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RESEARCH ARTICLE

Yuanxin ZHANG, Abdol CHINI, R. Edward MINCHIN Jr., Lourdes PTSCHELINZEW, Dev SHAH

Performance of seven highway construction contracting methods analyzed by project size

Abstract The conventional Design-Bid-Build (DBB) construction contracting method has had various drawbacks exposed in highway construction practice, including lack of communication, inefficient design, antagonizing relationships, and increased disputes. To mitigate the negative aspects of DBB, several alternative contracting methods and alternative project delivery systems have been devised and introduced to the industry over the past 30 years. Five such innovations were tested by a research team from the University of Florida under the sponsorship of the Florida Department of Transportation (FDOT). To perform a realistic assessment, this study categorized FDOT projects built between 2006 and 2015 into groups according to current contract amounts. Both absolute and relative metrics were defined and employed. For comparison purposes, a collective analysis on all gathered data was performed. Additionally, the influence of outliers on the results was examined. The results showed that analyses based on individual cost categories are more convincing because large projects tend to impose stronger influence on the analyses. In addition, outliers must be identified and screened to reach realistic and reliable conclusions. With regard to the actual performance of the contracting methods, each performs differently within different cost categories.

Keywords alternative contracting methods, time, cost, performance evaluation

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Yuanxin ZHANG
School of Management, Guangzhou University, Guangzhou 510006, China

Abdol CHINI (✉), R. Edward MINCHIN Jr., Lourdes PTSCHELINZEW, Dev SHAH
Rinker School of Construction Management, University of Florida, Gainesville, FL 32611, USA
E-mail: chini@ufl.edu

1 Introduction

Conventional Design-Bid-Build (DBB) has been the dominant contracting method for decades in the highway construction industry (Miller, 1995; Minchin et al., 2013; Molenaar et al., 2014). The DBB contracting approach emerged in the early 20th century from the medieval master builder mechanism, under which the master builder performed design, engineering, and construction work (Beard et al., 2001). The advancement in knowledge of materials and construction technologies and the complexity of facilities led to the distinction of design and construction as specialized entities to be completed separately (Konchar and Sanvido, 1998). Consequently, the master builder transitioned to DBB, which is a sequential contracting method involving two independent phases: design and construction. Since its birth, DBB has delivered many projects on time and under budget.

With further specializations in design and construction over time, and the increased complexity of facilities, DBB has displayed numerous disadvantages in practice, such as lack of communication, inefficient design, adversarial relationships, and increased disputes (Konchar and Sanvido, 1998). The inefficiency associated with DBB necessitated the development of some alternative contracting mechanisms to overcome its shortcomings while meeting the project owners' challenges with tight budgets and short timeframes.

A series of alternative contracting methods have been developed over the past few decades to accelerate delivery and reduce the cost of financially and technically sophisticated projects. In the late 1980s, the Federal Highway Administration (FHWA) initiated Special Experimental Project No. 14 (SEP-14) to assess promising non-conventional contracting methods employed by state Departments of Transportation (DOTs).

As a pioneer and leader in the use of alternative contracting methods, the Florida Department of Transportation (FDOT) obtained permission from FHWA to execute a Design-Build (D-B) demonstration program in 1987 (Ellis et al., 1991). Due to the success of this pilot program on highway construction projects in Florida, FHWA granted federal funds to allow FDOT to use the D-B method in 1996. Since then, D-B has become increasingly popular on highway construction projects in Florida (Minchin et al., 2013). Furthermore, in response to the SEP-14 initiative, FDOT has explored a number of other alternative contracting methods, including A + B, Incentive/Disincentive (I/D), Lump Sum (LS), and No Excuse Bonus (NEB). These account for the majority of alternative contracting methods used by Florida and other state DOTs (Anderson and Damnjanovic, 2008; Strong et al., 2005).

Although alternative contracting methods were intended to perform better than the conventional DBB method in terms of cost and schedule, empirical data from previously completed projects must be used to examine whether their potential in time and cost savings was realized in practice. It has been observed that "an owner uses a particular contracting method simply because it is what they are used to, it appears to be the easiest" (Gordon, 1994). In fact, many projects failed due to the poor use of contracting methods (Herbsman and Ellis, 1992). Therefore, the objective of this research was to evaluate the time and cost performance of the alternative contracting methods using empirical data from the FDOT database. Furthermore, this study analyzed the time and cost performance of these contracting methods by project size, which has never been done in previous related works. The influence of outliers on the results was also examined in this study. Based on the evaluation, FDOT can subsequently adjust contract administration practices accordingly to improve efficiency.

