Essays on the Delivery of Public Infrastructure Projects:
Empirical Analyses on Transportation Projects in Florida

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Dedication

I dedicate this dissertation to my dear parents.

Abstract of Dissertation

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A common goal of two essays in this dissertation is seeking to answer the question how to enhance performance of public-sector infrastructure projects. The first essay focuses on project control after the outset of a project. Based on production theories, construction process is interpreted in terms of managerial principles, and the following two questions are sought to be answered: 1) whether or not the nature of a change is significantly associated with cost performance; and 2) whether or not the adverse effect of a change on cost performance is amplified as the timing of its occurrence gets delayed.

Analyses using data on roads, bridges, and traffic operations projects in Florida suggest that cost increase is attributable to the incompleteness in planning. In particular, a negative effect of owner-directed changes, e.g., plan modifications and changes resulting from engineering decisions, on cost performance, implies a potential advantage of extra effort in upfront engineering. In contrast, changes required to adopt efficiency-enhancing practices, e.g., partnering and value engineering, have a positive effect on cost performance. This suggests potential benefits that Design/Build delivery method may bring about through flexibility in coordination among project parties. Meanwhile, I observe only changes induced by natural environmental conditions to be time-sensitive, again emphasizing the importance of geotechnical engineering in project planning.

Inspired by some disagreements in previous studies as well as by the results from the first essay, the second essay attempts to tackle public perception regarding putative advantages of Design-Build (DB), over the traditional project delivery method, Design-Bid-Build (DBB). In doing so, I seek to answer the following three questions: 1) for what type of project a public owner is likely to employ one method or the other; 2) to whom a public owner tends to award each type of project; and 3) to what degree owner's decisions yield varying consequences under the two methods in terms of project cost and schedule.

Economic theories suggest that DB fits better with a large and environmentally uncertain project, thereby, requiring a better-qualified contractor (Bajari, McMillan, & Tadelis, 2009). However, the analyses of transportation projects in Florida over the last decade show that large and environmentally uncertain projects were not always delivered by DB especially for those assumed to have high impacts on road users or surroundings. Also, DB contractors having demonstrated histories of successful collaborations with the owner did not necessarily grab high chances of winning projects in the future. Regardless, the use of DB seems advantageous to schedule control while cost advantages of one over the other not being supported in this essay. These findings together call for further studies on how to enhance various benefits inherent in each delivery method.

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Chapter 1: Introduction

This dissertation consists of two distinct essays that jointly seek answers to the question how to enhance performance of public-sector infrastructure projects. Upgrading infrastructure in the U.S., roads and bridges in particular, is currently in great need (American Society of Civil Engineers [ASCE], 2013). Nonetheless, whether or not to invest more on those projects is still an ongoing debate. The primary issue is the possibility of wasting public money without positive effects on the economy (Cato Institute, 2009). Negative externalities caused by lengthy durations, e.g., increased gridlocks, commuting time, construction dust, noise, and so on, are major concerns as well (Lewis & Bajari, 2011). Researching ways to meet cost and schedule objectives in the empirical context of infrastructure projects is, therefore, timely and of great value.

The first essay focuses on project control after the outset of a project. This topic in the context of infrastructure projects has been addressed mainly in the descriptive Engineering and Construction (E&C) literature, which suffers from lack of comprehensive data as well as lack of theoretical underpinning. To ameliorate these limitations, this essay starts with interpreting the construction process in terms of managerial principles based on production theories, i.e., theories of transformation-flow-value (TFV) and lean production. Then a detailed data set collected from a public transportation agency is analyzed to examine whether or not the relationships between project changes and cost performance characterized by the theories hold in practice. Two main questions sought to be answered are: 1) whether or not the type of a change is significantly associated with cost performance; and 2) whether or not the adverse effect of a change on cost performance is amplified as the timing of its occurrence gets delayed.

With respect to the type of a change, I observe that cost increase can be attributed to the incompleteness in planning. Also, the analysis yields a negative effect of owner-directed changes, e.g., plan modifications or changes resulted from engineering decisions, on cost performance, indicating a potential advantage of extra effort in upfront engineering. In contrast, the analysis provides evidence that changes required to adopt efficiency-enhancing practices, e.g., partnering or value engineering, have positive effects on cost performance. This result suggests potential benefits that Design/Build delivery method may bring about through flexibility in coordination among project parties.

Support for the effect of timing is weak. Only changes induced by natural environmental conditions are observed to be time-sensitive, again emphasizing the importance of geotechnical engineering during project planning. Regarding insignificant results associated with the timing of other changes, I conjecture that the moderating effect of timing may be a convex function rather than a linear form that maximizes in the third quarter of the project duration (Bruggink, 1997; Coffman, 1997) or that the effect may differ depending on the level of complexity in the inter-relationships among activities (Turner, Zolin, & Remington, 2009). A more complete analysis needed for a clear conclusion is left for future research due to limited data.

Findings from the first essay consistently suggest potential benefits of implementing a more flexible delivery method. Hence, this dissertation now turns to project delivery methods. The second essay examines the decisions of a governmental owner and their consequences under two alternative project delivery methods to identify where, in the overall procurement process, improvement is possible. Inspired by some disagreements in previous studies, this essay attempts to tackle public perception regarding putative advantages of alternative delivery method, Design-Build (DB), over the traditional one, Design-Bid-Build (DBB). In doing so, I seek to answer the following three questions: 1) for what type of project a public owner is likely to employ one method or the other; 2) to whom a public owner tends to award each type of project; and 3) to what degree owner's decisions yield varying consequences under the two methods in terms of project cost and schedule.

Economic theories of contract selection suggest that DB fits better with a large and environmentally uncertain project, thereby, requiring a better-qualified contractor (Bajari, McMillan, & Tadelis, 2009). However, this study analyzing 1,512 transportation projects encompassing roads, bridges, and traffic operations in Florida over the last decade reveals that not all the decisions had been made according to the theories. Large and environmentally uncertain projects were not always delivered by DB especially if they were assumed to have high impacts on road users or surroundings. I also observed that DB contractors having demonstrated histories of successful collaborations with the owner did not necessarily grab a high chance of winning projects in the future. Regardless, the use of DB seems advantageous to schedule control while cost advantages of one method over the other not being supported in this study. These findings together call for more comprehensive studies on how to enhance various benefits inherent in each delivery method. It would be especially interesting for future research to see whether the fit between project characteristics (or contractor characteristics) and a particular delivery method would yield superior performance of the project or not.

