \exp(-z - \exp(-z)) & k = 0 \end{cases} \quad [\text{Eq.1}]$$

268

269

270 where $z=(x-\mu)/\sigma$, and k , σ , μ are the shape, scale, and location parameters respectively. The scale
271 must be positive ($\sigma > 0$), the shape and location can take on any real value. However, the range
272 of definition for the GEV distribution depends on k :

273

274 $1 + k \frac{(x - \mu)}{\sigma} > 0 \text{ for } k \neq 0$
275 $-\infty < x < +\infty \text{ for } k = 0$

[Eq.2]

276
277 Using the GEV PDF the probability of cost overrun of 23.75% is 73% (P=0.73). The proportion
278 of projects (67%) that experienced less than 25% cost overrun had a mean of 7.9%; the probability
279 a project exceeds its OCV is 0.58%.

280
281 The detailed financial summaries provided to the researchers by the contractor revealed that client
282 change-orders contributed to the cost deviations that were subjected to public sector clients'
283 approval. Non-conformances also materialized in the projects, but the rectification costs did not
284 impact the final contract value paid by the clients as these were the responsibility of the
285 subcontractors and suppliers.

286
287 The correlation analysis presented in Table 4 reveals that the size of a project in terms of its OCV,
288 its type, and the procurement method used were not significantly related with cost performance (p
289 <0.01). Studies examining the relationship between project size and the extent of cost overrun that
290 is incurred remains inconclusive and has been the subject of debate (e.g., Odeck, 2004; Love *et*
291 *al.*, 2013). In pursuing this unresolved issue, the analysis sought to determine if there was a
292 significant difference between a project's size (i.e. OCV) and cost performance. A one-way
293 Analysis of the Variance (ANOVA) was used in this instance to test for differences. Levene's test
294 for homogeneity of variances was not found to be violated ($p <0.05$), which indicates the
295 population variances for project size and cost performance were equal. Thus, there were no
296 significant differences between 'project size' and cost performance, $F(4,62) = 1.096, p <0.05$.

297 Furthermore, to determine whether there was a difference between procurement methods and cost
298 performance, a *t*-test was undertaken using the categories of ‘traditional’ and ‘non-traditional’.
299 Table 5 presents the mean and standard deviation for the cost performances for categorized
300 procurement types, and the results of the *t*-test are presented in Table 6. At the 95% confidence
301 interval, no significant difference in cost performance was experienced in projects delivered under
302 the different procurement categorizations that were established. Akin with previous research it can
303 be concluded that cost performance does not significantly vary with the procurement methods
304 employed (e.g., Love, 2002).

305

306 ***Change-Orders***

307 The mean amount of client approved change-orders that occurred in projects was approximately
308 AU\$5.1 million (10.6%) (Table 2). In addition, the total change-orders accounted for 11% of the
309 value of the work that was undertaken by the contractor between 2011 and 2014 (Table 3). To
310 determine if there was a significant difference between the change-orders and project size an
311 ANOVA was undertaken. Levene’s test for homogeneity of variances was found to be violated (p
312 = 0.00), which indicates the population variances for project size and cost performance were not
313 equal. Significant differences between change-orders and project size were found to occur, F
314 (4,62) = 5.525, $p < 0.01$. A Tukey’s HSD post-hoc tested showed that projects with lower a OCV
315 experienced smaller volumes of change-orders ($p < 0.05$).

316 ***Margin***

317 According to the NAO (2013) there is limited available knowledge and a lack of transparency
318 surrounding the margins of contractors. In contributing to this gap in knowledge, the analysis
319 revealed that the contractor’s mean margin (excluding overheads) was 9.89% of the OCV. Table

320 3 provides a breakdown of the mean margin allocated for each type of project, which ranged from
321 8.76% to 10.61%.

322

323 The lowest record margin was 3.98% of the OCV for a ‘Civil’ project that had an OCV of AU\$48.4
324 million and a final contract value of AU\$65.9 million. However, in this project the contractor’s
325 expected margin at the commencement of the works was AU\$3.8 million, but declined to AU\$3.2
326 million (-15.57%) due to issues surrounding rework, which they were accountable for. This
327 scenario was observed in several projects, for example, a AU\$64.7 million ‘Construct Only’
328 ‘Civil’ project that had an expected margin of AU\$2.9 million. With the client issuing scope
329 changes, the final contract value was AU\$61.6 million, a cost underrun of 4.06%. The contractor
330 experienced a staggering loss of AU\$38.2 million, which occurred due to an array of issues that
331 included rework, product non-conformances and delays to works (Table 2). Disastrous projects
332 of this nature can, and more often than not, usually result in contractors being liquidated. If,
333 however, as in this case, they are able to shoulder such costs, then their stock value, reputation and
334 image within the public and private sectors and the general community can be adversely impacted.
335 Losses in one project can be offset against gains in others that form part of a contractor’s portfolio
336 of work in progress. For example, the maximum recorded final margin as noted in Table 2 was
337 AU\$80.18 million for a project that had an OCV in excess of AU\$1 billion and incurred a cost
338 increase of 7.5%.