2 Definition of alternative contracting methods

According to Molenaar et al. (2014), a contracting method comprises three major components: the delivery system, the procurement procedure, and the payment arrangement. Gordon's (1994) definition of a contracting method is very similar to Molenaar's, but breaks a delivery system into project entities and contractual relationships with the owner. This research focused primarily on D-B, A + B, LS, I/D, and NEB, which are defined as follows:

2.1 Design-Build (D-B)

D-B contracts both design and construction functions to a single entity to maximize the contractor's flexibility in design, construction techniques, and material selection (Charoenphol et al., 2016; El Asmar et al., 2013; Ellis et al., 1991; Minchin et al., 2013). Because design and construction are performed by one entity, D-B contractors can overlap design and construction processes to accelerate the project schedule and, subsequently, cut cost. FDOT divides D-B into D-B (Major) and D-B (Minor) in contract administration (Minchin et al., 2016). Florida statutes stipulate that D-B (Major) contracts are projects with estimated costs greater than $10 million and are limited to major bridges, limited access facilities, rail corridors, and building projects (FDOT, 2017). In contrast, the D-B (Minor) description is authorized for smaller projects with estimated costs of less than $10 million. The common work types applicable to D-B (Minor) include minor bridges and resurfacing (no widening/shoulder work) (FDOT, 2017). D-B contracts in Florida are typically procured by either adjusted score or low bid (Ellis et al., 1991; Ellis et al., 2007).

2.2 A + B

A + B (aka cost-plus-time) is designed to reduce project duration by weighing time in the bid evaluation process (Choi et al., 2012; Herbsman et al., 1995). Contracts are awarded to low total bids consisting of a standard cost bid and a time bid, which is the product of proposed days to finish a project and road-user daily costs predetermined by FDOT. Contractors are incentivized to finish quickly by receiving credit for each day the work is to be accomplished ahead of the contracted schedule and, conversely, penalized for each day the work extends past the contracted time. Contract time can be adjusted for specific events including uncommon inclement weather, unforeseen conditions, or scope change by the owner (Ellis et al., 2007; Minchin et al., 2016).

2.3 Lump Sum (LS)

Lump Sum has been widely used in the vertical construction sector for decades but is new and considered radical to the horizontal construction sector (Ellis et al., 2007; Ibbs et al., 2003; Tran et al., 2013). It is a method of contracting in which a contractor submits a total cost for all work as opposed to individual pay items. It is intended to reduce design and contract administration costs and is suitable for projects with a well-defined scope, minimal risk of unforeseen conditions, and less chance for change orders (Molenaar and Yakowenko, 2007).

2.4 Incentive/Disincentive (I/D)

Incentive/Disincentive is designed to motivate the contractor to finish the project ahead of schedule by rewarding early completions and penalizing delays based on contract days (Choi et al., 2012; Meng and Gallagher, 2012; Minchin et al., 2016). Both incentive and disincentive monies are calculated on a daily basis in terms of administration cost, Construction Engineering &

Inspection (CEI), and daily road-user costs determined by FDOT. This method is commonly combined with other contracting methods in practice.

2.5 No Excuse Bonus (NEB)

To shorten construction time, NEB stipulates a substantial bonus in a contract, and the contract is awarded to a contractor if a project is completed within an agreed upon timeframe irrespective of any problems or unforeseen conditions that might occur during project execution (Ellis et al., 2007; Minchin et al., 2016). Time extensions are granted only when catastrophic incidents directly undermine the contractor's performance. The bonus can be tied to a specific milestone, project finish date, or both, for completing an element or the entire project within the specified time.

3 Literature review

Common to these alternative contracting methods is the goal of shortening project delivery times and lowering project life cycle costs. There has been continuous interest and need in assessing the time and cost performance of contracting methods to inform practitioners which method is more effective under which circumstances. Relevant research papers are subsequently summarized.

Some researchers found that alternative contracting methods are superior to the conventional DBB approach. Konchar and Sanvido (1998) compared D-B, Construction Management at Risk (CMR), and DBB using 351 projects from among several different types of facilities in the United States. This study measured some defined time and cost performance standards: unit cost, cost growth, schedule growth, construction speed, delivery speed, and intensity. The finding in this research was that D-B can greatly enhance cost and schedule performance.

Molenaar et al. (1999) evaluated the cost and time performance of D-B based on 104 out of a total of 512 surveyed projects. Cost and time performance was measured through a relative change from the original contracted budget and completion dates. The results reflected that most project owners were satisfied with the performance of D-B.

El Asmar et al. (2013) compared the performance of Integrated Project Delivery (IPD) with that of D-B, CMR, and DBB. They analyzed 35 healthcare and higher education research facility projects, based on cost and schedule performance metrics: unit cost, construction cost growth, delivery speed, construction speed, and construction schedule growth. They concluded that IPD performed better in six of the nine metrics.

Several other studies discovered that alternative contracting methods can only partially fulfill the expectations in cost and time savings. Ibbs et al. (2003) appraised DBB and D-B according to their cost, schedule, and productivity using data from 67 projects gathered from the Construction Industry Institute (CII). Comparisons were based on relative and absolute measurements in the form of percentage changes or percentage of projects. This study found that D-B saved time, but cost savings and productivity improvement were not clearly supported in this study.