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Chapter 2: Effects of a Change and its Timing of Occurrence on Cost Performance Evidence from Transportation Projects in Florida

1. Introduction

Cost discrepancy, particularly cost overrun, is a chronic problem in construction. While reported estimates vary from 5.8% to 30% of the total project cost throughout the literature, it is agreed that considerable portions of the discrepancies are attributable to changes in the original project plan during construction (Ibbs, 2005). With the total value of construction works approaching 1 trillion dollars (U.S. Department of Commerce, 2014), just 5.8% can be translated into an enormous monetary value about 50 billion dollars. As Carassus (1998) and Methodik (1986) argued, however, construction can be regarded as a prototype production (as cited in Koskela, 2000). That is, changes are inevitable over the flow of events as the original design and project plan can hardly reflect all the uncertainties occurring after the beginning of the production. This suggests that one of the ways to relieve the chronic problem of cost discrepancy in construction projects would be to alleviate adverse impacts of project changes on production cost.

Essentially changes are known to preclude a continuous and smooth workflow, thereby leading to suboptimal performance. However, not all changes cause the same consequences. Studies and field reports on change orders suggest that the impacts of changes would rather differ depending on where they have originated or how they are handled (See Perkins (2005) for a summary of the literature). So far little research has advised how to reduce the impacts resulted from changes. The effectiveness of solutions that have been offered to relieve the performance problem is also questionable. Lack of objective and sufficient data to yield meaningful empirical supports might be a reason. Some scholars also search for the reason from the lack of theoretical framework that provides guidance on the generic managerial process on site. To assist in managing changes efficiently, overcoming those key limitations is of pivotal importance in academic research.

In this study, I thoroughly examine the mechanism by which construction changes affect cost performance. Cost performance is measured from two angles, planning performance and management performance, where the former is the ratio of original contract amount to adjusted amount while the latter being the ratio of adjusted contract amount to actual payment to the contractor. Also, the following three limitations of existing literature including those noted above are addressed. First, this study tries to tackle the lack of theoretical framework based on two strands of production theories. Following the transformation-flow-value (TFV) theory of production proposed by Koskela and his colleague (Koskela, 2000; Koskela & Howell, 2002), the construction process is interpreted in terms of different managerial principles, based on which the nature of changes are categorized into seven types. In addition, the theory of lean production (i.e., it is beneficial to stop the assembly line and fix a quality defect right then as soon as it has been detected) is explored with focuses on the types of wastes and lean practices to provide benchmark for change-handling principles.

Next, while looking deep into the relationship between each type of change and cost performance, this study considers the timing of change as a change-handling principle. Grounded in the theory of lean production, the timing is regarded as an important variable that can amplify or mitigate the disruptive impact of changes (Ibbs, 2005). Yet, the evidence from the empirical literature is mixed. One reason may be the use of inconsistent measures across the studies. Also, lots of prior studies analyze pooled data while ignoring the natures of changes, which possibly mask dissimilar features that alter the dynamics. Some changes requiring more collaborations may be more time-sensitive than others. Others over which contractors have more control may be performed more efficiently regardless of the timing (Dvir & Lechler, 2004). By exploring what have been overlooked in the literature, this study seeks to find where improvement is possible.

Finally, this study attempts to ameliorate the lack of data by utilizing a large dataset on road and bridge projects offered by the Florida Department of Transportation (FDoT). Since the dataset is from one source in public sector, this study may not be free from criticism especially in terms of generalizability. As noted by Bajari and Tadelis (2001), though, public projects are usually more sensitive to changes due to their less flexible compensation schemes compared to private projects. Furthermore, the dataset is based on actual records in the daily logs of the FDoT, whereas most of the previous studies are built on surveys supplied by contractors. This enables me to measure the variables objectively, even though it is impossible to capture actual costs spent by contractors. Thus, the use of FDoT dataset is expected to provide detailed insights into the dynamics behind construction changes and project performance.

Findings of this study are summarized as follows. First, I observe that cost discrepancy at least in road and bridge projects in Florida can be attributable to the incompleteness in planning. Next, the analysis yields a negative effect of owner-directed changes, i.e., plan modifications and changes resulting from engineering decisions, on planning performance, indicating a potential advantage of extra efforts in upfront engineering. Besides, the analysis yields a positive effect of changes required to adopt efficiency-enhancing practices, e.g., partnering and value engineering. This suggests a potential benefit of implementing Design/Build delivery method that enables an early and frequent coordination among project parties. Regarding the timing, changes induced by natural environmental conditions are observed to be time-sensitive, emphasizing the importance of geotechnical engineering in project planning. Finally, insignificant results associated with the timing of other changes lead me to two conjectures: 1) the impact of timing may be a convex function that maximizes in the third quarter of the project duration (Bruggink, 1997; Coffman, 1997); or 2) the impact may differ depending on the level of complexity in the interrelationships among activities (Turner, Zolin, & Remington, 2009). However, the exact interpretation of this finding is unclear and left until further analysis is completed.

Mainly due to the limited nature of the dataset, this study has caveats as will be discussed in section 6. At a minimum, however, this study contributes to the literature and to the practice of construction project management by elaborating the dynamics concerned with changes that can vary project performance substantially. In doing so, an attempt is made to fill the void of theory in the discipline of construction management by providing empirical support about the possible relationships built on the theories of production. Evidence of the dynamics depending on the managerial principle will advise both owners and contractors how to preempt or incorporate changes without hurting cost performance. Meanwhile, a unique production by temporary multi-organization on site is no longer peculiar to construction according to Ballard and Howell (1998). Therefore, production industries other than public construction may also benefit from this study.

The remainder of this paper proceeds as follows. Section 2 introduces the procurement process of road and bridge construction and maintenance projects in Florida that the analysis of this empirical study is based on. Section 3 discusses construction projects from the perspective of production theories and reviews relevant literature in the fields of operations management (OM), project management (PM), and construction engineering management (CEM). Also, this section proposes testable hypotheses. Section 4 details the data set, and explains the analytic model as well as the set of variables to be employed for the analysis. Section 5 reports and discusses the results. Section 6 concludes with the summary and implications of the results, and limitations of this study. It also briefly suggests ideas for future research.

2. Background: Delivery of Transportation Projects in Florida

Figure 2-1 illustrates the typical delivery process of road and bridge projects in Florida that consists of three main phases, i.e., design, bidding, and construction. Once a need for new construction or maintenance has been raised, the Florida Department of Transportation (FDoT), along with the civil engineering designer, starts preparing design drawings and specifications that describe tasks and the quantities of each work item required for the tasks. The engineer also estimates the project cost and target duration, develops lane closure policies specifying when and how lanes can (or cannot) be closed for a given roadway over the project duration, and suggests an appropriate contracting method (e.g., fixed price, cost plus fixed fee, cost plus percentage fee, etc.) based on the size and the type of the project. The project plan containing all the information mentioned above is submitted to higher-level management in the FDoT for approval.