339 The project that had the highest margin (> 30%) was a ‘Building’ project with an OCV of AU\$3.38
340 million, which increased by 25.76% in value to AU\$4.87 million due to change-orders. In contrast
341 to the aforementioned example, this project’s margin increased from an expected value of
342 AU\$641,608 to AU\$1.37 million (114.33%). Surprisingly, the projects with margins in excess of

343 20% of their OCV varied in size, type, and location. Figure 4 identifies three ‘borderline’ and two
344 ‘outlier’ projects that possessed high margins. For example, a ‘Civil’ project had an OCV of \$138
345 million with a margin of 22.82%. Conversely, a ‘Building’ project had an OCV of AU\$2.5 million
346 with a margin of 28.98%.

347
348 Considering the prevailing ‘outliers’ the ‘best fit’ distribution was computed, and can *ceteris*
349 *paribus* be used to determine the likelihood of a contractor’s margin by the public sector. As above,
350 the K-S and A-D ‘Goodness of Fit’ tests were undertaken. The results of the ‘Goodness of Fit’
351 tests revealed that the *Wakeby* distribution provided the ‘best fit’ for the dataset. The K-S test
352 revealed a *D*-statistic of 0.07573 with a *P*-value of 0.80413 and the A-D statistic A^2 was revealed
353 to be 0.47668 at the critical nominated α values of 0.01. The *Wakeby* is a form of *GEV*
354 distribution. The parameters of a *Wakeby*, $\alpha \beta \gamma \delta \xi$ are all continuous. The domain for this
355 distribution is expressed as $\xi \leq x$, if $\delta \geq$ and $\gamma > 0$, $\xi \leq x \leq +\alpha/\beta - \gamma/\delta$ if $\delta < 0$ or $\gamma = 0$. The
356 distribution parameters for the range were $\alpha = 21.367$, $\beta = 4.5569$, $\gamma = 1.71$, $\delta = 0.45437$, $\xi = 3.0078$.
357 The *Wakeby* distribution is defined by the quantile function (i.e. inverse CDF):

358
359
$$x(F) = \xi + \frac{\alpha}{\beta} \left(1 - (1 - F)^\beta \right) - \frac{\gamma}{\delta} \left(1 - (1 - F)^{-\delta} \right) \quad [\text{Eq.3}]$$

360
361 The *Wakeby* PDF is used to determine the likelihood of a mean of 9.89% margin if applied to a
362 project; in this instance, there is a 62% (P=0.62) probability that this margin would be applied.
363

364 The mean margin OCV contract award for various sizes of projects can be seen in Table 7. It can
365 be seen the mean margins do not significantly vary between one and another rendering the Wakeby
366 distribution identified above as a basis for determining the likely margin that would be applied.
367 Levene's test for homogeneity of variances confirms this observation as it was not found to be
368 violated ($p < 0.05$), which indicates the population variances for project size and margin are equal.
369 Thus, there were no significant differences between 'project size' and margin, $F(4,62) = 3.04$, p
370 < 0.05). A significant association, however, was found to be present with the percentage increase
371 of the final margin with project size, $r = -0.38$, $n = 67$, $p < 0.01$, two tails and cost performance and
372 $r = -0.46$, $n = 67$, $p < 0.01$, two tails. It can be therefore implied that the likelihood of an increase in
373 expected margin at contract decreases with smaller OCVs. In addition, the margins of a contractor
374 increase as a project experiences larger cost overruns.

375
376 To determine whether there was a difference between procurement methods and margin, a t -test
377 was undertaken using the categories of 'traditional' and 'non-traditional'. Table 8 presents the
378 mean and standard deviation for the cost performances for categorized procurement types, and the
379 results of the t -test are presented in Table 9. At the 95% confidence interval, no significant
380 difference in margins was determined under the different procurement categorizations that were
381 established.

382
383 The dominant paradigm within the public sector assumes that differing procurement options can
384 provide varying degrees of cost certainty and will influence the level of a contractor's margin,
385 which is a reflection of their risk profile; the findings presented from this illustrative case study
386 suggest the contrary, and provide a basis for the public sector to better understand the unintended

387 consequences of change-orders that can arise during the delivery of their assets. The level of a
388 contractor's margin is a small component of their cost, yet having an understanding of this amount
389 is important, as the balance of risk and reward can distort their behavior if they are not aligned
390 (Love *et al.*, 2011). Thus, the balance of risk and reward is dependent upon the structure of the
391 contract and how well it is managed (NAO, 2013).