Minchin et al. (2013) chose 60 highway projects completed between 2002 and 2010 in Florida through a random process. All selected projects were $7 million or greater in contract amount. The objective of this study was to compare the cost and time performance of D-B with that of DBB. The criteria used to judge their performance were the difference between original estimate and contract award amount, difference between original contract estimate and final contract amount, and difference between contract duration and final duration. The results showed that DBB significantly outperformed D-B in cost savings but not in time savings.

Chen et al. (2016) gathered 418 projects from the Design Build Institute of America's (DBIA) online database to conduct an analysis on cost and time performance of D-B. Their evaluation criteria included time overrun rate, early start rate, early completion rate, and cost overrun rate, and their results indicated that 75% of D-B projects were completed on time or before the contract finish date; however, 50% of the projects experienced cost overruns, and the proclaimed cost savings capability of D-B was not bolstered by the results. The findings also exhibited that different procurement methods have significant influence on the time performance of D-B; and cost performance was considerably affected by owner types and payment methods.

Based on 94 valid cases, Col Debella and Ries (2006) compared time and cost performance of the Single Prime, Multiple Prime, and Multiple Prime with an Agent Construction Manager methods. Time and cost performance metrics defined in this study included construction speed, unit cost, percent cost growth, and percent construction schedule growth. They first analyzed all data sets and then conducted a partial data analysis on projects over $10 million. No significant difference among these methods was discovered from the analysis.

Shrestha et al. (2011) selected six D-B projects and 16 DBB projects with total design and construction cost greater than $50 million through a systematic process. Multiple criteria were used to evaluate the performance of D-B and DBB, such as contract award cost growth, total cost growth, actual cost per lane distance, total schedule growth, project delivery speed per lane distance, construction speed per lane distance, and cost per change order. This study discovered that construction speed and project delivery speed per lane distance of D-B projects performed significantly better than on DBB projects, but no significant difference was indicated in cost performance between the two methods.

In summary, the literature reflected that several studies were conducted to evaluate time and cost performance of a variety of contracting methods based on actual field data. Some studies confirmed the touted advantages in practice; others failed to see the designed superiority with the alternative approaches. Countless factors can contribute to the inconsistent findings: metrics, analytical approach, sample size, project size, project type, project location, etc. As a result, this study collected data from many projects of differing sizes and employed a stringent approach in analyzing data based on cost and time performance metrics defined in this research.

4 Research methodology

This research collected all projects completed by FDOT, within a specific timeframe, using the contracting methods being investigated. With the collected data, the team identified and filtered obvious outliers from the initial data pool. To obtain realistic and reliable results, projects were divided into categories based on project cost. The distribution of the number of projects was also factored into the categorization process. Considering the significance of the categorization process, professional opinions were also sought. The appraisal metrics were then defined with respect to cost and time performance. After that, the contracting methods of interest to this research were evaluated using these defined metrics to show the differences in time and cost performance in absolute and relative scales. In this process, the data were first collectively analyzed per contracting method. The performance of the contracting methods was then evaluated using all gathered data sets per cost category. After that, a further assessment was conducted by excluding statistical outliers. The following two sections detail the data collection process and performance metrics used in this study.

4.1 Data acquisition

A total of 2721 projects completed between 2006 and 2015 were initially retrieved from FDOT's online database, which included those completed using the alternative contracting methods pertinent to the research as well as those classified as DBB (as the basis of comparison for performance evaluation). In all, a total of seven contracting methods were investigated: DBB, D-B (Minor), D-B (Major), LS, I/D, A + B, and NEB.

A total of 282 projects were eliminated because their work types were not directly related to heavy/highway construction (i.e., painting, landscaping, walkways, etc.). Project types include bridge, bridge repair, interstate construction, maintenance construction, miscellaneous construction, new construction, reconstruction, resurfacing, widening, and traffic operation. Upon investigating projects that exhibited conflicting information, 3 projects were found to have been terminated and were thus considered outliers, which were excluded from analysis. In the end, 2436 projects were investigated for cost and time performance. Table 1 illustrates the paring down process and distribution of the projects, respectively.

The projects were broken up into cost categories based on commonly used contract cost divisions. The categories formed were as follows: under \$1 million, \$1 to \$5 million, \$5 to \$10 million, \$10 to \$20 million, and over \$20 million. The breakdown of projects by contract cost is shown in Table 2 for all categories. Table 3 details the distribution of projects exceeding \$20 million.

4.2 Performance metrics

This study used current contract days (i.e., present contract duration after including weather days, change orders, or supplemental agreements) as well as days used (i.e., actual duration of the project) to assess time performance of the contracting methods. Current contract amount (i.e., present value of the contract after change orders) and estimate paid to date (i.e., actual cost paid on the contract) were used to evaluate the cost performance of the contracting methods. To provide a better understanding of the performance of the contracting methods, both absolute and relative values of time and cost savings (or losses) were produced and presented per cost category.

