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Make-or-Break During Production: Shedding Light on Change-Orders, Rework and Contractors Margin in Construction

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Abstract

A total of 98 construction projects with a combined value of $8.5 billion were examined to explore the nature and value of rework and change-orders and their influence on a contractor's margin. Only 65% of projects experienced a cost increase during their construction, though a mean rework cost of 0.39% of the contracted value was incurred, which had a negative impact on the contractor's overall margin. In addition, the difference between approved client change-orders and those by the contractor for subcontractors was 0.5% of the total costs incurred for the sampled projects, which had an adverse impact on the organisation's profit. The upshot here is that the contracting organisation underwent a mean loss in profit of 23% per annum over the period of analysis. It is suggested that margin losses might well have been higher as rework was seldom formally documented and reported.

Keywords: Construction, change-orders, contractor's margin, rework

Introduction

> "Yesterday is not ours to recover, but tomorrow is ours to win or lose" Lyndon B. Johnson.

Delivering construction projects within their budgeted cost remains a major challenge as change-orders and rework are inevitable, despite every effort to mitigate their occurrence (Ahiaga-Dagbui *et al*., 2017). Not all construction projects experience an increase in their production costs, as changes-orders can also result in decreases to the Original Contract Value (OCV) (Ahsan and Gunawan, 2010; Love *et al*., 2018a). However, there is a general perception that construction projects are repeatedly confronted with cost increases during their delivery, particularly those procured by the public sector (Love *et al*., 2017a; Invernizzi *et al*., 2018). This view has often been exaggerated and sensationalised by the media, opposition political parties, and even dubious academic research (Love and Ahiaga-Dagbui, 2018).

For example, Flyvbjerg *et al*. (2002) claimed that nine out of ten transport infrastructure projects (e.g., roads, rails and bridges) experienced cost overruns. This claim, it is contended, is at best a gross exaggeration. Indeed, its close examination reveals a different story that has gone uncontested: it was based on an unrepresentative sample and predominantly secondary and fundamentally flawed data (Love and Ahiaga-Dagbui, 2018). Still, many academics and journalists continue to promote this misleading claim (e.g., Shane et al., 2009; Jaffe, 2013). Markedly, Flyvbjerg et al. (2002) did not focus on mega-projects per se, as their sample includes projects ranging in value from US$1.5 million to US$8.5 billion. The number of projects exceeding the $1 billion threshold, which has been traditionally used to define a mega-project, was not specified. Yet, despite these flaws, Flyvbjerg et al.'s (2002) study has been heralded not only as a "classic in megaproject management" (Flyvbjerg and Turner, 2018), but also as the seminal work to illustrate that mega-projects consistently exceed their budgets. Irrespective of a project's size (i.e. dollar terms), they can, however, be subjected to cost increases or decreases. This variability has been overlooked by studies that have examined the cost performance of infrastructure projects. The upshot, however, has been that emphasis is placed solely on cost overruns.

Definitions of cost overruns vary and are dependent on the specific points in time over a project's life that is used to calculate their occurrence (Brookes *et al*., 2017; Invernizzi *et al*., 2018; Love and Ahiaga-Dagbui, 2018). The corollary, for example, is that any cost overrun that is calibrated between the decision-to-build and the completion of construction (Flyvbjerg *et al*., 2002) would be greater than those that measure from contract award to completion of construction (Jahren and Ashe, 1991; Ahiaga-Dagbui and Smith, 2014). Furthermore, there is a tendency for stakeholders to vary in their view of what constitutes a cost overrun, though there has been a paucity of empirical research outlining these differing positions in the extant literature (Invernizzi *et al*., 2018).

By and large, the dominant point of view taken to examine the cost performance of infrastructure projects presented in the literature is that of the public-sector client (e.g., Jahren and Ash, 1991; Bhargava et al., 2010; Anastasopoulos et al., 2014; Baccarini and Love, 2014; Love et al., 2018a). Moreover, most studies on infrastructure project cost performance focus on secondary data and questionnaire surveys (e.g., Flyvbjerg *et al*., 2002; Flyvbjerg and Sunstein, 2016). Very few authors have attempted to study project cost performance from a main contractor's perspective.

Even rare are empirical studies that have investigated the influence of change-orders[1] and rework[2] on the cost performance and margin[3] of a contractor, not to mention with real project data. One notable exception is the work of Love *et al*. (2017a) who examined cost performance from a contractor's perspective, with a particular focus on the impact of change-orders and rework on their margin. There has, however, been limited empirical research that has examined the influence of change-orders and rework on the cost performance of contractors during the production process of construction. This research paper fills this void, and uses data derived from 98 construction projects delivered by a main contractor with a combined value of $8.5 billion to examine the nature of change-orders and rework costs and their influence on the contractor's margin.

The significance and relevance of this research are threefold. First, it aims to replicate the work and findings of Love *et al*. (2017a) and as such contributes to the literature at a time when there is an unprecedented level of concern about the reliability of research findings and a resulting crisis of confidence in engineering, management, and science[4] (e.g., Pasher and Wagenmakers, 2012; Baker and Penny, 2016; Bergh et al., 2017; Fanelli, 2018). Second, it offers unprecedented insights not only into change-orders and rework, but also on their actual impact on cost performance and the margin of a contractor. Indeed, a lack of transparency generally prevails in relation to the margins of contractors and, as a rule, access to this type of data is restricted due to commercial sensitivity (NAO, 2013). And third, the paper sheds light on the subtle nuances that influence cost performance and margin of a contractor, supported with empirical data. Indeed, the decreases and increases in costs due to change-orders during construction and their financial impact on contractors have been, by and large, downplayed as there has been an overwhelming focus on clients' exceeding their budgets, especially those from the public-sector (Love et al., 2017a).

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[1] A change-order is typically a client or their representative's written instruction to a contractor, issued after the signature of a construction contract, which authorizes a change to the work being undertaken and thus to the contract time and/or amount (Love et al., 2017a).

[2] Defined as the "unnecessary effort of re-doing an activity or process that was incorrectly implemented the first time" (Love, 2002:p.19).

[3] Defined as "an amount or proportion added for profit and additional overhead costs (including administration, supervision, establishment and attendance costs) incurred solely as a result of a variation, but not including any overhead costs relating to delay, disruption or interference caused by the variation" (Tozer, 2007:p.49).

[4] Reproducibility has been a core mechanism used to help establish the validity and importance of scientific findings since Philosophical Transactions of the Royal Society was established in 1665 (Allison et al., 2018). Progress is made within a field based upon a foundation of reliable results with reproducibility being core. Therefore, the replication of studies forms an integral part of science and is needed for the advancement of knowledge. The process of replication involves a study to be repeated using the same methods, different subjects, and experimenters. Replication, therefore, is important for a number of reasons, which include to: (1) provide assurance that results previously obtained are valid and reliable; (2) determine their generalisability or the role of extraneous variables that have been examined; (3) apply the results to real world situations (e.g., to practice work); and (4) identify new research directions in consideration of previous findings from similar studies (Heffner, 2016).

The paper commences with a brief review of cost performance literature in construction to provide a contextual backdrop for the research that is presented. This subject matter has received a considerable amount of attention over several decades and includes the works of Jahren and Ash (1991), Hinze *et al.* (1992), Odeck, (2004), Siemiatycki (2009), Bhargava *et al.* (2010); Anastasopoulos et al. (2014), Ahiaga-Dagbui *et al.* (2017), and Callegari et al. (2018) to name just a few.

An Overview of Cost Performance

Cost performance is generally defined as the value of the work to be completed compared to the actual cost of progress made on the project (Baccarini and Love, 2014). For the clients who construct on a regularly basis such as the public sector, the ability to reliably predict the final cost of construction and ensure it does not experience an overrun is paramount for ensuring the planning and resourcing of other projects or those in the pipeline. Cost overrun is defined here as the ratio of the actual final costs of the project to the estimate made at full funds authorisation measured in escalation-adjusted terms (Merrow, 2011). In this instance, an overrun is treated as the margin between the authorised initial project cost and the real final cost incurred after adjusting for expenditures due to escalation terms. Thus, cost increases during the design phase are accommodated in this case, but their determination and consideration has received limited attention (Welde and Odeck, 2017).