392

393 **Discussion**

394 What matters most to the taxpayer is whether contracted out services can provide improved quality
395 at an appropriate overall cost (NAO, 2013: p.15). Taxpayers concerns, however, are not being
396 adequately addressed; evidence of this can be seen with the sheer number of public sector projects
397 that have and continue to experience cost overruns. This is not to say that the public sector is
398 neglecting such concerns; quite the contrary, as it is acknowledged that significant effort has been
399 undertaken to redress the issues that adversely impact the delivery of infrastructure projects. After
400 all public-sector employees are also taxpayers and therefore there should be a resounding
401 motivation for them to ensure assets and services are delivered, operated and maintained cost
402 effectively. However, despite noble intentions, there is a residing suspicion that spending other
403 peoples' money on other people absolves them from any form of accountability, which often
404 results in assets not providing the VfM that was initially intended. This case in point was originally
405 highlighted by Milton Friedman (2004) who perceptively stated: "I can spend somebody else's
406 money on somebody else. And if I spend somebody else's money on somebody else, I'm not
407 concerned about how much it is, and I'm not concerned about what I get. And that's government".
408

409 The magnitude of change-orders that occurs in projects is troublesome and hinders public sector
410 ability to cost effectively ensure the asset being delivered is ‘future proofed’; that is, resilient to
411 unexpected events and adaptable to changing needs, uses or capacities. Changes during
412 construction may lead to sub-optimal solutions (e.g., design, functionality, materials, running
413 costs) being incorporated into an asset’s fabric to minimize cost and meet the committed
414 completion date.

415

416 Irrespective of the procurement strategy adopted, change-orders were found to materialize during
417 construction. An analysis of the nature of change-orders is outside the remit of this paper, but it
418 was observed that changes in scope, and errors and omissions in documentation predominated.
419 Such levels of change indicate that the ‘design’ process has not been effectively managed,
420 irrespective of the procurement option, and the use of BIM, though as noted this was only used in
421 a limited number of projects. The authors did not have access to the construction contingency of
422 the public-sector clients, but a deterministic figure between 2% and 5% (Baccarini and Love 2014),
423 which is often applied would have obviously been inadequate for the sampled projects. Prior to
424 the commencement of construction, a contingency in excess of this value would be unacceptable
425 for the public sector as there is unequivocally a need for cost certainty. But, there remains the
426 ‘elephant in the room’, with no party wanting to be held accountable for contributing to the
427 development and production of an incomplete scope and poor quality tender documentation.
428 Naturally, contractors will submit a bid based upon the information that they have been provided
429 and may opportunistically price items within the BoQ where they anticipate future changes to
430 materialize to maximize their margin.

431

432 In light of the *status quo*, cost overruns due to change-orders will continue to prevail and could
433 even be exacerbated as there is a misconception that digitization of the design process enabled by
434 the use of BIM will reduce errors and omissions. Simply superimposing a 21st century innovation
435 such as BIM to procurement practices where contracts do not wholly support collaborative working
436 and have been essentially developed for the 20th century, will not leverage the benefits that can be
437 afforded from its adoption. Thus, to mitigate change-orders, behavioral, cultural, legal and
438 structural issues associated with the delivery of public sector assets need to be transformed to
439 effectively accommodate the benefits that can be afforded by BIM, especially if they are to be
440 future-proofed. The inclusion of contractors and asset managers in the design process is needed to
441 help reduce changes using visualization and enable future-proofing to take place (Figure 5). This
442 can be done by ensuring the information needed to effectively operate and maintain an asset is
443 captured and provided in a usable format that is readily accessible (Figure 6).

444

445 Considerable effort has been and continues to be made to address the aforementioned issues to
446 support the digitization of assets throughout their life-cycle, particularly in the United Kingdom
447 (e.g. Construction Industry Council, 2014). While such efforts provide the building blocks for
448 enabling the much-needed transformational change, many public-sector agencies are still ‘sitting
449 on the fence’ with regard to rolling out BIM and implementing the new procurement practices that
450 are required, despite being cognizant of the problems associated with existing approaches of asset
451 delivery. Indeed, this is a bold proposition, however, if the public sector is to make headway in
452 ensuring that assets are delivered cost effectively, then a charter focusing on procurement reform
453 needs to be initiated, managed and maintained; changes initiated in the past have been ephemeral.

454

455 **Conclusion**

456 Public infrastructure projects that experience cost overruns adversely impact taxpayers. It is
457 therefore imperative that they are not only delivered within budget but also continue to be of
458 value into the future. Providing infrastructure that is resilient and adaptable to changing needs,
459 capacities and uses should be the ultimate goal of the public sector. The path to attaining this goal
460 can be derailed when change-orders (e.g., in scope) are required during construction, and can lead
461 to sub-optimal assets being delivered. The taxpayer pays for this additional cost, while contractors
462 are rewarded with an increase in their margins; this is the ‘elephant in the room’ within the public
463 sector, which is underpinned by ‘spending somebody else's money on somebody else’.