Once the plan is approved, the FDoT starts bid letting by advertizing the project and qualification information on its webpage. Projects over $35,000 must follow formal procedures called request for proposals or invitation to negotiate. Contractors interested in projects greater than $250,000 are required to be prequalified with the FDoT. Any interested (and prequalified if necessary) contractor can bid on the project by submitting a proposal that includes per unit price of each work item. Although engineer's cost estimate is not disclosed prior to the contract award, FDoT's budget, which is based on the estimate, is available in the advertisement. The project is typically awarded to the bidder with the lowest bid amount, where the amount is determined by the sum product of submitted unit prices and quantity estimates. If A+B (cost + duration) bidding is used, the contractor proposing the lowest weighted score of those two factors wins the project.

The selected contractor starts the construction with planning and scheduling activities based on the design and specification provided by the FDoT. Using the critical path method, the contractor structures various distinct activities, allocates budget, duration, and labor-hours to each activity, and determines activities in the critical path that should not be delayed to complete the project on time. Once the construction begins, the project manager checks whether everything is going according to the original plan. If that is the case, the final cost and duration should be the same with the estimated ones. As discussed earlier, however, the nature of the works always requires the project to be adapted during the construction process. Inadequate designs and specifications, unanticipated site and environmental conditions, unforeseen events, etc. are reasons for the changes frequently mentioned in the CEM literature (Ibbs, 2005).

It is ideal if all the changes can be covered by "contingency" included in the original contract. Otherwise, they need to be supported in several forms. First, unforeseen works can be funded by a pre-approved amount in the form of "contingency supplement agreement" once at least 50% of the initial contingency amount is billed. Second, the majority of changes are financed based on "supplemental agreement" that includes a written agreement between the department and the contractor about the scopes and prices associated with changes. Third, if it is hard for the FDoT to reach agreement with the contractor, the department makes "unilateral payment" to the contractor for the time being and settles up later to keep up with project time. Finally, it is very common that additional days are granted due to inclement weather or holidays. This does not add any direct cost, but may be disruptive to project cost due to any inefficiency caused.

At the end of the project, these processes typically result in the discrepancy between the originally estimated cost and the final payment to the contractor mainly for the following four reasons. First, they lead to changes in production costs because estimated quantities and actual ones seldom perfectly match. Second, there may be costs needed to be increased to catch up with the schedule disrupted by them (Cioffi, 2005). Third, they may generate costs associated with bargaining, disputes and lawsuits. Finally, in the case that the contractor completes the project either ahead of or behind the target schedule, the FDoT assesses the daily savings or damages based on the type and size of the contract, and incorporates them into the payment. The amount of bid that the FDoT ends up paying the contractor adjusts all these factors and rarely equals the estimated cost (Bajari, Houghton, & Tadelis, 2014).

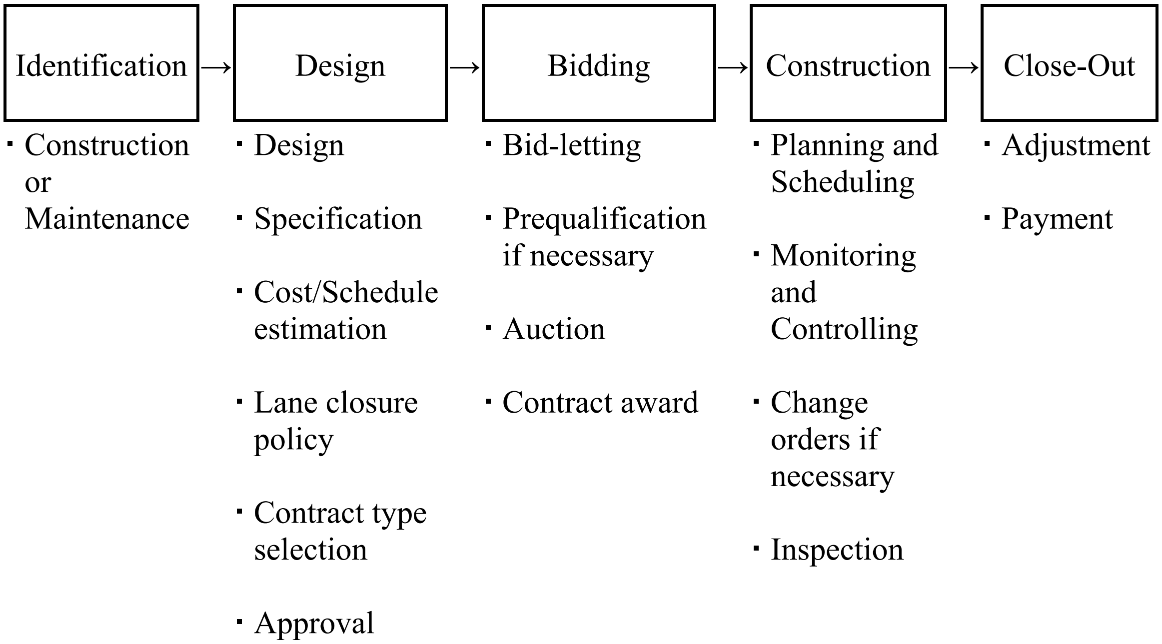

Figure 2.1 Typical delivery process of transportation projects

3. Theoretical Background: Construction from the View of Production Management

3.1 Root causes of waste generation and value loss: Characteristics of construction[1]

In production theories, there are three common viewpoints on production; transformation from input to output; flow of activities; and generation of value for the customer. In the first one, production is the process of manufacturing a target product via a chain of tasks that transforms inputs to outputs (Slack, Chambers, Harland, Harrison, & Johnston, 1995). Thus, it includes not only the performance of tasks, but also the decomposition of the production process into lower-level tasks and the acquisition of necessary inputs. The second viewpoint considers the process before, between, and after transformation, e.g., waiting, moving, inspection and so forth, as important as transformation itself (Shingo, 1988). Finally, for those who have the third viewpoint, production is the process of

[1] This section relies on the work of Koskela (2000).

fulfilling customers' needs by accurately translating their needs into the product design and realizing products that adequately reflect the design (Koskela, 2000).

As the descriptions imply, each process requires distinct managerial principles (Koskela, 2000). For instance, the essence of transformation management is the efficient performance of value-adding tasks, which can be achieved by acquiring resources at low costs and performing tasks in time on budget. On the other hand, flow management puts emphasis on compressing lead time, improving flow reliability, increasing flexibility, and simplifying operation through which non-value-adding processes can be minimized. Meanwhile, the goal of value management is eliminating value loss by delivering products that conform to customer requirements in the best possible manner. Accordingly, the key to this goal is apprehending all those requirements accurately, minimizing defects, and evaluating values with objective measures for continuous improvement.

In this vein, the cycle of production management can be described by value management, task management, flow management, and again, value management in order. Value management comes first as a production process starts with identifying customer needs and translating them into product design. Once the design gets ready, the next step is determining who will perform what has to be done, which is the core of task management. Then, the selected party (or parties) starts execution by planning and scheduling tasks while considering the flow of resources and interdependencies between tasks. The focus of this process naturally becomes flow management to make sure that the process progresses smoothly. When it comes to the finish, an issue of the first importance is whether the product satisfies customers with respect to cost, time, and quality. This is the stage that value management comes to the fore again.