The percentage change of days used over current contract days was calculated for each contracting method per individual cost category using Eq. (1):

$$\text{Percentage change of days (PCD)} = \frac{[\Sigma(\text{Days used}) - \Sigma(\text{Current contract days})]}{\Sigma(\text{Current contract days})}. \quad (1)$$

Table 1 Final distribution of all projects by contracting methods

Categories	DBB	D-B (Minor)	D-B (Major)	LS	I/D	A + B	NEB	Total
Original number of projects	1654	147	86	728	73	21	12	2721
Removed by type	157	-	-	125	-	-	-	282
Removed as data set outlier	2	-	-	1	-	-	-	3
Final total analyzed	1495	147	86	602	73	21	12	2436

Table 2 Distribution of projects by cost categories

Cost categories	DBB	D-B (Minor)	D-B (Major)	LS	I/D	A + B	NEB
< 1 million	609	89	15	357	16	0	0
$1 million–$5 million	658	42	27	205	36	6	5
$5million–$10 million	135	10	10	31	13	3	4
$10 million–$20 million	63	3	12	8	5	6	2
> $20 million	30	3	22	1	3	6	1
Total	1495	147	86	602	73	21	12

Table 3 Distribution of projects over $20 million

Contracting methods	$20 to $30 million	$30 to $40 million	$40 to $50 million	$50 to $60 million	$60 to $70 million	$70 to $80 million	$80 to $90 million	$90 to $100 million	$100 to $125 million	Total
DBB	16	7	2	1	2	0	1	1	0	30
D-B (Minor)	1	2	0	0	0	0	0	0	0	3
D-B (Major)*	10	6	2	0	1	1	0	0	1	21
LS	1	0	0	0	0	0	0	0	0	1
I/D	1	0	1	0	0	0	0	0	1	3
A + B	4	1	0	1	0	0	0	0	0	6
NEB	1	0	0	0	0	0	0	0	0	1

*Design-Build (Major) has 1 project worth $438 million.

Similarly, the average days saved was calculated using Eq. (2):

$$\text{Average days saved (ADS)} = \frac{[\Sigma(\text{Current contract days}) - \Sigma(\text{Days used})]}{\text{Number of projects}}. \quad (2)$$

The percentage change of cost for the individual cost categories was calculated using Eq. (3):

$$\text{Percentage change of cost (PCC)} = \frac{[\Sigma(\text{Estimate paid to date}) - \Sigma(\text{Current contract amount})]}{\Sigma(\text{Current contract cost})}. \quad (3)$$

The average cost saved for each contracting method per individual cost category was calculated using Eq. (4):

$$\text{Average cost saved (ACS)} = \frac{[\Sigma(\text{Current contract amount})\Sigma(\text{Estimate paid to date})]}{\text{Number of projects}}. \quad (4)$$

Throughout, negative time and cost values suggest average time delayed and cost escalation, while positive time and cost values reflect average project time and cost savings, based on Eqs. (2) and (4). Likewise, positive percentage values indicate time delay and cost escalation, while negative percentage values represent time and cost saved according to the metrics definitions, based on Eqs. (1) and (3).

5 Time and cost performance analysis on collective data

According to Table 4, which did not break down the projects based on cost categories, all 7 contracting methods reduced project duration to various extents. Only LS and D-B (Minor) lowered cost. Specifically, all alternative contracting methods, except LS, underperformed DBB in time savings. It is noteworthy that not only did D-B (Minor) and LS shorten project delivery time, they also reduced cost more substantially than the other methods. A + B, I/D, and NEB performed much better than the other contracting methods in time savings, but they caused a significant cost increase.

The results presented in Table 4 indicated that all 7 contracting methods are effective in lessening project delivery time, but most of them are less effective at controlling cost. Only D-B (Minor) and LS effectively curtail cost growth. Furthermore, NEB, A + B, and I/D are viable alternatives to DBB in acceleration of project schedule. D-B (Minor) and LS are effective alternatives to DBB in cost reduction. However, the findings based on the same data analysis approach conflict with that of prior studies. According to Anderson and Damnjanovic (2008), A + B leads to delays for large and complex projects, which is also supported by Choi et al.(2012). I/D may only be effective when incentives are large enough to motivate contractors to finish on time (Anderson and Damnjanovic, 2008; Choi et al., 2012). The results also agree with the previous research findings that showed DB to be an effective tool to reduce project duration, but often incurred cost growth (Anderson and Damnjanovic, 2008; Ibbs et al., 2003).