464

465 In examining the cost performance of public infrastructure projects an illustrative case study was
466 undertaken. Cost information from 67 projects constructed between 2011 and 2014 were provided
467 by a contracting organization. The cost overruns/underruns that were experienced were calculated
468 from the contract award to when final accounts were completed. The analysis revealed that the
469 cost performance of projects ranged from -42.88% to + 270.93%, with a mean cost overrun of
470 23.75%. and a probability of occurring of 73%. In alignment with previous research no significant
471 differences in the magnitude of cost overruns were found to exist by a project’s contract value,
472 types, and procurement method. It revealed that change-orders accounted for a significant
473 proportion of the cost overruns that emerged in the projects, with a mean of 10.6% as a proportion
474 of the original contract value. Notably, significant differences were found to occur between a
475 project’s size and change-orders; that is, those with a smaller original contract value experienced
476 a smaller volume of change-orders.

477

478 Limited knowledge has existed about the margins that contractors apply to projects. However, the
479 mean margin applied to the sample of public sector projects was revealed to be 9.89%, and the
480 likelihood of such a value being applied was computed to be 62%. The analysis revealed that the
481 margin applied by the contractor did not vary with project type, its size and the procurement
482 method being used to construct the asset. The analysis also demonstrated a positive association
483 with an increase in change-orders and the contractor's margin. More specifically it was found that
484 contractor's margins increase with larger cost overruns. A significant proportion of the projects
485 were delivered using traditional 'Construct Only' and there is no incentive for contractors reduce
486 change-orders as they have had no involvement in the design process. Even when the contractor
487 was involved in the design process, change-orders still occurred, though their extent was unable
488 to be determined.

489
490 Involving the contractor as early as possible in the design process, providing incentives, and open-
491 book tendering are considerations that should be enacted as initial steps to mitigate change-orders.
492 As the public sector embraces the era of digitization, which is being enabled by Building
493 Information Modelling, the need to integrate design and construction and engender collaboration
494 is imperative to ensure assets can be delivered cost effectively and future-proofed. Emphasis here
495 should not necessarily be placed on the technology but ensuring information is structured in a
496 standardized format, captured, openly-shared, stored and accessible so that parties can effectively
497 work in a collaborative environment. The research in this paper provides invaluable empirical
498 evidence, though based on a limited dataset of 67 projects, to support the need for a change to the
499 way the public sector procures their assets. If change is not embraced, then cost overruns will
500 continue to be a nemesis.

501

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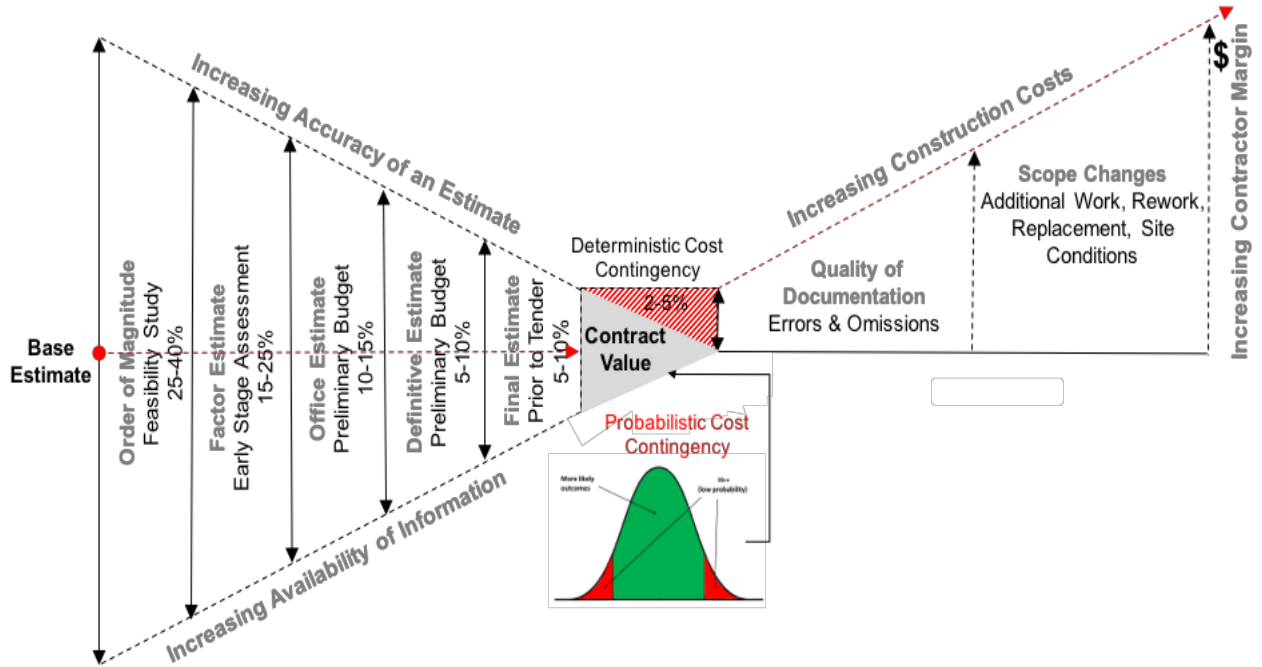
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Figure 1. Traditional cost scenario for infrastructure projects