As a type of manufacturing, construction projects can also be comprehended based on the processes characterized above. Although lots of prior studies addressing the theory of production focus only on one of the three, they should be regarded as complementary processes particularly in construction where each of them is related to a certain aspect of a construction project and dependent on each other. At first glance, management of construction projects seems centered on transformation, i.e., decomposing a project into a series of tasks, allocating resources to each task, and performing each task according to the plan. However, this process is severely affected by the flow of various inputs, e.g., design, materials, equipments, labor, information, etcetera. At the same time, the flow of these inputs is also dependent on the delivery of precedent tasks. Thus, neglecting the flow of non-productive inputs may result in significant waste[2] generation.

The interplay of value generation and the other two processes is also worth discussing. Translating customer needs into product design is typically the mission of project owner and design architect. While experienced owner such as government agencies usually have systematic ways of doing this, they are not fully knowledgeable about the transformation and flow processes. Moreover, construction projects have a wide range of customers including future users, all the needs of whom can hardly be reflected in the design. As a result, the best can be expected from them is a kind of prototypic design that requires continual identification of defects and changes to them during construction. And the changes originated from the failure in accurately capturing

[2] Waste is defined as anything or process that does not add value to a product (Holweg, 2007), which will be discussed in more detail in the following sections.

the needs affect the transformation and flow by generating wastes, which in turn, lead to value loss in the end.

In addition to those commonalities, construction as the production of one-of-a-kind goods in fixed place by temporary multi-organizations bears peculiarities that traditional manufacturing as the mass production in factory by one major organization does not. The major source of one-of-a-kind nature is not materials, equipments, or technologies since they are usually similar from project to project. It is rather derived from varied needs of project stakeholders and differing opinions about the best product design or production system (Warszawski, 1990), which are truly the features of temporary multi-organization affecting value management. The characteristic of site production also increases the degree of uniqueness through natural and social environments specific to the location. In addition, constructing a target product at the site of its final operation entails uncertainties and complexity associated with land acquisition, production infrastructure, and workstation movement unlike stationary production. Finally, multi-organizations temporarily participating in a particular construction project do not necessarily share common objectives. The necessity of additional movement of information as well as inputs across them may easily result in out-of-sequence flow or unsatisfactory outcome due to the risks of missing information, opportunistic behaviors, or fragmented system.

3.2 Direct causes of waste generation and value loss: Construction changes

Aforementioned production management principles and peculiarities, if not addressed properly, may cause changes to original design and project plan during construction projects, which, in turn, result in waste generation and value loss. Suppose that design drawings and specification are inadequate to reflect customer needs. This problem of incompleteness in design and plan might originate from failure in transferring various requirements to the project or lack of detailed planning. They are realized as design errors or omissions, design modifications or incorrect estimates of material quantity, as a result of which change orders follow. Given that deficient design and planning are reported to cause the largest portion of defects in terms of both cost and frequency (Josephson & Hammarlund, 1996), changes caused by them are expected to contribute to waste generation significantly.

During construction project teams suffer from various reasons to change. Since all or substantial portion of tasks are performed by subcontractors, any mismatch of flows of tasks across different parties is likely to result in changes to the plan. There can be industry-wide material shortage or supplies of defective materials, causing a bottleneck in the normal flow. Hence, major changes that occur during construction are attributable to site management or supply chain management, each of which needs additional efforts to coordinate suppliers, crews, and subcontractors as a result. The feature of temporary multi-organization may exacerbate these situations. Under the decentralized decision-making system, it is hard for each party to yield optimal solutions for the entire project phases. Increased parties, implying increased complexity in coordination, usually leads to increased risks of abnormal flow, which is aggravated by insufficient prior collaboration.

The feature of site production may also impose additional burdens that would not have been serious issues for traditional manufacturers. It increases risks and uncertainties associated with natural and social environments, e.g., inclement weather, unexpected site condition, local codes and regulations, public opinion, and so forth. The problem is that they can hardly be addressed in detail at the outset of any project. When it comes to the point of implementing changes, none of the organizations are generally willing to be responsible for the changes that may lead to value loss. There are rather chances of opportunistic behaviors unless responsibilities are clearly specified or business goals are congruent across different organizations. Due to those adversarial relationships, changes associated with contract management in the form of haggling, disputes, and claim are deemed one of the main problems in construction projects.

CEM literature actually reports the following as major sources of construction changes: errors and omissions; quantity changes from inaccurate estimations; unexpected site conditions; unforeseen events; and external factors (Gkritza & Labi; 2008). Consider an example of the Central Artery/Tunnel project (unofficially the Big Dig) in Boston. In the middle of construction, the original design had to be changed because it had erroneously depicted a 19,600-seat arena as an obstacle-free area to lay utility lines. Since the construction was under way in the heart of a major city, there were various on-site barriers unexpected at the design phase including a number of pipes and utility lines, foundations of buried houses, and even sunken ships lying within the reclaimed land. Even worse, after 10 years from the first ground breaking, an unforeseen flood gushed into one of the tunnel crossings and caused a significant schedule change. Finally, the opposition of the city of Cambridge to the visual impact of the original design forced the project team to redesign the Charles River crossing (Lewis & Murphy, 2003).

3.3 Wastes and value loss: Consequences of changes

Then what kinds of wastes are generated from the changes mentioned above? In the production management literature, Ohno (1988) in Toyota Production System defined seven forms of waste generated from production (i.e., muda): 1) inventory; 2) over-production; 3) transport; 4) motion; 5) waiting; 6) over-processing; and 7) defects, all of which imply activities or materials in excess of what "are required for the processing." For example, materials waiting to be used usually tie up resources without generating any revenue. Work-in-process or products ahead of demand may increase the risk of obsolescence loss or write-off while being stocked up. Excessive movements of crews, materials, equipment, or products, are likely to be associated with extra cost, damage, loss, delay, etc. for no value added. Waiting between production steps and over-processing may result in the depreciation of products or equipment. Finally, defects may incur extra time and cost of identifying and fixing them.

In spite of peculiarities, wastes generated by construction can be categorized based on the same vein. Changes stemming from lack of details in design or in planning usually lead to added or reduced work. If the scope of work is reduced, unused materials turn from resources to wastes. Even without scope change, over-purchased materials are merely wastes, accounting for about 13% out of 400 million tons of total materials according to Lockie (2010). Incomplete design may also result in quality failure, causing rework to rectify defects. The problem of these changes is that even a small change could contribute to inefficiencies in the entire process on site. The need for new or additional materials or equipment usually affects the sequence as well as duration of the successive tasks by adding waiting and transport time. If changes are not accompanied with sufficient extra time of execution, the implementation of them may require subsequent changes, e.g., additional crews, increased man-hours, overtime, and work shifts, to accelerate the progress. Such changes become the causes of what are so-called wastes in construction such as idle time, site congestion, safety hazards, low morale and motivation, and loss of learning curve effect. After all, everything converges into productivity loss that may cause more changes that cause further drop in productivity.