6 Time and cost performance analysis per cost category

Collectively analyzing projects of different sizes in terms of current contract amounts cannot convey the complete story because large projects exert a greater influence on the results. The value of that variable would not be interpreted the same way for different cost categories. As an example, if the percentage change of actual cost over current cost was 10% for projects under \$1 million, then the best interpretation is that the actual cost was approximately \$100000 (10% of \$1 million) more than the current cost. Similarly, if the percentage change of actual cost over current cost was 10% for projects over \$100 million, then the best explanation is that the actual cost was approximately \$10 million (10% of \$100 million) more than the current cost. Because a large majority of the projects were under \$1 million, evaluating the contracting methods by cost categories protected the calculations from being skewed under the influence of the higher-priced projects.

It is noted throughout that for analyzed categories with fewer than five projects, the research team refrained from making any interpretations. While no significant conclusions can be drawn from the analyzed categories with too few projects, the calculations are presented in the tables that follow for the benefit of observation.

6.1 Projects over \$20 million

The results indicated that D-B (Minor), LS, and NEB are rarely used on projects over \$20 million. According to Table 5, all 3 contracting methods (DBB, D-B (Major), and A + B) effectively curbed time growth while incurring significant cost escalation. It should also be noted that DBB not only underperformed A + B in time savings but also sustained a greater cost increase than A + B, which contradicts the finding that A + B causes serious delays (Anderson and Damnjanovic, 2008; Choi et al., 2012). On the other hand, DBB performed slightly better than D-B (Major) in both time and cost growth, which conflicts with the Minchin et al. (2013) finding that D-B is effective in time savings, but not in cost control.

6.2 Projects between \$10 and \$20 million

Table 6 shows that all 5 contracting methods under consideration (e.g., DBB, D-B (Major), LS, I/D, and A + B) reduced project duration; furthermore, A + B and I/D cut project duration substantially more than the others. Only LS was shown to decrease project cost in practice. All alternative contracting methods performed better than DBB in terms of time savings. However, I/D, A + B, and D-B (Major) incurred greater cost increase than DBB.

Table 4 Collective time and cost savings analysis of all contracting methods

Contracting methods	DBB	D-B (Minor)	D-B (Major)	LS	I/D	A + B	NEB
Total number of projects	1495	147	86	602	73	21	12
PCD	–1.97%	–1.64%	–1.39%	–2.46%	–10.42%	–9.12%	–11.04%
ADS	5	5	6	3	35	44	50
PCC	0.03%	–0.54%	1.69%	–0.98%	2.46%	4.54%	1.37%
ACS	–\$855	\$11936	–\$135470	\$14485	–\$151948	–\$679947	–\$120764

Table 5 Time and cost savings analysis for projects over \$20 million

Contracting methods	DBB	D-B (Minor)*	D-B (Major)	LS*	I/D +	A + B	NEB*
Total number of projects	30	3	22	1	3	6	1
PCD	–3.00%	–0.20%	–3.00%	–0.30%	–7.00%	–5.20%	–21.30%
ADS	28.7	2	27.3	2	88.7	43.7	250
PCC	3.70%	1.40%	2.60%	–8.30%	3.80%	3.40%	2.60%
ACS	–\$1317046	–\$436072	–\$1469581	\$2079629	–\$2278408	–\$1035405	–\$660372

* No interpretations have been made for categories with fewer than 5 projects.

Table 6 Time and cost savings analysis for projects between $10 and $20 million

Contracting methods	DBB	D-B (Minor)*	D-B (Major)	LS	I/D	A + B	NEB*
Total number of projects**	63	3	12	8	5	6	2
PCD	– 0.20%	3.80%	– 0.50%	– 4.40%	– 14.70%	– 17.10%	– 1.30%
ADS	1.4	– 28.3	3.9	19.6	95	97.8	10
PCC	1.40%	– 1.20%	1.50%	– 0.70%	5.50%	4.50%	– 0.60%
ACS	-$178,909	$136,399	-$209,815	$98,085	-$774,658	-$709,287	$89,565

* No interpretations have been made for categories with fewer than 5 projects.
** Please note, data set outliers here were removed due to being erroneous and/or from terminated projects.

The analysis revealed that A + B and I/D were more effective in schedule control than the rest of the contracting methods for projects between $10 and $20 million. All but LS led to significant cost increase, indicating that LS was the most effective tool in curbing cost growth for projects of this size.

6.3 Projects between $5 and $10 million

According to Table 7, the time and cost performance of all contracting methods under consideration (DBB, D-B (Major) and (Minor), LS, I/D) varied by different degrees. I/D showed a tremendous advantage in time savings compared to the other contracting methods. D-B (Major) and D-B (Minor) performed better than the other contracting methods in cost savings while incurring time delays. Among these alternative contracting methods, I/D, and LS significantly underperformed the other methods in cost reduction. D-B (Major) and D-B (Minor) decreased cost considerably.