The variability between an elemental cost plan and final tender sum can range from −14% and +16% (Adafin et al., 2015). It has been widely documented that changes in client/stakeholder requirements, design changes and the paucity of accurate information for reliable cost estimating during a project's front-end contribute to cost growth (Adafin et al., 2016; Welde and Odeck, 2017). Estimates that are undertaken during the design process are only as good as the information that they are based upon (Ahiaga-Dagbui and Smith, 2014). In general, it has been assumed that the accuracy level of an estimate increases as more information becomes available and tenders are sought from contractors (Love et al., 2017a,b). Then again, according to Aibinu and Pascoe (2008) the pre-tender estimates of Quantity Surveyors (QS) are often higher than the tenders received as material prices tend to be over-estimated and the scale of works to be more complex inasmuch as a project's size is judged to be large. Though, it needs to be clear that Aibinu and Pascoe (2008) did not define the meanng of ‘large’ in the context of their study. In providing an explanation for the differences between pre-tender estimates prepared by a QS on behalf of a client and contractor’s tender, Akintoye (2000) has suggested this variance materialises for a number of reasons which include prevailing market conditions (e.g., availability of skilled-labour and inflation), changes to legislation, method of construction, and site conditions.

Cost Performance in Production

For contractors, the determination of a project’s cost performance commences from a contract’s award to the completion of construction works and the issue of certificate of practical completion. When a contractor engages with a Public Private Partnership (PPP), the measurement and management of cost may continue to operations and maintenance of an asset (Liu et al., 2018). This has led for a call for the traditional perspective of a project’s temporality to be re-defined to incorporate the longevity of PPPs and large-scale infrastructure works (Brookes et al., 2017; Alexander, 2018). In this case, focusing solely on construction cost only provides a snapshot in time about a project’s performance (Anastasopoulos et al., 2014; Liu et al., 2018). Publicly available and published cost information for the operation and maintenance phases of PPPs are rarely, if at all, made accessible.

Using the contract award as an anchor and using data provided by a public-sector client, Thurgood et al. (1990) examined cost overruns rates for 817 projects constructed between 1980 to 1989. They found that cost overrun rates were below 5% until 1984, and then the proportion of projects exceeding this amount from 1984 to 1988 increased. This increase was attributable to having less experienced pre-construction staff employed due to staff retiring. Similarly, Hinze et al. (1992) reported a mean cost overrun for roads constructed to be approximately 5%.

Love (2002) found that cost overruns from the final tender sum to completion of construction for a sample 169 building projects to possess a mean cost overrun of 12.6%. Rework was found to account for 52% of the cost overrun that was incurred in the projects, though this figure included approved changer-orders that required work to be re-done during construction. Additionally, Love (2002) revealed that cost overruns and rework did not vary by project type, contract size and contract type. This finding, however, is in stark contrast to Forcarda et al. (2017) who examined

788 incidents occurring across 40 projects by a contractor and found rework costs varied between building and civil engineering projects (i.e. project type), private and public-sector clients and those delivered by a joint venture or sole contractor (i.e. contract type). The actual mean rework cost per project borne by the contractor was found to be 2.75% of a project's OCV.

Ahiaga-Dagbui and Smith (2014) examined 1,600 water projects from a public-sector client and found an average cost overrun of 16.75%. Similarly, Baccarini and Love (2014) study of 228 Australian sewer and water projects revealed a slightly lower mean cost overrun of 13.58%. Confirming Love's (2002) finding, Baccarini and Love (2014) demonstrated that cost overruns did not vary in their magnitude with project type, contract size and contract type. To understand the changing nature of costs, the cost profiles of 1,093 water infrastructure projects that were delivered by a water utility company were examined by Love et al. (2018a). Cost overruns were experienced in 656 projects. Only one project was delivered on budget with the remaining 436 being completed under their 'Final Budget Approval'. Mean cost overrun and underrun of +19.97% and -32%, were found, respectively. In line with previous studies, Love et al. (2018a) also revealed that a project's type and size did not influence cost performance.

Using cost data from 67 projects from contract award provided by a contractor, Love et al. (2017a) found a series of overruns/underruns was experienced. The analysis revealed that the cost performance of projects ranged from −42.88 to +270.93%, with a mean cost overrun of 23.75%. Love et al. (2017a) were provided with the margins (excluding overheads) that the contractor had allocated for each project at the award of contract, which ranged from 8.76% to 10.61% with a mean of 9.89%. Furthermore, Love et al. (2017a) examined the influence of a project's characteristics on their cost performance and found that project and contract types, as well as their size, did not vary. The study did reveal that change-orders accounted for a significant proportion of the cost overruns that emerged in the projects, with a mean of 10.6% of OCV being reported. Surprisingly, significant differences were found to occur between a project's size and the magnitude of change-orders that were issued; that is, those with a smaller OCV experienced a smaller amount of change-orders.

Love et al. (2017b) found the actual costs expressed as a percentage of the contract value for 16 rail projects constructed by a contractor ranged from -4.19% to 96.73%, with a mean of 23%. Contracts that provide a traditional lump price experienced a mean cost increase of 11%. However, rail projects procured using a cost reimbursement (also referred to as cost-plus) form of contract incurred a mean cost increase of 75%. In all the projects sampled, cost increases were attributable to change-orders. Reimbursement contracts or management contracting are used when performance, quality or delivery time is a much higher concern than cost, and there is a need for flexibility, allowing for changes in specifications to made.

In this paper, the influence of change-orders and rework on a contractor's margin during the production of an asset are examined. Besides the study undertaken by Love et al. (2017a) the influence of rework on a contractor's margin has remained unexplored. Contractors are well aware of the negative impacts of rework, but they are often considered to form a part of normal operations or simply ignored or even concealed (Love et al., 2018b). Rework is therefore 'uncomfortable knowledge'[5] for contractors, which has contributed to their ignorance, especially as there is a general unwillingness to measure and proactively manage its occurrence during construction. Nonetheless, rework has been repeatedly identified as being a chronic problem within construction that stymies project and organisational performance (Forcarda et al., 2017), but more seriously is a major contributor to safety incidents/accidents (Wanberg et al., 2013; Love et al., 2018b). So, to further understand and create much-needed knowledge about the 'make-or-break' issues that influence production costs and the subsequent performance of contractors, Love et al.'s (2017a) study is replicated, albeit within the confines of data accessibility.

Case Study

Acknowledging that there has been limited research on the influence of change-orders and rework on cost performance and contractor's margin, attention is drawn to Love et al. (2017a), who used case study approach to examine these issues. Therefore, in line with Love et al. (2017a), an

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[5] Uncomfortable knowledge is "that knowledge which is in tension or outright contradiction with those versions [and] must be expunged" (Rayner, 2012: p.107). Four strategies to deal with uncomfortable knowledge are: (1) denial – there is not a problem; (2) dismissal – it is a minor problem; (3) diversion – I am working on it; and (4) displacement - the model we have developed tells us that real progress is being achieved. In this case, the focus is on denial.

exploration to acquire an understanding of the nature of major production costs that influence project performance is undertaken using a case study. Yin (1984) defined a case study approach "as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (p.23). In this research, an illustrative case study is used to describe an event or in this case utilise one or two instances to demonstrate the reality of a situation such as change-orders, rework and the impact on a contractor's margin (Fry et al., 1999). An illustrative case study aims to make the 'unfamiliar, familiar', and promulgate meaning to a problem. The process of replication in this research required a homogenous data-set to be obtained (i.e. in terms of processes, technologies, procedures and processes) from a contractor that had constructed projects of a similar nature and time period presented in Love et al. (2017a).