Aforementioned wastes are realized as direct additions or subtractions of project costs, durations, or both. In general, changes associated with controlling work items on the critical path result in the changes in both. Non-compensable but excusable types of changes, e.g., weather days, are accompanied with days of extension without extra cost (Serag, Oloufa, Malone, & Radwan, 2010). More importantly changes may incur indirect costs above and beyond the direct costs by disrupting the planned workflow. Consider, again, an illustrative example from the Big Dig project in Boston. The engineers failed to design a viable scheme that was supposed to support an elevated roadway while excavation proceeded below it. This problem was discovered after construction crews had already begun work and set off the delay of eight months for resolution in the end. Consequently, in addition to the direct cost of at least $16 million for redesign and reengineering, indirect cost of about $10 million was required because additional coordination was needed to catch up with the disrupted schedule (Lewis et al., 2003). In the case that the project owner and the contractor need to renegotiate the contract to reach consensus about the extent of changes or the way of compensating for changes, extra costs or durations associated with claim settlement could be generated.

The ultimate consequences derived from those wastes, namely value losses broadly fall into one of two categories. The chronic problems in construction projects, failure in meeting the target cost or schedule at the close-out phase, seem to be the simplest, but the most noticeable type of value loss. Another type of value loss is that the performance goal of functionality fails to materialize during the operation and maintenance phase of constructed product. The nature of long life span have given both researchers and practitioners hard time to objectively measure and evaluate the functionality performance, which is probably why its relationship with construction changes has not been examined rigorously in prior studies. On the other hand, much of the CEM literature has dealt with the linkage of construction changes with productivity loss or with cost discrepancy as will be discussed below.

Prior studies addressing the impacts of construction changes on labor productivity present evidence that larger amount of changes are associated with greater loss of productivity, although different measures are used in terms of the amount of changes. In a pioneering study in this area, for example, Leonard (1988) finds cumulative impact of changes, meaning that productivity loss is exacerbated by concurrent productivity-related causes such as "acceleration" and "inadequate scheduling and coordination." A series of analyses conducted by Thomas and Napolitan (1995) indicates that changes are associated with increased number of disruptions, which in turn, affects labor productivity negatively. Ibbs (1997) report similar results while noting that the impact of changes on productivity becomes more detrimental once installation and fabrication had begun compared to the impact during design phase.

Some researchers look at the relationship more closely either by considering contextual variables such as the type of work and the characteristics of changes, or by using different type of data set. For instance, Moselhi, Leonard, and Fazio (1991) suggest that the relationship differs by the type of work in that productivity loss for electrical and mechanical works is greater than for civil and architectural works at the same level of changes. Hanna and his colleagues (1999a; 1999b) focus on identifying the characteristics of changes affecting labor productivity. In doing so, they detect the significance of the estimated change hours and their ratios to the estimated base hours, frequency, timing, and impact classification.[3] When the same research team (2002) turns their attention to some intermediate factors between change and productivity loss, overtime and over manning, absenteeism and turnover, manpower ratio, and processing time[4] are found to be critical ones determining whether a project had been impacted by changes during execution.[5] Meanwhile, Thomas and Napolitan (1995) track down daily productivity of 522 workdays from three industrial projects and conclude that some of the changes could be implemented without adversely affecting labor productivity; although their analysis does not allow them to suggest how to do so.

The literature on the linkage between construction change and cost discrepancy is less extensive. It is merely alluded that lost productivity would lead to cost overrun as labor cost accounts for fairly a large proportion (30 – 40%) of the total construction cost. There is a study reporting that larger amounts of changes require larger amounts of labor

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[3] Impact classification is a dummy variable, indicating 1 if a project is impacted by changes, and 0 otherwise. The classification had done based on survey (Hanna et al., 1999a; 1999b).

[4] Processing time is defined as the time between the initiation of a change order and the owner's approval of it (Hanna et al., 2002).

[5] The authors define an impacted project as any project with a probability greater than 0.5 based on the logistic regression model.

costs (Ibbs, 1997). Considering design changes only, Cox and colleagues (1999) observe that the direct costs of changes comprise 5.1 – 7.6% of the total project cost, most of which stem from designer's omission in tender documents, employer's change in requirements, and new information on existing site conditions. Finally, based on an exploratory analysis of 16 road and bridge projects in Florida, Serag and colleagues (2010) find change-related factors that contribute to the increase in contract price by greater than 5%, including major quantity difference, unforeseen conditions, expenditure[6], and compensation[7].

While the prior studies present at least some evidence of a negative impact of changes either on labor productivity or on cost performance, there are some common weaknesses among them. First, most of the early studies suffer from a limited data set. For instance, the study of Moselhi et al. (1991) has attracted considerable criticism as it had been developed based on the projects experiencing disputes (McEniry, 2007). The 522 workdays analyzed by Thomas et al. (1995) are extracted from just 3 industrial construction projects. While the studies by Hanna et al. (1999a; 1999b) can be deemed better than others in terms of the sample sizes, they have a weakness that data sets are collected by surveying contractors as similar studies do. As a result, the outcomes of those studies not only can hardly represent the population of interest, but can be the reason for owner-contractor disagreement regarding the validity of the relationship (Serag et al., 2010).

Also, there was no consensus about the measure for the amount of changes or labor productivity, even for cost performance. For the amount, either frequency or

[6] This variable includes three categories: scope addition/reduction; rework; and idle.
[7] The authors categorize the compensation methods by three: time and material; unit price; and lump sum.

proportion is used without a clear rationale, where the former and the latter respectively refer to the number of change orders per contract duration and labor hours directly supplemented due to changes compared to total labor hours in the original contract. Regarding labor productivity, some characterize it using labor hours added by changes either directly or indirectly; others include both in their calculations; still others use the product of productivity and labor hours. A more serious issue is that productivities are assessed based on survey in some studies. In the same vein, subjective measures are employed for cost performance, which, along with the inconsistencies in others, might threaten the validity and the reliability of the studies by introducing biased estimates.