The results indicated that for projects between $5 and $10 million, I/D is the best substitute for DBB to accelerate schedule, although it tends to lead to dramatic cost increase. To effectively control cost, D-B (Minor) and D-B (Major) are better alternatives to DBB. Nevertheless, DBB turned out to be the best option to simultaneously reduce cost and time for projects of this size.

6.4 Projects between $1 and $5 million

As shown in Table 8, all contracting methods except D-B (Major) saved time; meanwhile, all but A + B lowered cost. It is noted that DBB outperformed D-B (Major), D-B (Minor), LS, and A + B in terms of both cost and time. NEB led to not only the most significant time decrease but also the greatest cost reduction among all contracting methods. I/D also reduced both project delivery time and cost to a great extent. A + B minimally shortened project duration but incurred substantial cost growth.

The results revealed that DBB and LS were still the most widely used approaches in practice even though they are widely criticized for numerous shortcomings. NEB and I/D turned out to be effective options for schedule acceleration as well as cost savings; nevertheless, there was insufficient application of these techniques for meaningful analyses. A + B seemed to be the least preferable method because it caused only a negligible time decrease but a dramatic cost escalation. D-B (Major) seemed to be the least effective

Table 7 Time and cost savings analysis for projects between $5 and $10 million

Contracting methods	DBB	D-B (Minor)	D-B (Major)	LS	I/D	A + B*	NEB*
Total number of projects	135	11	10	31	13	3	4
PCD	– 1.90%	1.60%	0.30%	– 2.10%	– 11.80%	– 10.20%	– 3.50%
ADS	8.3	– 9.8	– 2	5.4	55.4	23.3	12.3
PCC	– 0.60%	– 2.00%	– 0.60%	0.10%	2.90%	14.90%	4.00%
ACS	$41317	$126084	$42873	– $6744	– $203315	– $1168445	– $315778

* No interpretations have been made for categories with fewer than 5 projects.

Table 8 Time and cost savings analysis for projects between $1 and $5 million

Contracting methods	DBB	D-B (Minor)	D-B (Major)	LS	I/D	A + B	NEB
Total number of projects	658	45	27	205	36	6	5
PCD	– 2.20%	– 0.60%	2.80%	– 2.20%	– 8.30%	– 0.20%	– 21.30%
ADS	6	2.2	– 11	4.2	21.8	0.3	55.2
PCC	– 1.90%	– 0.50%	– 1.30%	– 0.20%	– 1.80%	2.20%	– 1.70%
ACS	$45641	$9831	$30102	$3871	$49865	– $50900	$59037

approach for schedule acceleration. This also contradicts with previous research findings (Col Debella and Ries, 2006; Minchin et al., 2013).

6.5 Projects under $1 million

All 4 contracting methods analyzed in this study showed both time and cost savings by various scales (see Table 9). Specifically, I/D performed considerably better than the rest of the contracting methods in both cost and time savings. D-B (Major) also outperformed the other methods, except for DBB, in both time and cost savings. On the other hand, D-B (Minor) underperformed all contracting methods in cost reduction and all contracting methods, except LS and DBB, in time savings. DBB slightly outperformed LS in both time and cost control.

For projects under $1 million, A + B and NEB were not applied in practice. All employed methods exhibited effectiveness in cost and time control in this price range. I/D turned out to be the most preferable option in both cost and time savings. Following I/D, D-B (Major) also performed well in both schedule acceleration and cost control. The unanimous effectiveness in cost and time control with all four contracting methods might be ascribed to explicit scope definition and low complexity.

7 Time and cost performance analysis after excluding outliers

7.1 Identification of outliers

Outliers are the data points that stray from most of the data and have the potential to distort analysis results, often producing misleading conclusions and false inferences. Hence, it is critical to identify all potential outliers in the data set and screen out true outliers.

There are several basic types of outliers in terms of causes. The first type of outlier is caused by errors introduced in the process of data collection, storage, and transfer. For instance, people working in the field may input project information erroneously. Alternatively, project information may be stored to a wrong place or transferred mistakenly. This type of outlier is the most difficult to discover and should be eliminated from analysis because using those flawed data points leads to erroneous results. A second type of outlier results from abnormal contractual events, such as termination and abortion of projects. These outlier data should be dropped from the analysis as well because they could reduce the extent of contrast or even shift results in the opposite direction. The third type of outlier is produced under some extreme conditions (e.g., "Acts of God"; differing site conditions) or abnormal situations (e.g., excessively long material delivery delays; social, political, or economic disturbances), which can yield extremely long project durations or escalate project costs. This type of outlier should be carefully examined and used with caution.