Case Selection

Due to the specific data requirements (e.g. similar size projects, time frame, and data availability) that were needed to ensure replication, purposive sampling of a homogenous nature was required (Patton, 2015). Homogenous sampling aims to obtain a sample where the unit of study (e.g., cases) shares the same (or very similar) characteristics to others. The case study organisation selected for this study became aware of the study reported in Love et al. (2017a) and recognising that rework was a problem they volunteered to engage with the research and provide access to a similar sample of projects that they had implemented. The researchers had previously collaborated with the contracting organisation on a number of earlier studies and therefore were familiar with their processes, procedures and staff. As a consequence, access to cost and quality data were provided to the researchers for analysis with commercial confidentiality being ensured.

Dataset

Access to the construction organisation's project cost data from 2009 to 2015 was provided. The time period of the analysis in Love et al. (2017a) was 2011 to 2014 and was restricted to public sector projects. From a total of 346 projects made available by the contractor, only 98 had a similar profile to those presented in Love et al. (2017a) in terms of their project size (i.e. value in dollar[6]

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[6] Costs reported are in Australian Dollars.

terms) and had their rework costs available, which were based on non-conformance reports (NCRs) issued during construction. In addition, projects in excess of \$500 million were excluded, as Love et al. (2017a) did not examine projects of this size. After reviewing the distribution of OCVs, the following categorisation was adopted: (1) <\$50 million; (2) \$51- \$100 million; (3) \$101-\$150 million; (4) \$151-\$200 million; and (5) > \$200 million. While the intention was to replicate Love et al. (2017a)'s study, some data was not made available (e.g. actual margin). Thus, a direct comparison is not possible, but the data does provide additional insights particularly the adverse consequences of rework on margin.

The dataset comprised of a mixture of public and private sector projects. It should be noted that the contractor was financially responsible for the rework that incurred in the projects sampled. Akin to Love et al. (2017a), rework in this case was defined as "an action on a non-conforming product to make it conform to requirements". There may have been instances where these costs were the responsibility of a subcontractor and monies were back-charged to them for the rework that occurred, but the researchers were not privy to this data, except in the case of approved change-orders.

The cost data provided included the OCV, final contract value, expected margin, client and contractor approved variations, and rework costs. The full detailed information of client approved change-orders was only available for 67 of the 98 of the projects. To ensure parity between the two sets of change-orders, those approved by the contractor were reduced to 67. Supplementary reports such as 'financial assurance reviews' and 'project reviews' were made available to provide a context for the costs that were incurred. Data relating to NCRs was also provided to enable an understanding of the rework costs that were incurred. Informal discussions with managers involved with the organisation were undertaken on a weekly basis over a three-month period while the data collection and analysis were being undertaken.

Analysis

Descriptive statistics are used to provide an overview of the change-orders, rework and margins that were incurred in the sampled projects. Pearson's correlation coefficients were computed to determine the strength of linear association between the following project characteristics: (1) client type; (2) project type; (3) contract type; (4) project size; (5) cost difference % (i.e. difference between OCV and final contract value); (6) margin %; and (7) client approved changes-orders %. In addition, a one-way analysis of variance (ANOVA) was undertaken with the sample of construction projects to determine whether there were any statistically significant differences between their mean cost of rework, change-orders, and margins for different clients, project and contract types, and project size. In essence, an ANOVA was used so that findings could be compared with Love et al. (2017a) and other rework studies such as Hwang et al. (2009) and Forcada et al. (2017). To determine if project characteristics were predictors of the contractor's cost performance, a forward stepwise regression was performed.

Results

A total of 98 projects were analysed that equates to $8.5 billion worth of construction works (Table 1). The projects were implemented throughout Australia, and their location has been concealed to prevent them from being identified. Private and public-sector projects accounted for 46 and 52 projects of the sample, respectively. The mean value of projects awarded to the contractor was approximately $87 million with the minimum and maximum being $690,565 and $484 millions, respectively. It was revealed that 35 (33.3%) projects did not experience a cost increase from the award of a contract, and one project was delivered less than the contracted value.

Table 1. Summary of total costs for the sample of projects

Factors	Mean ($)	Std. Dev.($)	Min.($)	Max.($)	Total ($)
Cost of projects at contract award	87,294 800	19,962,612	690,565	483,764,036	8,554,890,525
Rework (cost)	248,287	129,0690	-	12,561,056	24,332,181
Client approved change-orders	46,313,387	999,669	-12,941,360	31,030,218	310,302,961
Subcontractor change orders	5,325,973	551,292	-14,163,083	102,250,903	356,840,218

Rework costs were directly borne by the contractor in 93% of projects. To reiterate, change-order data that had been approved by clients was only available for 67 of the 98 projects sampled[7]. Change-orders accounted for 3.6% of the total value of contracts that were awarded. Change-orders, for example, required by a public-sector client during construction resulted in an overwhelming cost increase of $310 millions to a project (Table 1).

Subcontractor change-orders which are works approved by the contractor were almost $357 million. It can be seen from Table 1 that ~$46 million worth of additional works needed to be accommodated by the contractor. When this sum and rework (i.e. ~$25 millions) are combined, a staggering ~$71 millions was forfeited by performing unplanned work. The mean yearly profit for the contractor over the six-year period of analysis was $51 millions. Thus, a mean loss $11.8 millions (~23%) of profit was forgone from these 98 projects alone. Considering that these projects only constituted 25% of the total delivered during the period of analysis, it is suggested that this loss in profit may, in fact, be an underestimate, especially as data to determine the difference between client and contractor approved change-orders for 29 projects were missing.

The descriptive statistics for the cost factors that have been the focus of this study are presented in Table 2. The mean cost difference was revealed to be 81.29% and the median 4.36%. Two projects experienced significant cost increases from the OCV to the final contract value (FCV), as can be observed in Figure 1.

Table 2. Descriptive statistics for cost factors

Factors	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Variance**
Margin %	0.00	32.33	7.56	6.43	41.39
Rework %	0.00	12.32	0.39	1.35	1.81
Change-order %	-1627.43	323.13	-35.73	270.41	73124.16
Cost difference %	-0.76	3353.89	81.29	448.82	201439.70

The maximum cost overrun was in excess of 3000% for a building project that was procured using a design and construct contract. Context is important here and understanding the nature of the contracting strategy that is put in place and agreed between client and contractor requires

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[7] Again, data pertaining to rework that arose due to changes-orders and design omissions was not made available for this study.

consideration. Though, there has been a proclivity for previous studies that have examined cost performance of projects to dismiss the importance of contracting strategies that are used to deliver projects (e.g., Flyvbjerg et al., 2002; Flyvbjerg and Sustein, 2016). In the case at hand, the project's OCV was $848,000 and the final contract value was $29.2 millions and 12.32% rework were experienced. At face value, a cost overrun may be assumed, but this was not the case. This was a private sector project that initiated some miscellaneous works and then relied on an addendum to the contract to fit-out the entire building. While the percentage of rework is the highest of the sample as a proportion of OCV, accounting for $104,000 no change-orders were formally issued. If rework costs were based on the FCV then they would have been 0.35%, which is below the mean of 0.39%, but greater than the median of 0.04%.

The other outlier project identified in Figure 1 with cost increase in excess of a 2900% increase was associated with a rail system constructed to transport iron ore from a mine to a port facility. The project used construct only contract with an OCV of $1.2 million and a FCV of approximately $36.69 millions. Again, context is needed to understand why the project's cost increased by such a significant amount. The project in question was constructed in a remote location (i.e. roughly two thousand kilometres from a capital city), and the original works focused on the repair and maintenance of existing track. Labour and equipment had been mobilised and rather than requesting new tenders from additional contractors to undertake the additional works, it was decided to let the contract to the existing contractor to save time.