Lastly, not many studies explain factors that may shape the association between changes and performance other than the amount of change. Even if they do, they do not control for the factors concurrently in regression models. Leonard (1988), for example, produces three separate trend lines by differentiating major causes of productivity loss rather than by incorporating them in the model. Distinctive approaches like Leonard's make it hard to pinpoint whether the results are actually attributable to changes or they are as the result of other factors. This may be a source of diverse results with respect to statistical significance and may explain why little guidance for reducing adverse impacts of changes has been provided. In sum, research necessities emerging from prior studies include ; 1) an analysis of extensive data with a large number of observations to avoid erroneous conclusions that may be random properties of the selected sample, 2) the use of a measure that represents the amount of change more objectively to yield more robust results, and 3) a detailed exploration of the relationships contingent on different managerial procedures inherent in various types of changes to derive opportunities from the dynamics. To that end, managerial principles that potentially mitigate the impact of change are elaborated below based on the theory of lean production, which is followed by the descriptions of the measure and data.

3.4 Practices: Application of lean principles to construction

Is it possible to eliminate the causes of changes that are prone to contribute to or amplify the impact of waste, and eventually value loss? Perhaps a complete removal of them may not be practically possible. Even if that is the case, however, there may be some effective principles that prevent waste generation or mitigate the adverse impact of waste on project performance. In the field of traditional manufacturing, lean production has been suggested as one of the strategies for that. The central tenet of lean production is yielding superior results, e.g., cost reduction, while consuming fewer resources (Browning & Heath, 2009). This strategy differs from buffered approaches in that it regards any effort consuming resources without creating value for the end customer as a waste to be eliminated, where value is defined as things for which the customer would be willing to pay for (Hopp & Spearman, 2004; LaGanga, 2011).

The effort to reduce wastes drove firms to implement so-called lean practices. Internally, they focused on the reduction of inventory and the prevention of over-production (Hall, 1983). They also endeavor to improve the production process by simplifying process, eliminating non-value-adding tasks, introducing pull systems and preventive maintenance. (Furlan et al., 2011; Hall, 1983; Schonberger, 1986; Shah & Ward, 2003). To reduce externally-oriented waste, firms have focused on facilitating information exchange with suppliers. For example, they have put efforts into frequent and rapid exchange of information with suppliers by extensive use of computerized information (Ansari, 1986; Levy, 1997; Nassimbeni, 1995; Wu, 2003). Applying agile ordering systems or involving supplier in production process improvements can also be understood in the same vein (Schonberger & Gilbert, 1983; Ansari, 1986).

Looking deeper into the process, however, implementation of aforementioned practices to reduce muda would not necessarily lead to better performance. Therefore, practitioners as well as scholars started expanding their attention to the other types of waste that were believed to be root causes of *muda*, namely *mura* and *muri* (Emiliani, Stec, Grasso, & Stodder, 2007). *Mura* means unevenness in the process that arises when the production process flows inconsistently by losing its balance. This, in turn, leads to another type of waste, *muri*, which burden materials, equipment, and crews with more than what they were supposed to perform. In short, *muri* is an overburden that inevitably results in activities for no value added, *muda*. Therefore, to eliminate *muda*, managers are recommended to consider its connection to *mura* and *muri*. Otherwise, *muda* can always come back and feed back to the vicious cycle of wastes (Emiliani et al., 2007).

The shift of viewpoint turns the focus from what to how (Browning et al., 2009), based on which Womack and Jones (2003) derive five principles of lean production: 1) specifying all the values for the customer; 2) identifying all the tasks to get the customer a target product; 3) developing a continuous and smooth flow while removing bottleneck; 4) preventing over-production; and 5) encouraging continuous improvement through which customer's expectation is fulfilled. These principles may not be fully applicable to other industries as they have been identified and studied mainly in car manufacturing industry. Yet scholars argue that operations managers face universal problems during production. Hence, even non-Japanese or non-car industries should benefit from adopting lean principles to their own industry, although each of them may need different mix and extent of the practices (Browning et al., 2009; Hines, Holweg, & Rich, 2004; Koskela & Howell, 2002).

The principle of reducing variability in the process is especially relevant to construction projects as construction relies heavily on craftsmen as opposed to mass production relying on machines. As discussed earlier, productivity loss resulted from increased variability in the flow of process is a major source of waste generation and value loss in construction. While Thomas et al. (1995) suggest that changes, the sources of wastes and value loss, could be performed without efficiency loss, there has been little research advising how to mitigate wastes and value loss resulted from changes. Indeed, the emphasis of the studies from the CEM field has been more on after-the-fact resolution methods for negotiation and litigation. However, additional review of the literature in OM and Economics as well as CEM reveals that opportunities may be found by the application of lean principles to the construction process. The problem on site is that a contractor is the only party that actually works on changes, whereas both owner and contractor can order them. As an actual performer, a contractor generally has more information on how to incorporate changes in the existing process, how long it will cost, and how long it will take. Therefore, it may not be an exaggeration that the essence of lean production in the context of construction is the pursuit of efficiency in contractor's business process, especially in managerial process.

The examination of the literature points to "timing" as a key principle that can be applied, i.e., early or late implementation of change in the original design or project plan.

As discussed above, under the traditional production system, an effort to remove defects ironically adds risks and uncertainties to the construction process in terms of the flow of process and the capacity of labor, material, and equipment. Late changes are typically associated with insufficient coordinate time, let alone difficulties in correcting errors after installation has been progressed to a considerable degree. As such, they have the potential for obstructing the reliable flow of process, ultimately causing a suboptimal performance. On the other hand, early detection and implementation of changes are expected to decrease the undesirable impact of changes by allowing a more flexible adaptation for contractors above and beyond the elimination of issues as early as possible.

Unlike the relationship between the amount of change and labor productivity, the hypothesis that the later a change occurs, the more adversarial its influence on labor productivity, and in the end, on cost performance, is not fully supported in the empirical literature. Ibbs and Allen (1995), for example, attempt to argue that later changes are carried out in a less efficient way than early ones by analyzing 104 industrial and commercial projects, which is unsuccessful in the endeavor. Similarly, Hanna et al. (1999a) test the hypothesis that the impact of change increases linearly from project inception to completion, but fail to obtain the expected result based on mechanical and electrical construction projects data. Meanwhile, Cox et al. (1999) draw the cumulative cost versus fractional duration graphs in the hope to identify characteristic patterns indicating the costs of modification over the project duration. Nothing definite can be found though. Ibbs (2005) also produces three separate regression lines characterizing a negative relationship between the amount of changes and labor productivity for early, normal, and late projects. He claims that “late change is about twice as detrimental to productivity as normal or early ones" based on the slopes of the regression lines. Interestingly, these lines appear to agree with those of Leonard (1988) that show the effect that major causes of changes, e.g., lack of materials, out-of-sequence work, acceleration, and over manning, have on labor productivity. Given that what he describes major causes are actually wastes generated in later phases of project, it seems reasonable to assume that there exists a negative relationship between the timing of change and labor productivity. Nevertheless, the result has been criticized due to the unreliable productivity measure and has not yet endorsed by the industry (McEniry, 2007).