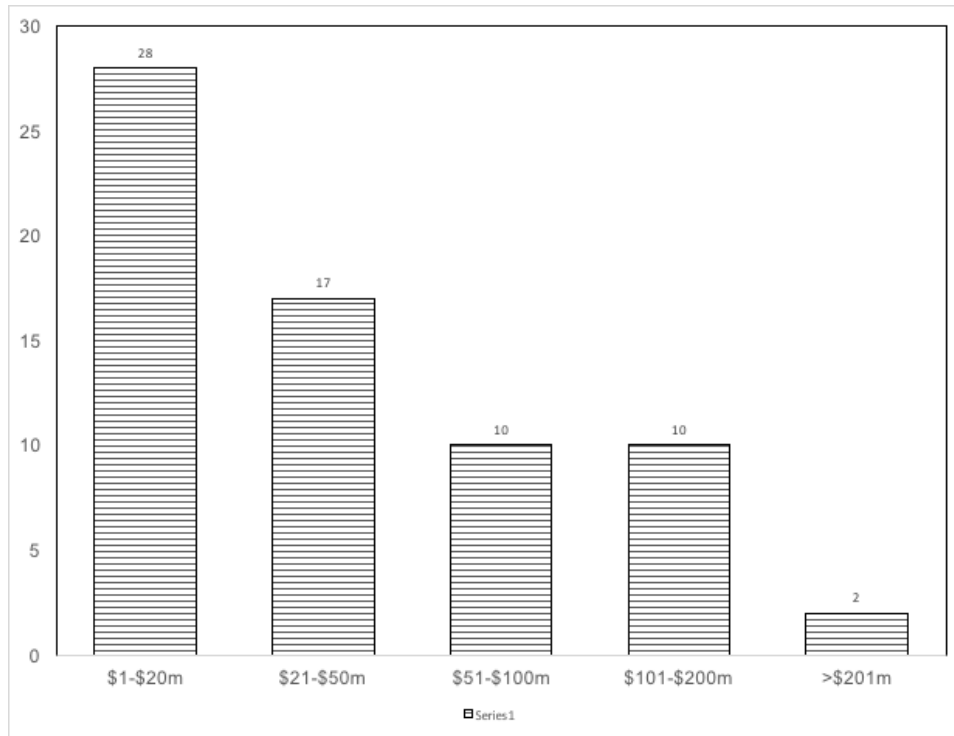
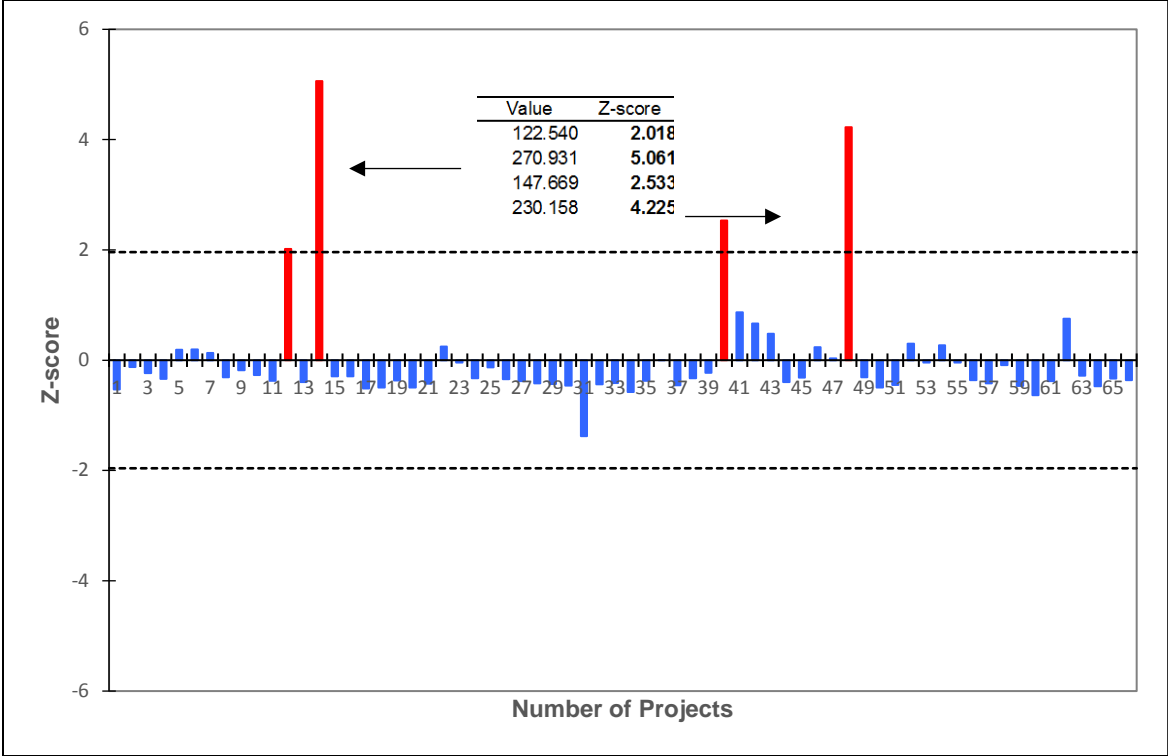