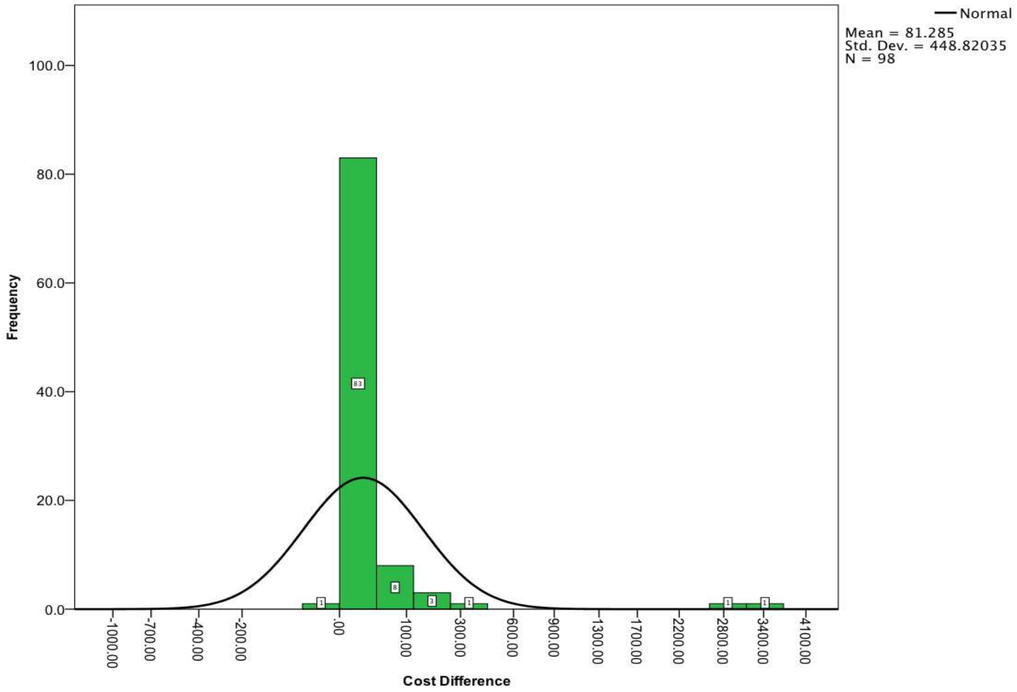


Figure 1. Distribution of cost differences between the OCV and FCV

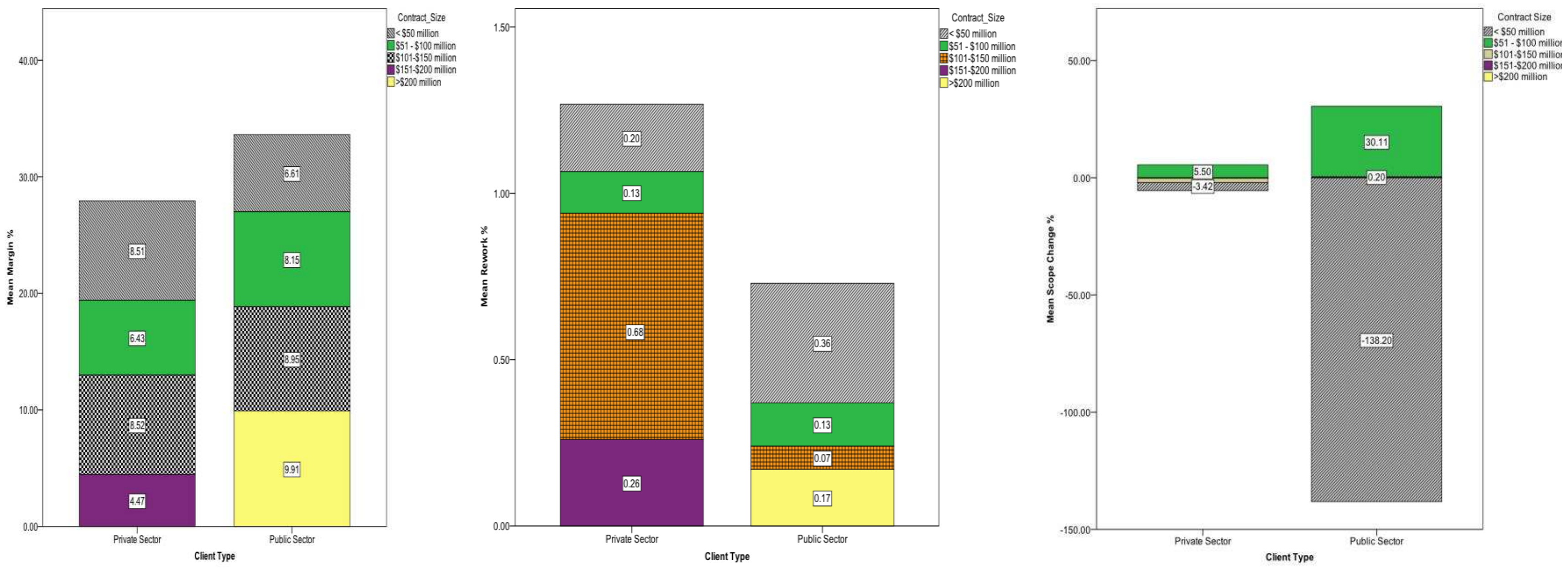
Interestingly no rework was reported, however, it may not have been formally documented and reported, as management within the contracting organisation was generally disparaging of NCRs being raised as considered them to reflect poorly on their operations and business. While management's view was widely known amongst staff, not all project managers adhered to this position and refrained from the non-reporting of NCRs.

The mean cost percentage for margin, rework and change-orders by client type and project size are displayed in Figure 2. It can be seen in Table 3 that projects less than $50 millions formed 77.5% of the sample, which is also comparable with Love et al. (2017a). The mean margins of contractors do not appear to significantly vary and fluctuate between 6% and 9% of OCV, but in the case of the private-sector it is lower for those projects that range between $101 to $150 millions. From Figure 3 the differences in mean rework costs can be observed. But, the most pronounced variance occurs between private and public sectors projects valued between $101 to $150 millions where figures of 0.68% and 0.07% are presented, respectively.

Explicitly, it can be seen that private-sector clients in this sample of projects experienced less change-orders leading to reductions in the OCV than the public sector, especially for those less than $50 millions where a mean reduction of 138.20% was recorded. Overall, however, a median reduction of 0.28% was experienced for the combined types of client (Table 3).

Two rail projects delivered for a public-sector client were responsible for the substantial mean reductions in scope that are presented in Figure 2. These ranged from $101 to $150 millions (Figure 2), and were procured using a design and construct contract. While there was a decrease in the scope of works, rework was found to have been reported only in one project, which was 0.04% of OCV. Considering the prevalence of rework, particularly in infrastructure projects such as rail (Love et al., 2018c), it is surprising that no NCRs were reported and documented. Though, the underlying rationale for the non-reporting of NCRs was outside the scope of this study.

The mean cost difference and rework cost by client, contract and project type are presented in Figure 3. For private sector clients, a mean cost increase of 266.32% was identified, which was predominately incurred in building projects. The cost increases were primarily attributable to rework, particularly in the design and construct projects where a mean of 1.28% of OCV was computed. In Figure 4, a service contract for track inspection and maintenance for a private-sector rail project had the highest margin of 32.33% of its OCV whereas the lowest mean was 5.25% for a design and construct contract for a public-sector client. The mean margins applied to building projects were higher for public sector clients at 22.82%. Two defence projects had been allocated margins of 26% and 32% and two new hospitals with figures of 23% and 29%. Changes in scope leading to reductions in workload outweighed those leading to additional works. Contractors typically benefit financially from undertaking change-orders, but this was not the case for organisation in this study. It can be seen that public sector clients were prone to requesting changes to the scope of work. However, change-orders requiring a reduction in works tended to occur in infrastructure projects such as rail and water.