This research first reviewed all selected projects by looking at obvious errors with projects, or projects that were abnormally terminated. It was found that three projects were terminated much earlier than the contract finish date. After confirmation from FDOT personnel, these projects were eliminated from analysis. Based on the Empirical Theorem, this research employed the two- and three-sigma methods (see Eqs. (5) and (6)), which identified suspicious outliers with approximately 95%–99% confidence. The team then investigated detailed project information to determine whether in fact these projects were true outliers. Additionally, the research team utilized a graphical method, in which bar charts with two horizontal lines representing the lower and upper bounds (both two- and three-sigma confidence intervals) were generated to highlight outliers. A corresponding analysis after removing outliers identified through the two- and three-sigma methods was performed, and the results are tabulated in Table 10 (see 7.2.1 below) according to the extent of influence on the results. This table exhibits results only for the contracting methods in each cost category containing outliers.

$$\begin{aligned}&95\%\ \text{Confidence Interval (CI)}\\&= \text{Average Time or Cost Saving}\ \pm 2\sigma\end{aligned} \tag{5}$$

$$\begin{aligned}&99\%\ \text{Confidence Interval (CI)}\\&= \text{Average Time or Cost Saving}\ \pm 3\sigma\end{aligned} \tag{6}$$

7.2 Results after excluding identified outliers

7.2.1 Projects over $20 million

Filtering identified outliers did not cause dramatic changes

Table 9 Time and cost savings analysis for projects under $1 million

Contracting methods	DBB	D-B (Minor)	D-B (Major)	LS	I/D	A + B	NEB
Total number of projects	609	85	15	357	16	0	0
PCD	−2.10%	−5.20%	−6.50%	−2.60%	−15.20%	-	-
ADS	3	9.8	16.7	2.4	21.4	-	-
PCC	−4.90%	−2.60%	−3.90%	−4.30%	−4.40%	-	-
ACS	$22,816	$9,698	$19,197	$14,765	$29,018	-	-

from cost and time savings to cost overrun or time delay for D-B (Major) and DBB. Specifically, time savings for D-B (Major) first saw a slight increase after excluding the outliers identified by the three-sigma method and then dropped to a smaller scale by screening out more outliers detected through the two-sigma method. Cost data also showed similar trends of fluctuation. DBB showed more cost savings after removing the outliers identified. However, exclusion of the outliers caused its time savings to first slightly decline and then increase. The two- and three-sigma approach did not identify any outlier projects for other contracting methods. For the sake of clarity, the results are not presented in Table 10, which applies to all other cost categories.

7.2.2 Projects between \$10 and \$20 million

The two- and three-sigma methods identified outliers only among DBB projects. It should be noted that cost savings drastically plunged to cost overruns after separating the identified outliers. This downward trend continued with the exclusion of more outliers. Regarding the influence on time performance, time savings plummeted first and then bounced back in the process of removing the outliers identified by the two- and three-sigma methods.

7.2.3 Projects between \$5 and \$10 million

The cost performance of LS showed a significant change from cost escalation to cost savings after excluding outliers. Its time performance saw only a slight decline. Regarding DBB, cost savings initially decreased to a greater extent and then increased but never reached the performance shown with the outliers. Time savings declined gradually as more outliers were eliminated from the original analysis.

7.2.4 Projects between \$1 and \$5 million

The time performance of D-B (Major) changed from delay to early finish after removing the outliers identified by the two-sigma approach; its cost savings was initially decreasing slightly and then rebounded. The remaining contracting methods did not exhibit such a drastic fluctuation. The cost savings of D-B (Minor), for instance, rose steadily when the outliers were excluded. Its time savings initially rose and then fell to approximately zero. LS saw a continuous increase in time savings when the outliers were excluded but fluctuated in cost savings. I/D also fluctuated in both cost and time savings by excluding the outliers. Noticeably, both time and cost savings of DBB declined slightly but steadily after excluding the outliers.

7.2.5 Projects under \$1 million

The results showed no significant changes among all contracting methods in terms of either cost or time savings after exclusion of the identified outliers. This is mainly because each of the contracting methods had many projects, and the project sizes were relatively small.

8 Summary and conclusions

Despite the touted merits of alternative contracting methods in time and cost reduction, project distribution showed that DBB and LS were still the most widely applied methods in practice. There must be a more strenuous promotion in the use of alternative contracting methods, in which the empirical analysis exhibited advantageous performance in time and cost control. This requires a collaborative effort from all stakeholders. Since project distribution based on costs indicated that most projects were under \$10 million, the contracting methods that work well for the corresponding cost categories in empirical analysis should be promoted to effectively curb cost and accelerate project delivery in practice.

The analytical results on the collective data demonstrated a discrepancy in time and cost performance, compared with the results of the divided categories. The collective evaluation suggested that all contracting methods reduced time, but all increased cost except for D-B (Minor) and LS. However, in the individual analysis per cost category, small projects (under \$5 million) saw both adequate time and cost performance, which conflicted with the collective analysis. However, these individual analyses are more convincing based on the following reasons: it is intuitive that contracting methods should perform better on small projects because small projects are simpler and easier to manage; and, this research showed that serious cost escalation on large projects obscured cost savings on the small projects, which is exposed by the individual analysis.