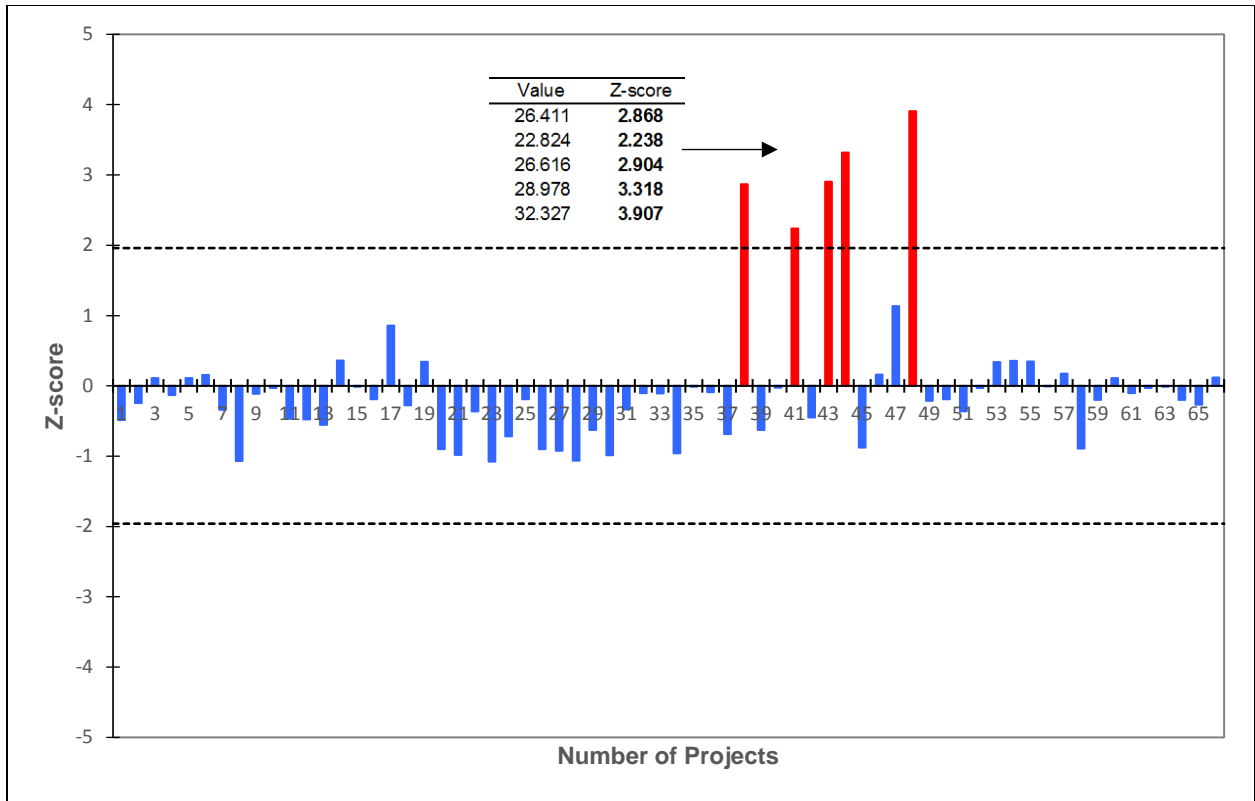
Figure 2. Number of infrastructure projects

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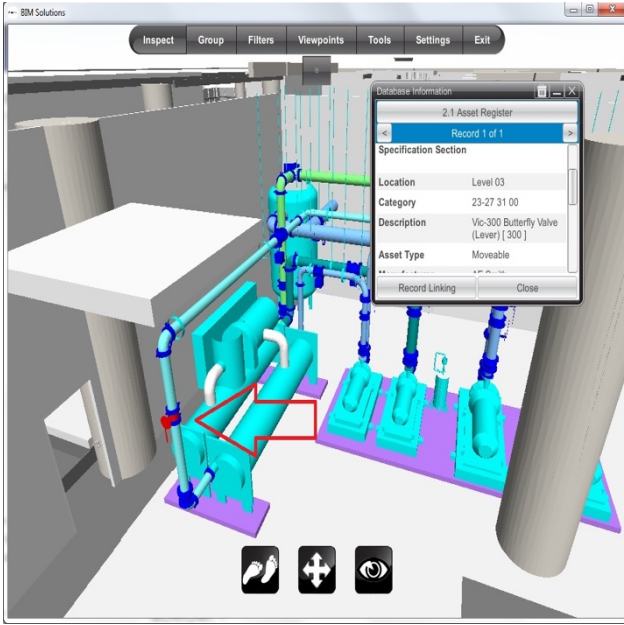
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Figure 3. Determination of outliers for cost performance