(a) Client type and margin

(b) Client type and rework

(c) Client type and change-orders

Figure 2. Mean costs by client type and project size

Table 3. Project size descriptive statistics as a percentage of OCV

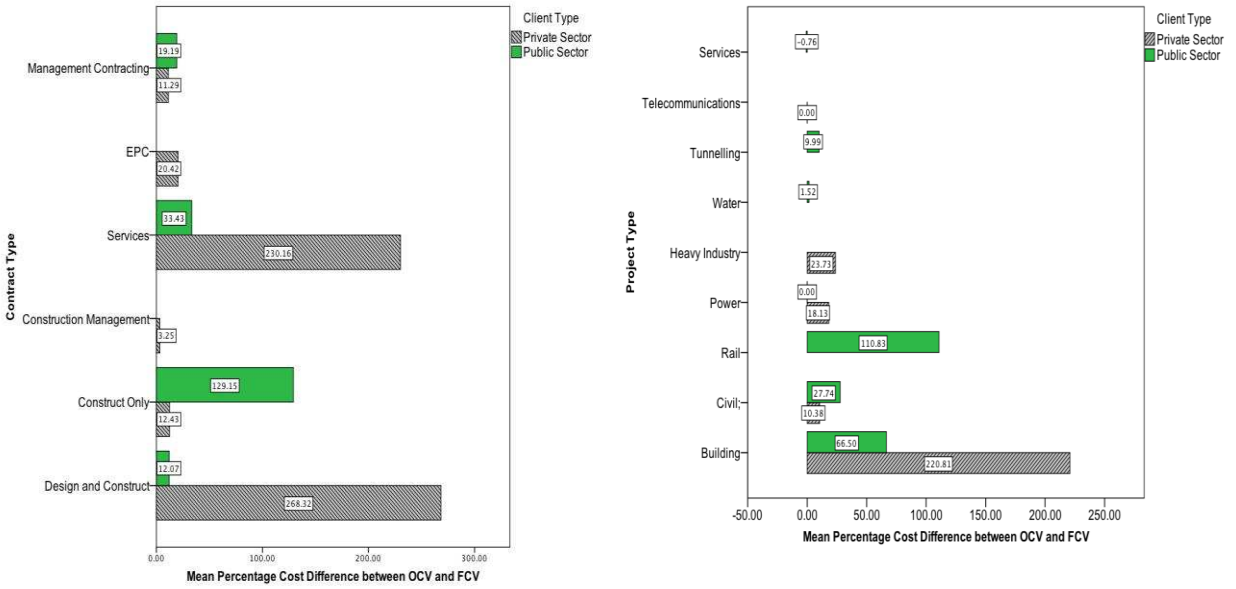
Factors		**Cost difference %**			**Rework %**			**Change-order %**			**Margin %**		
Project Size	N	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
< $50m	76	98.41	3.34	508.82	0.40	0.015	1.50	-48.61	0.28	312.71	7.24	7.38	6.86
$51 - $100m	10	14.28	9.50	12.54	0.19	0.13	0.16	5.99	0.76	11.97	8.29	8.51	3.38
$101-$150m	8	22.88	16.28	23.34	0.62	0.53	0.72	-1.61	0.45	7.88	10.36	9.53	5.62
$151-$200m	2	74.67	74.67	103.23	0.20	0.20	0.07	-0.14	-0.14	-	7.20	7.20	3.86
> $200m	2	5.51	5.51	7.79	0.21	0.21	0.06	0.20	0.20	-	5.51	5.51	7.79
Total	98	81.28	4.36	448.82	0.39	0.04	1.34	-35.73	0.38	270.41	7.56	8.00	6.43

Differences and Associations Between Cost Factors

Considering the differences shown in Figures 3 and 4 regarding the mean costs between client and project characteristics, a one-way analysis of variance (ANOVA) was undertaken to determine if a statistical difference existed. Table 4 presents a summary of the ANOVA results and the following significant differences were found: (1) project type and change-orders ($F(62,4) = 6.21$, $p < 0.05$); (2) project size and rework ($F(42, 55) = 0.000$, $p < 0.05$); and (3) project size and cost difference ($F(63,34) = 1.867$, $p < 0.05$).

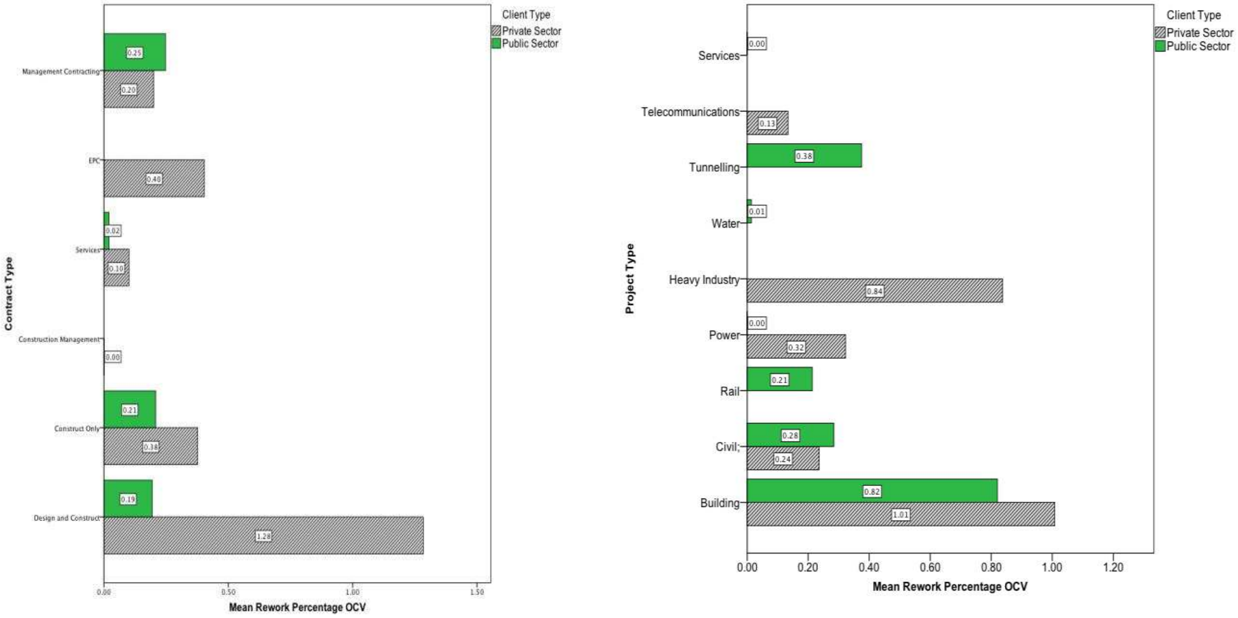
While significant differences are identified in Table 4, context again needs to be given as there is a danger of falling foul to issues surrounding the use of P-value of 0.05 and accepting the results presented at face value. Indeed, the significant results should be treated cautiously as there has been an over-reliance on a P-value of 0.05, which cannot determine whether a hypothesis is true or if the results are important. A P-value simply signifies that if the null hypothesis is true, and all other assumptions made are valid, then there is a 5% chance of randomly obtaining a result at least as extreme as the one observed. Hence, a P-value threshold cannot really indicate the importance of a finding. The extreme values need to be taken into account and thus should not be discounted.

An understanding of why they occurred enables the establishment of a context and the ability to make sense of the findings. In this instance, two infrastructure projects with a contract value less than $50 millions experienced rework costs between 2% and 4% of their projects' OCV and another valued at $101 millions. Addendums to contract values as a result of changes in scope led to revised contract values.