At least partially subjective measure of timing and unobserved heterogeneity may explain the lack of empirical support. For the timing of change, various measures had been used. What is worse, it is known that proceeding with changes in informal ways without appropriate paperwork is common in practice (McEniry, 2007). These might make it hard for researchers to capture the timing that a change actually caused disruption. Furthermore, prior studies do not distinguish the natures of changes across which their impacts on the feedback loops of inefficiency[8] and the degrees of communication necessities vary (Dvir et al, 2004). As a result, statistical significance might be weakened by unobserved heterogeneity across changes having different natures. Once those concerns are addressed, it is expected that more robust statistical results will be observed. Specifically, in line with the central tenet of the theory of lean production, a negative effect of timing on the relationship between changes and cost performance should be observed.

[8] For the descriptions of the feedback loop, see Cioffi (2006), and Ibbs, Nguyen, & Lee (2007).

4. Hypotheses

4.1 Project changes

Type of a change

As discussed in the literature, changes after the beginning of construction may increase variations in the planned workflow, which eventually affects cost performance by generating wasteful activities in the process (Koskela, 1992). However, previous studies suggest that not all changes account for the same amount of variations. Which changes are more likely to increase variations depends on how predictable or controllable changes are to contractors (Perkins, 2009). The party that actually performs changed works is the contractor, while any party of the project may request changes. Thus, changes less predictable or less controllable by contractors are expected to be more costly or time consuming to be performed, which is likely to lead to bad cost performance in the end. Overall, owner-requested changes and natural environment-driven ones may be considered 'less predictable' from the perspective of construction manager (Perkins, 2009). Also, changes for design or scope modifications might be 'less controllable' to contractors as they not only require increased interactions with other parties of the project to be dealt with, but also are likely to bring about subsequent changes to meet the modified requirements (Cioffi, 2006; Dvir et al., 2004).

Meanwhile, not all changes are deleterious to cost performance (Ibbs, 2005). For example, "partnering" creates opportunities for higher project performance by promoting efficiency among project parties (Koskela, 2000). A "value engineering" change, once approved, enables both the owner and contractor to benefit from it through a method that decreases cost while increasing the value of the project (Perkins, 2009). Hence, changes in the original plan to adopt those practices should lead a project to a better cost performance by decreasing wasteful activities.

H1a*: A change is likely to be associated with worse cost performance if it is a) resulted from owner-side engineering decisions, b) induced by environmental conditions, or c) related to design or scope modifications.*

On the other hand, a change is likely to be associated with better cost performance if it involves: a) partnering or b) value engineering.

Timing of a change

As also discussed in the literature review, it is well noted that negative effects of changes are amplified depending on the timing of them: harmful effects increase with further progress of a project (Riley, Diller, & Kerr, 2005). While it is common for prior studies not to consider the natures of changes when analyzing the impact of the timing, other studies addressing causes of changes allow me to conjecture that the sizes of timing effects may vary across changes with different natures. For instance, Dvir et al. (2004) distinguishes between "goal changes" and "plan changes," where the former reflect changes in the project design, scope, requirements, etcetera, and the latter is rather a result of errors, omissions, a lack of coordination in contract documents, and so on. Therefore, goal changes are likely to introduce the feedback loops to meet the updated requirements and to involve intensive communication among project parties to be controlled (Dvir et al, 2004). In contrast, plan changes can normally be controlled by project managers without serious subsequent changes introduced. Accordingly, I would expect severer timing impacts on cost performance for changes that lead to goal change-type of results, e.g., natural environmental condition-induced changes, design modifications, engineers-driven changes, despite an absence of any empirical evidence.

H1b: *A negative association between a change and cost performance will be amplified as the timing of its occurrence gets delayed if it is: a) resulted from owner-side engineering decisions, b) induced by environmental conditions, or c) related to design or scope modifications.*

4.2 Project characteristics

The delivery of a construction project requires a set of activities involving multiple parties for a certain period of time. Project cost as well as schedule is determined depending on the number, durations, and interdependencies of those activities (Clark, 1989). Therefore, project characteristics known at the time of contract award, e.g., cost, duration, and type, may connote potential variability inherent in the project, which in turn enables us to envision cost performance of the project to some extent. By including the following three characteristics in the model, this study not only tests hypotheses associated with them, but also controls for their impacts to capture the effects of changes more clearly.

Project cost

Studies addressing the relationship between project characteristics and performance suggest that project size appears to have a significant relationship with cost performance (Flyvbjerg, Holm, & Buhl, 2004; Gkritza et al., 2008; Korman & Daniel, 1998). With respect to the directionality of the relationship, however, findings from those studies are mixed. Some argue that large projects are more likely to be associated with bad performance due to increased difficulties in managing larger number of activities (Jahren & Asha, 1990; Rowland, 1981). Others, e.g., Odeck (2004), report the opposite result with an interpretation that large projects are typically managed by more capable contractors with abundant resources. Nonetheless, the relationship between project size and cost performance is hypothesized in a negative direction as variables that would control for the effects of contractor capabilities or of resource levels are not available to be considered in this study.

H2a*: Project cost representing the size of a project is negatively associated with cost performance.*

Project duration

Unlike the results of project cost, previous studies consistently report a negative relationship between project duration and cost performance. Specifically, it has been argued that all other things being equal, a longer duration is more likely to be associated with a larger cost overrun mainly because of the longer exposure to uncertain conditions (Flyvbjerg et al., 2004; Gkritza et al., 2008). Hence, a hypothesis regarding project duration is proposed as follows:

H2b*: Project duration representing the size of a project is negatively associated with cost performance.*

Project type

Project type could serve to some extent as a proxy for the inherent level of uncertainty as the likelihood to encounter design problems, scope changes, unforeseen site conditions, and so on, differs by project type. For instance, new constructions are more likely to entail uncertainties related to those aspects, for which they are usually regarded more complex than others in terms of management as well as engineering techniques. Regarding structural type, practices associated with road projects are considered routine as opposed to those of bridges or traffic operations projects that require more challenging technical as well as managerial skills (Gkritza et al., 2008).

> ***H2c****: Project type will have a significant relationship with cost performance. Specifically, new construction projects will show worse cost performance than maintenance or capacity addition projects, while road projects will show better cost performance than bridge or traffic operations projects.*

5. Data and Analytic Method

5.1 Data

5.1.1 General description

Data set includes construction and maintenance projects of roads, bridges, and traffic operations facilities in Florida from the fiscal year of 2000 to 2011 (Table 2-1). The data set is from the FDoT that is well-known for being active in public offering of data and information. During the period, there had been thousands of projects all over the state. However, most of them but 349 are excluded for the purpose of this study as they lack detailed information on contract changes. Each project included is accompanied with cost data (e.g., FDoT's original estimate, original and adjusted contract amounts, final payment to the contractor, etcetera) and schedule data (e.g., original and adjusted contract durations, actual duration, and non-compensable time extension, etcetera) as well as data related to project types, contractual dates, and the form of contract used. The main information in the data is outlined in Table 2-2.