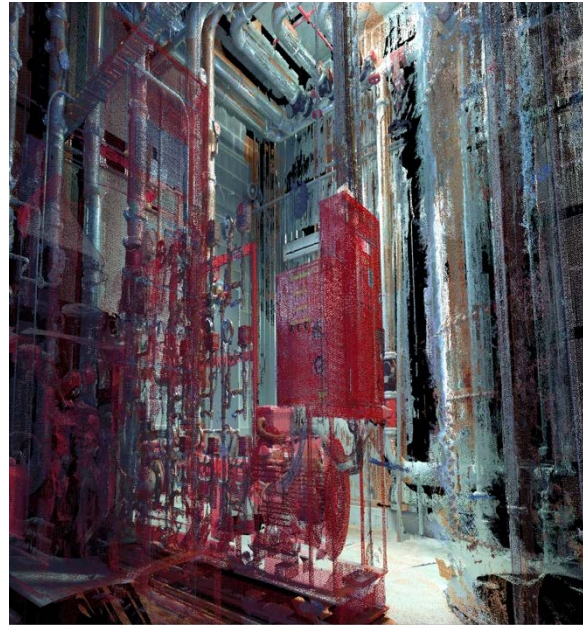


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Figure 4. Determination of outliers for margin



(a) A 3D visualization of what is to be constructed



(b) Actually constructed

Figure 5. 3D visualization

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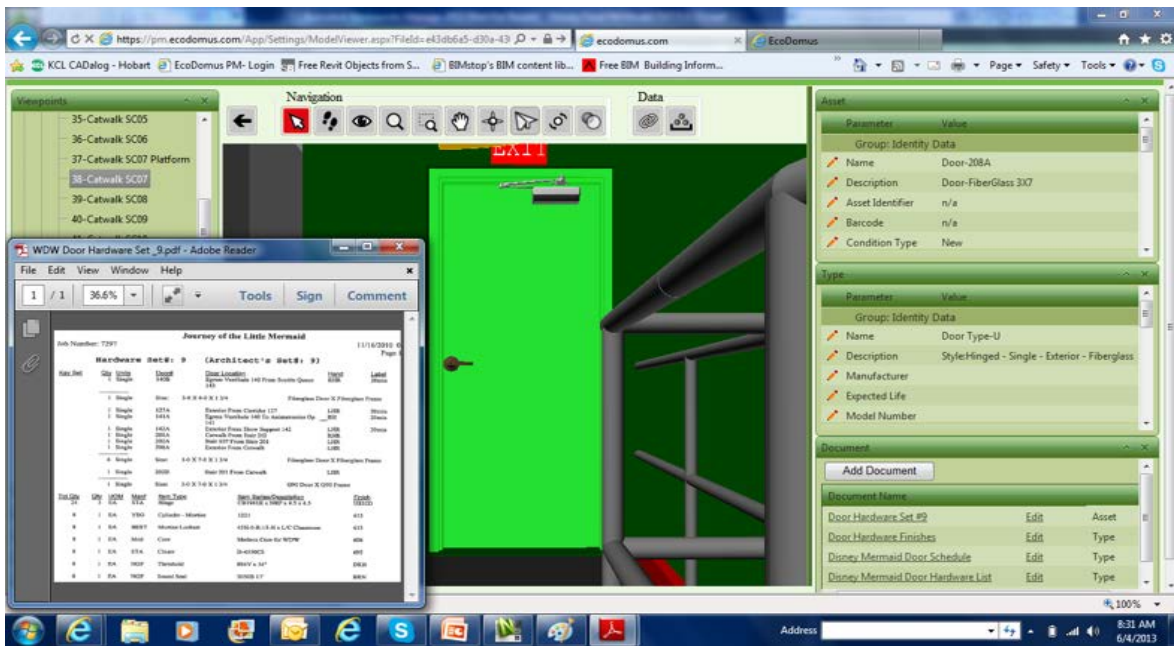


Figure 6. Centralization of asset information for operations and maintenance

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Table 1. Projects and procurement methods