(a) Mean cost difference by contract type

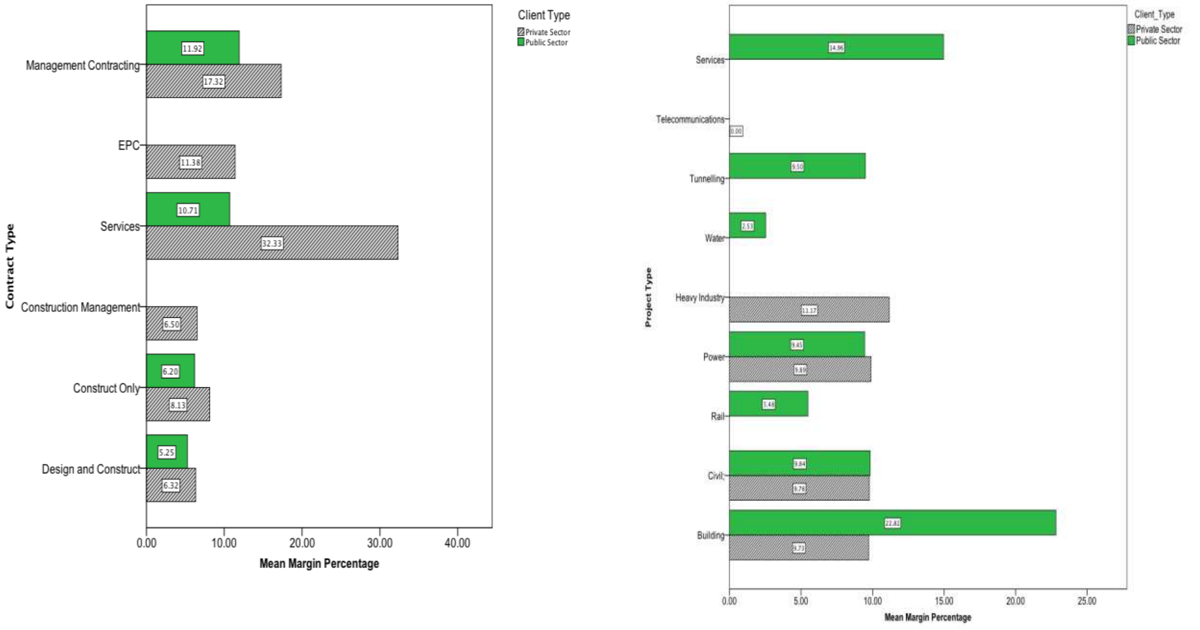
(b) Mean cost difference by project type



(c) Mean rework cost by contract type

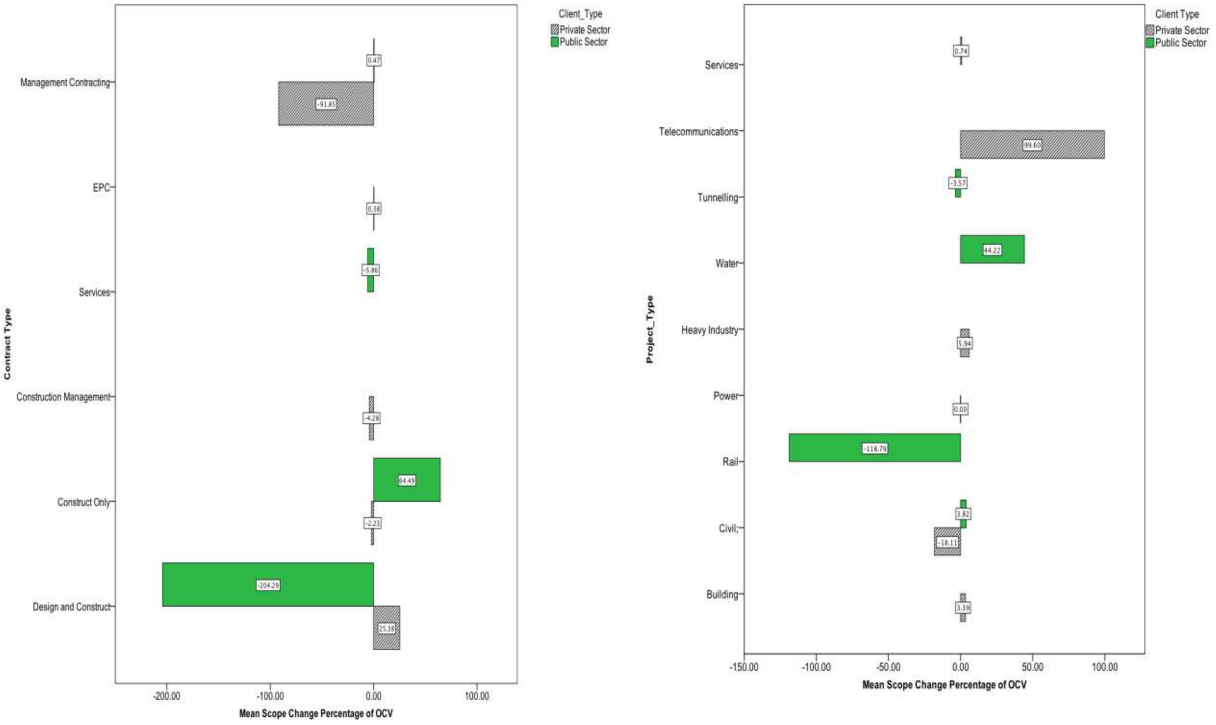
(d) Mean rework cost by project type

Figure 3. Mean cost difference and rework for contract and project type



(a) Mean margin by contract type

(b) Mean margin by project type



(c) Mean change-order by contract type

(d) Mean change-order by project type

Figure 4. Mean change-order and margin for contract and project type

Table 4. One-way ANOVA results

Factor	Cost difference	Rework	Change-order	Margin
Client type	F (64, 33) = 1.066, $p < 0.05$	F (42,55) = 0.111, $p < 0.05$	F (62,4) = 0.837, $p < 0.05$	F (64, 33) = 0.45, $p < 0.05$
Project type	F (63, 34) = 0.869, $p < 0.05$	F (42,55) = 1.261, $p < 0.05$	F (62,4) = 6.21, $p < 0.05$ *	F (64, 33) = 0.745, $p < 0.05$
Contract type	F (42,55) = 1.506, $p < 0.05$	F (42,55) = 1.486, $p < 0.05$	F (62,4) = 0.055, $p < 0.05$	F (62,4) = 0.283, $p < 0.05$
Project size	F (63,34) = 1.867, $p < 0.05$*	F (42, 55) = 0.000, $p < 0.05$*	F (62,4) = 6.187, $p < 0.05$	F (63, 34) = 0.025, $p < 0.05$

* Significant differences

The rework costs reported based on OCV may, therefore, have been artificially inflated. In one particular project, a value of 12.32% for rework was reported, but taking into account the addendum that was added, it should have been noted as being 0.35%. Without an understanding of the context of these figures, which is the bane of most previous studies in this area, such reported rework figures may be taken out of context. No definitive explanation can be provided as to why rework would vary by project size, especially as previous research has demonstrated this is not the case (Love and Sing, 2013). In this instance, the significant ANOVA findings that are presented should be considered with some skepticism. Correlations are used to further explore associations that may exist between the variables used in this study (Table 5).

Table 5 identifies that client and project types had a significant negative association ($p < 0.01$). Referring to Figure 3, it is explicit that the margins applied to private sector clients were lower than their public-sector counterparts. Juxtaposed with observations presented in Figure 3 and correlations, it is assumed that the contractor may have lowered their margin for private sector clients and specific project types.

Table 5. Bi-variate correlations between project characteristics and cost factors

Factors	**Client type**	**Project type**	**Contract type**	**Project size**	**Cost difference %**	**Margin %**	**Rework %**	**Change-order %**
Client type	1							
Project type	0.168	1						
Contract type	-0.102	0.018	1					
Project size	-0.145	-0.174	0.046	1				
Cost difference %	-0.018	-0.111	-0.056	-0.059	1			
Margin %	-.199*	-.272**	.398**	0.053	-0.132	1		
Rework %	-0.152	-0.121	-0.078	-0.008	.662**	-0.005	1	
Change-order %	-0.127	0.78	0.128	0.112	-0.107	0.56	0.218	1

* Correlation is significant at the 0.05 level (2 tailed).
** Correlation is significant at the 0.01 level (2 tailed).

Predictors of Cost Performance

To determine if project characteristics and cost factors were predictors of cost performance a forward stepwise regression was performed. Factors such as client, project and contract types, size and margin were not identified as being predictors of cost performance. But, rework was identified as being a significant predictor accounting for 43% in the variance of a project's cost performance $R^2 = 0.43$, $F (1,96) = 74.880$, $p < 0.01$. Figure 5 presents a scatter-plot of the relationship between cost difference and rework. Both ANOVAs and regression results are highly sensitive to outliers and therefore the latter are often deleted from analyses. However, in this case, they are considered to have occurred due to random variation and it was therefore considered appropriate for them to remain (Rousseuw and Hubert, 2011).