Furthermore, it is imperative to identify outliers in the analyses. The two- and three-sigma methods employed in this study demonstrated that some outliers posed a significant effect on the results. The exclusion of outliers turned cost or time savings to cost escalation and time delay. Therefore, without screening out outliers, the results would be distorted and misleading.

For projects over \$20 million, A + B was the most effective method in schedule acceleration while incurring considerable cost escalation based on the individual analysis. Cost growth is an endemic issue among all contracting methods, probably due to their complexity and difficulty in scope definition. For projects between \$10 and \$20 million, LS performed better in both cost and time savings, and A + B was superior in time control. For projects between \$5 and \$10 million, I/D appeared to be effective in schedule reduction although it led to significant

Table 10 Summary of analysis results before and after excluding outliers

Contracting methods	With outliers					3 standard deviations					2 standard deviations				
	Total number of projects	PCD	ADS	PCC	ADS	Total projects after removing outliers	PCD	ADS	PCC	ACS	Total projects after removing outliers	PCD	ADS	PCC	ACS
> \$20 million															
D-B (Major)	22	−3.03%	27.3	2.64%	\$(1469581)	21	−3.15%	28.6	2.39%	\$(1347184)	19	−1.87%	16.8	1.07%	\$(403785)
DBB	30	−3.00%	28.7	3.65%	\$(1317046)	29	−2.03%	19.3	3.64%	\$(1296898)	26	−2.15%	20.2	3.14%	\$(1057038)
\$10–\$20 million															
DBB	64	−0.97%	6.6	−0.07%	\$9142	63	−0.21%	1.4	1.35%	\$(178909)	62	−1.11%	7.5	1.39%	\$(184231)
\$5 to \$10 million															
LS	31	−2.06%	5.4	0.10%	\$(6744)	29	−1.47%	3.9	−0.53%	\$34786	29	−1.47%	3.9	−0.53%	\$34786
DBB	136	−2.34%	10.4	−1.14%	\$78719	134	−1.46%	6.5	−0.03%	\$2416	132	−1.40%	6.3	−0.24%	\$16364
\$1–\$5 million															
D-B (Minor)	45	−0.56%	2.2	−0.47%	\$ 9831	43	−0.69%	2.7	−0.55%	\$11544	39	−0.09%	0.4	−0.95%	\$19773
D-B (Major)	27	2.78%	−11.0	−1.28%	\$30102	26	1.49%	−6.0	−1.19%	\$27976	21	−1.06%	4.3	−1.49%	\$35341
DBB	658	−2.21%	6.0	−1.86%	\$45641	633	−1.93%	5.2	−1.44%	\$35326	607	−1.45%	3.9	−1.21%	\$29647
LS	206	−2.54%	4.7	−0.84%	\$17973	203	−2.71%	5.0	−0.11%	\$2432	196	−2.76%	5.2	−0.28%	\$5894
I/D	36	−8.31%	21.8	−1.81%	\$49865	35	−8.36%	22.3	−2.37%	\$66196	31	−10.94%	28.3	−1.94%	\$55265
< \$ 1million															
D-B (Minor)	85	−5.20%	9.8	−2.60%	\$9698	82	−4.06%	7.74	−2.35%	\$8827	76	−2.56%	4.99	−2.41%	\$9238
D-B (Major)	15	−6.50%	16.7	−3.90%	\$19197	15	−6.52%	16.73	−3.94%	\$19196	14	−3.48%	8.79	−3.68%	\$18248
DBB	609	−2.10%	3	−4.90%	\$22816	599	−2.27%	3.22	−4.95%	\$23177	556	−1.69%	2.43	−5.09%	\$24001
LS	357	−2.60%	2.4	−4.30%	\$14765	349	−2.77%	2.58	−4.28%	\$14898	315	−2.10%	1.97	−4.39%	\$15401
I/D	16	−15.20%	21.4	−4.40%	\$29018	16	−15.18%	21.44	−4.36%	\$29018	14	−14.45%	21.36	−5.27%	\$35083

cost growth, and D-B (Minor) was the optimal option to cut costs while incurring a slight time delay. For projects between \$1 and \$5 million, most contracting methods showed excellent performance in cost reduction and time control. Specifically, NEB and I/D revealed advantageous performance in decreasing both time and cost, compared to other approaches. For projects under \$1 million, all contracting methods are effective tools and save both time and cost. Furthermore, I/D and D-B (Major) showed exceptional performance in simultaneously reducing cost and time.

Finally, the results show the importance of matching the contracting method to the correct projects. A contracting method that performs well on a smaller project may not perform well on a larger project, even if the projects are of the same type (e.g., both are bridges). It is evident that some methods perform better on more complex projects and some on less complex projects. While this research was limited in that it did not attempt to categorize projects by type, it did show that project size (probably also project complexity) should be considered when deciding the delivery system or contracting method by which a project should be considered.

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