	Procurement Method						
	Construct Only	Design and Construct	Service Contract	Alliance	Construction Management	Management Contracting	EPC
Project Type	N (%)	N (%)	N(%)	N(%)	N(%)	N(%)	N(%)
Rail	13(33)	2(15)	1(100)	1(100)			
Road	2(5)	1(7.5)					
Tunnel	3(7.5)	1(7.5)					
Civil	13(30)	4(30)				1(33)	3(100)
Building	10(25)	2(15)			2 (5)	2(67)	
Power	3(7.5)	1(7.5)					
Water	1(2.5)	2(15)					
Total	44 (100)	13(100)	1(100)	1(100)	2(100)	3 (100)	3(100)

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Table 2. Descriptive statistics for cost performance parameters

Cost Parameter	Minimum	Maximum	Mean	Std. Deviation
Original Contract Value (OCV)	\$1,851,459	\$318,307,311	\$48,201,497	\$58,619,500
Cost Performance	-42.88%	270.93%	23.75%	48.51%
Final Contract Value	\$3,334,068	\$453,869,568	\$59,501,002	\$81,674,335
Original Margin	\$224,496	\$31,543,968	\$4,431,586	\$6,278,123
Final Margin	-\$38,204,212	\$80,188,944**	\$6,171,254	\$14,305,630
Client Approved Change-Orders	\$-519,141.62	\$80,655,072.00	\$5,107,252	\$11,364,666

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** Specific details are suppressed due to reasons of commercial in confidence. Similarly, this applies to the location of all projects

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Table 3. Original contract values and approved change orders

Project Type	N	Total value of projects (\$)	OCV Minimum Value (\$)	OCV Maximum Value (\$)	Mean Value (\$)	Mean Margin (%)	Total Client Approved Change Orders (\$)
Rail	16	645,736,621	1,851,459	318,307,311	40,358,538	8.76	57,710,882
Road	2	47,145,336	8,822,453	38,322,883	23,572,668	10.48	4,290
Tunnel	4	230,234,197	30,179,736	102,465,401	57,558,549	10.61	23,244,545
Civil	22	1.39E+9	4,970,945	224,575,457	63,0323,333	10.17	207,114,979
Building	16	823,883,239	2,258,943	180,049,561	51,492,702	10.41	46,791,411
Power	4	488,534,403	4,519,860	200,825,529	12,213,350	9.89	4,185,061
Water	3	46,936,231	4,611,781	23,396,953	15,645,410	9.60	3,134,747
Total	67	3.23E+9	1,851,459	318,307,311	48,201,497	9.89	342,185,917

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Table 4. Correlations between project characteristics and cost measures

Variable	Project Type	Procurement Method	Project Size	Cost Performance	% Original Margin	% Final Margin to OCV
Project Type	1					
Procurement Method	0.114	1				
Project Size	0.065	0.218	1			
Cost Performance	-0.113	0.157	-0.057	1		
% of Margin of OCV	0.079	0.111	-0.013	0.207	1	
% of Final Margin to OCV	-0.24	-0.111	-.389**	.462**	-0.049	1

** Correlation is significant at the 0.01 level (2-tailed).

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Table 5. Cost performance for procurement types

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Procurement Type	N	Mean	Std. Deviation	Std. Error Mean
Traditional	44	18.1933	45.81480	6.90684
Non-traditional	23	35.8728	53.43433	11.39224

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Table 6. *t*-test for difference between cost performance and procurement types

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	Levene's Test for Equality of Variances		<i>t</i> equality of-Test for means				Mean difference	Std. error difference	Lower	Upper
	F	Sig.	T	df.	Sig. (2-tailed)					
Equal variances assumed	0.537	0.466	-1.398	65	0.167	-17.679	12.650	-42.951	7.592	
Equal variances not assumed			-1.327	36.844	0.193	-17.679	13.322	-44.677	9.318	

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Table 7. Size and margin % of contract value

Project Size	N	Mean (%)	Minimum (%)	Maximum (%)	Std. Deviation
\$1-\$20m	28	10.26	3.98	32.33	6.15
\$21-\$50m	17	8.54	0.00	26.41	5.79
\$51-\$100m	10	10.60	4.01	26.62	6.69
\$101-\$200m	10	10.32	6.17	22.82	4.81
>\$201m	2	9.91	9.91	10.04	0.91
Total	67	9.89	0.00	32.33	5.79

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Table 8. Margin for procurement types

Procurement Type	N	Mean	Std. Deviation	Std. Error Mean
Traditional	44	9.568	5.501	0.829
Non-traditional	23	10.61	6.529	1.392

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Table 9. *t*-test for difference between contractor's margin and procurement types

	Levene's Test for Equality of Variances		<i>t</i> equality of-Test for means		Sig. (2-tailed)	Mean difference	Std. error difference	Lower	Upper
	F	Sig.	T	df.					
Equal variances assumed	0.329	0.568	-0.682	65	0.498	-1.042	1.529	-4.098	2.013
Equal variances not assumed			-0.644	36.318	0.524	-1.042	1.620	-4.328	2,242

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