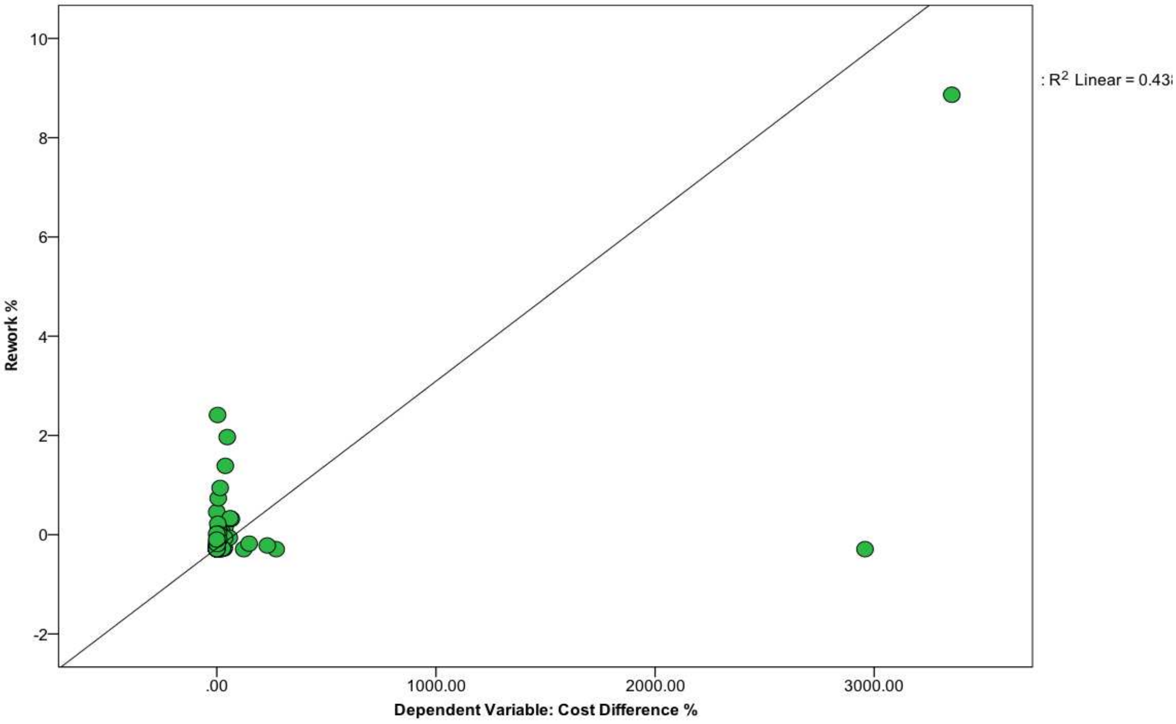


Figure 5. Scatterplot of rework and cost difference

The distribution of rework costs is presented in Figure 6. It can be seen that rework does not follow a Normal distribution. If a construction organisation was to predict the likelihood of rework arising a priori, then the probability distribution that best describes their behaviour is needed.

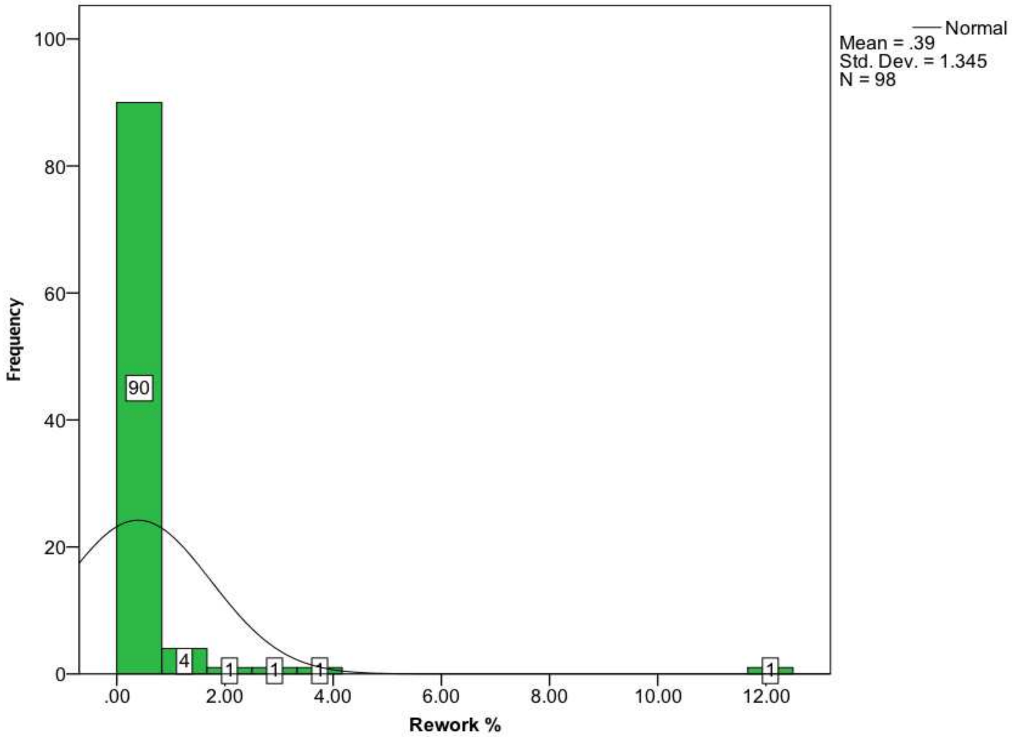


Figure 6. Distribution of rework costs

The Anderson-Darling (A-D) and Kolmogorov-Smirnov (K-S) non-parametric tests were used to assist in determining the goodness of fit for probability distributions. The A-D statistic A^2 was revealed to be 108.77. The K-S test revealed a D statistic of 0.11676 with a P-value of 0.0271. Both the goodness of fit tests accepted the H_0 for the distribution of rework costs. The domain of a Beta distribution can be viewed as a probability and can be used to describe the distribution of an ‘unknown’ probability. The Beta distribution is defined by the following parameters, which are all continuous: α_1, α_2 and a, b. The shape parameters are α_1 ($\alpha_1 > 0$) and α_2, ($\alpha_2 > 0$), with a, b the boundary parameters ($a < b$). The domain for this distribution is expressed as $a \leq x \leq b$. The probability density function (PDF) for a Beta distribution is defined as:

$$f(x) = \frac{1}{B(\alpha_1, \alpha_2)} \frac{(x-a)^{\alpha_1-1}(b-x)^{\alpha_2-1}}{(b-a)^{\alpha_1+\alpha_2-1}} \qquad \text{[Eq.1]}$$

The cumulative density function (CDF) is expressed as:

$$F(x) = I_Z(\alpha_1, \alpha_2) \qquad \text{[Eq.2]}$$

where,

$$z = \frac{x - a}{b - a} \qquad \text{[Eq.3]}$$

B is the Beta Function, and I_z is the Regularised Incomplete Beta Function.

In this case, the parameters of the distribution are α_1=0.10064, α_2=1.8815, a=6.3264E-15, b=22.008. Using the Beta PDF, the mean and median rework costs probabilities are calculated. As the mean and median rework costs are 0.39% and 0.05% of OCV, the probability of occurrence is ≤ 90% and ≤ 59%, respectively.

Discussion

There has been a proclivity for studies examining project cost performance to be based on secondary data and questionnaire surveys (e.g., Flyvbjerg et al., 2002; Flyvbjerg and Sunstein, 2016) or from a public-sector client perspective by examining a litany of their completed projects (e.g., Jahren and Ash, 1991; Bhargava et al., 2010; Anastasopoulos et al., 2014; Baccarini and Love, 2014; Love et al., 2018a). Seldom has the cost performance of projects been evaluated from a contractors' standpoint. Obtaining real-data from contractors about their costs and margins arising during production is rare due to issues of commercial sensitivity.

In addressing the prevailing research void building upon the work presented in Love et al. (2017a), this study aimed to re-examine the nature of cost performance from a contractor's perspective, with particular reference to change-orders and margin to provide a realistic view of what is actually occurring in practice. To reiterate, this study was unable to obtain data for the contractor's final (i.e. actual and not expected) margin. Rather, rework cost and approved subcontractor change orders data were provided, which had not been made available in Love et al.'s study (2017a). In Love et al. (2017a), a significant negative association between the contractor's final margin and project size and cost performance was revealed. Table 6 compares the key findings derived from this research with those presented in Love et al. (2017a).

Table 6. Key findings

Factors	**Findings** (2009 to 2015)	**Love et al. (2017a)** (2011 to 2014**)**
Sample size	98	67
Total value of projects	$8.5 billion	$3.2 billion
Mean contract value	$87 million	$48 million
Approved client change orders % of the total value of work	3.6%	11%
Approved subcontractor change orders % of the total value of work	4.17%	-
Cost performance range from OCV	-0.76% to 3353.89%	-42.88% to +270.93%
Mean cost performance (i.e. difference) Median	81.29% 4.36%	23.75% 8.12%
% of projects experiencing a cost increase from OCV	65%	67%
Mean margin Median	7.56% 8.00%	9.89% 9.00%
Mean final margin as % OCV	-	12.8%
Mean rework cost as % OCV Median	0.39% 0.04%	-

The results presented in Love et al. (2017a) have not been replicated per se, but commonalities and additional knowledge have been identified. The margins applied to projects are comparable or even almost similar, when the median is taken into account. The projects were constructed during a significant period of economic growth in Australia and relative certainty as a result of demand for minerals and resources from countries such as India, China, and South-Korea and strong population growth. The construction sectors in states such as Northern Territory, Queensland, and Western Australia where numerous mega-project developments (e.g., iron ore mines and liquefied natural gas plants) and large-scale infrastructure (e.g., hospitals and rail) works that had been delivered financially benefited this economic activity. The major resource projects are now complete and low economic activity and uncertainty in these states has meant that the margins of these may now be significantly lower. Though, New South Wales and

Victoria are in the midst of an infrastructure boom so it is suggested that the margins for contractors undertaking projects in these states are more robust.

In the United Kingdom (UK), for example, margins have been reported to be as low as 1% in 2017 compared to those in 2007 when they were approximately 4% (Ernst and Young, 2017). According to a survey conducted by Ernst and Young (2017), the margins of contractors in the UK are significantly lower than their opposite numbers in Australia where they are between 4% and 5%. This figure marries somewhat with the median figure of 4.36% reported in this study. Contractors have typically maximised their margins through change-orders. However, with the public sector facing budget pressures, changes in scope may be used to reduce costs. As a consequence, the potential for increasing their margins is lost. Perhaps what should be of immediate concern to contractors is the negative impact that rework may have on their profitability. If a contractor operates with margins of 1%, ceteris paribus, then this could be reduced, on average, by nearly 50% if they do not put in place mechanisms to reduce and contain their rework. The danger here is that if the conditions that result in rework occurring are not addressed, not only will a contractor's profit, competitiveness and reputation be jeopardised but also their survival. Thus, contractors need to build business resilience and actively enact and engender strategies to redress rework causation. In actual fact, rework is the elephant in the room and it can make or break contractors when faced with a period of economic uncertainty. While this is well-known and widely discussed amongst industry practitioners, rework remains a zemblanity (i.e. an unpleasant unsurprise) (Love et al., 2018c).

Conclusion

While there has been a considerable amount of research that has examined the cost performance in construction projects, a quagmire exists surrounding what constitutes an overrun. There is an overstated perception that cost overruns are a norm. However, cost overruns depend not only on the points of reference or the stakeholder point of view that are used to determine their occurrence. The research presented in this paper sought to add clarity to this problem by replicating previous empirical research and further knowledge, from a contractor's view, by determining the costs from the award of a contract to the issue of practical completion.

In this study, a total of 98 projects constructed by a large contractor with a combined value of $8.5 billion were examined to explore the nature and value of rework, margins and change orders. The sample comprised of projects procured by the public and private sectors using an array of contract types, with the most popular being construct-only, accounting for 49.5%. Only 65% of projects experienced a cost increase during their construction, though a mean rework cost 0.39% of OCV occurred, which had a negative impact on the contractor's overall margin. In addition, the difference between approved client change-orders and those by the contractor for subcontractors was 0.5% of the total costs incurred for the sampled projects, which adversely impacted the organisation's profit. The upshot here was that the contracting organisation was subjected to a mean loss in profit of 23% per annum over the period of analysis. Being able to provide a quantifiable adverse impact of rework on a contractors' margin in this instance is a first in the academic literature. However, it is anticipated that margin losses may well have been higher as rework was seldom formally documented and reported. Future research is therefore required to explore in more detail why and how these costs materialise in practice for a contractor.

At this juncture, however, it is appropriate to outline the limitations of the research presented in this paper. They need to be made explicit so that future studies can address them and enable further developments in knowledge to come to the fore. The sample size was purposively sampled and thus the potential for bias emerges. Moreover, the non-probability-based selection of projects used in the study means there may not necessarily be representativeness. Being cognisant of these limitations, future research needs to focus on obtaining larger samples that are randomly selected from several organisations. However, constraints surrounding the commercial sensitivity of the type of information that would be required to conduct further research with contractors will be a barrier that would need to be addressed. Future cost performance research needs to ensure context is used to explain 'outliers' to prevent alarmists from unnecessarily reporting cost overruns to suit an agenda that they may be pushing. Apart from contractors needing to tackle the rework problem during construction, clients, especially from the public sector, need to rethink their front-end project definition processes to mitigate changes to their requirements once a contract has commenced.

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Dr Dominic D Ahiaga-Dagbui is Lecturer of Construction Management at the School of Architecture and Built Environment, Deakin University, Australia. He gained his PhD from the University of Edinburgh, UK (2014) and a Masters in Civil Engineering and Construction Management from Heriot-Watt University, UK (2010). Dominic is keenly interested in practical and transformational research that is of direct benefit to the civil and construction industry. His research focuses on delivery of large and complex infrastructure projects, taking into consideration future operational costs, adaptability and end-user needs. His academic contributions are in the areas of infrastructure cost overrun, front-end project governance, client-capabilities development for cost-effective asset delivery and future-proofing infrastructure.

Dr. Giorgio Locatelli is an Associate Professor of Infrastructure Procurement and Management at the University of Leeds (U.K.). He has a Bachelor and Master of Science degree in Mechanical Engineering (2006) and a PhD in Industrial Engineering, Economics and Management from the Politecnico di Milano (Italy) (2010). His research and teaching is focuses on Project Management in Infrastructure/Megaprojects with a particular emphasis on benchmarking cost-benefit analysis, risk management, ethics & corruption, governance and temporary organisations, financing, modularisation. Giorgio also acts as a consultant and visiting academic for several institutions. He is the author of more than 100 international scholarly journal and conference publications. His membership includes: Member of the CEO Council on Transformational megaprojects – World Economic forum; Associate Editor for the Project Management Journal; and serves on the Editorial Board of Construction Management and Economics and the International Journal of Project Management

Dr Michael C.P. Sing is an Assistant Professor (Research) in the Department of Building and Real Estate at Hong Kong Polytechnic University. He has Master's degree in Building Engineering from City University of Hong Kong and PhD in Construction Management and Engineering from Curtin University, Australia in 2012. His research interest includes: (a) infrastructure delivery and asset management and (b) project performance and evaluation using machine learning and modelling (equivalent to construction business), and (c) sustainability in design and construction. Dr Sing is currently undertaking several industry-funded research projects that focus on risk management of infrastructure projects and sustainable building design.