Table 2-1. The number of projects in each year

Fiscal year \ Contractual year	Award Year	Work Begin Year	Accepted Year	Passed Year
2000	3	1	0	0
2001	13	5	0	0
2002	67	45	11	3
2003	60	65	63	39
2004	51	58	28	37
2005	26	36	71	61
2006	19	18	24	39
2007	40	35	15	11
2008	25	33	58	54
2009	33	34	21	29
2010	12	18	48	44
2011	0	1	10	32
Total	349	349	349	349

* Accepted year is when the work was accepted and the final estimate has been performed.
* Passed year is when documentation was passed to the Comptroller's office for final payment to the contractor. In most cases, the physical project had been completed and the public had been enjoying its benefits for some time.

Table 2-2. Main information in the data set

Contract	Dates	Cost	Duration	Change
· Contract number · Contractor ID · Contractor name · Contract type	· Let date · Award date · Execution date · Work begin date · Accepted date · Passed date	· DoT's estimate · Original and adjusted contract amount · Contingency · Work to date · Contract adjustments · Actual expenditure	· Original and adjusted contract days · Used days · Weather days · Holiday days	· Change order amount · Premium cost · Change order days · Time extension · Change order date

A merit of this particular data set is that it contains detailed information on the contract changes associated with those projects, where the total number of occurrence reaches 2700. For each of the changes, the data provides the cause and description of the changed work, a direct change in cost or schedule, and the change order date[9] that is usually unavailable from other data sets. The date, along with the work begin date[10], enables a more accurate observation of the timing that a change was actually influential over the project duration. Another merit of this data set is that it includes a unique identification number and name for each contractor who had performed each project, which allows me to account for any variation in managerial capability across different contractors. Following Hanna et al. (1999a) and Bajari et al. (2014), this study proxies for the capability with a contractor's prequalified status and collaboration experience with the FDoT.

[9] The FDoT defines the change order (CO) date as the date that a change order was approved by the FDoT (FDoT, 2012). Although CO dates are not always the same with notice to proceed (NTP) dates, they are the most reasonable data available to measure the timing as contractors are not allowed to perform the changed work until it is approved. Hence, it is reasonable to assume that the change order date is a proximate timing that a change actually started affecting the existing work flow.

[10] Days are charged to the contract beginning on the work begin date.

5.1.2 Sizes of projects

Table 2-3 presents the characteristics of the projects in the data including FDoT's original estimate of the project cost, planned and actual costs as well as durations in the contract. As can be seen in the table, there is a great deal of heterogeneity in each characteristic. On average, the projects are estimated to cost $11.0 million with a standard deviation of $20.1 million. Original contract amounts range from $24,225 to almost $193 million with the average of roughly $9.88 million, while the average amount paid to the contractors is approximately $10.3 million with the lowest and the highest of $34,698 and $211 million, respectively. Similarly, original contract days vary from 15 days to 1,717 days with the mean of 338 days, while the projects required an average of 397 days to complete with the shortest of 13 days and the longest of 1,908 days. These data are logged prior to the empirical analyses as their distributions are right-skewed (Figures 2-2 – 2-5).

Table 2-3. Costs and schedules of the projects

Categories \ Statistics	Obs.	Mean	Std. Dev.	Min.	Median	Max.
1. FDoT's original estimate	303*	$11,002,313	$20,107,719	$44,146	$3,466,843	$200,443,348
2. Original contract amount	349	$ 9,876,289	$18,894,472	$24,225	$3,135,884	$192,789,218
3. Adjusted contract amount	349	$10,319,851	$20,030,943	$34,698	$3,249,289	$210,797,783
4. Difference between original and adjusted contract amounts	349	4.1%	6.8%	-23.6%	2.3%	43.2%
5. Final payment	349	$10,508,214	$20,777,958	$32.698	$3,361,206	$227,534,848
6. Difference between adjusted contract amount and final payment	349	-0.6%	5.8%	-34.6%	-0.4%	51.0%
7. Original contract days	349	338 days	305 days	15 days	225 days	1717 days
8. Adjusted contract days	349	414 days	364 days	23 days	288 days	1908 days
9. Actual duration	349	397 days	361 days	13 days	271 days	1908 days

* The original estimates for 46 projects performed in the early 2000s are unavailable.

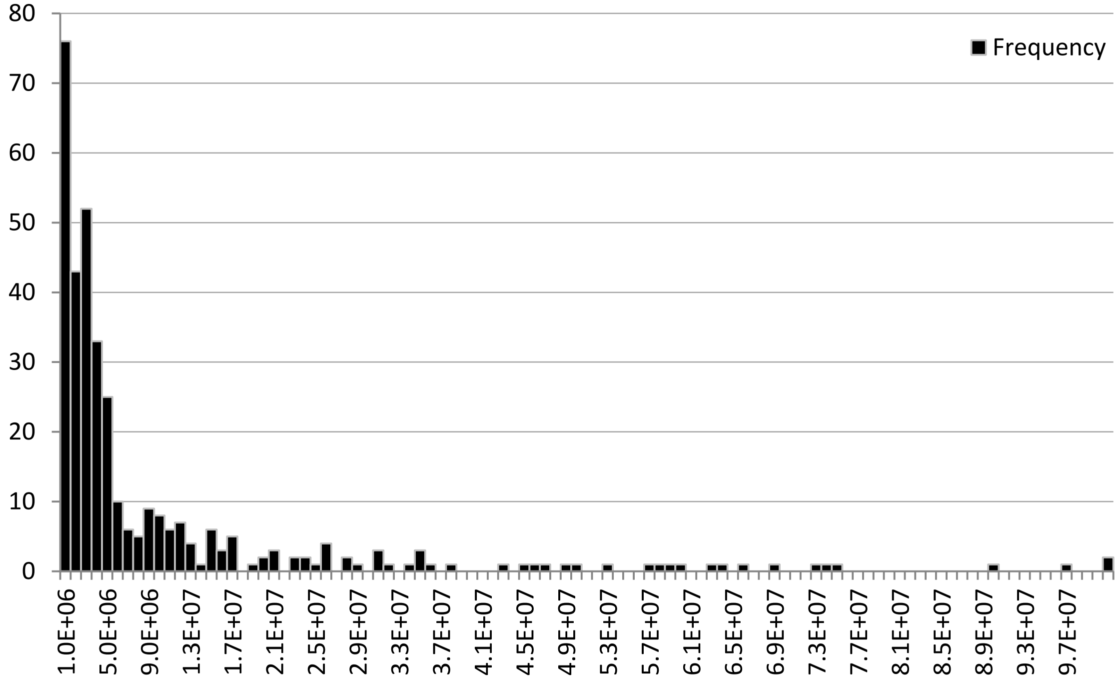

Figure 2-2. Distribution of original contract amount (in dollars)

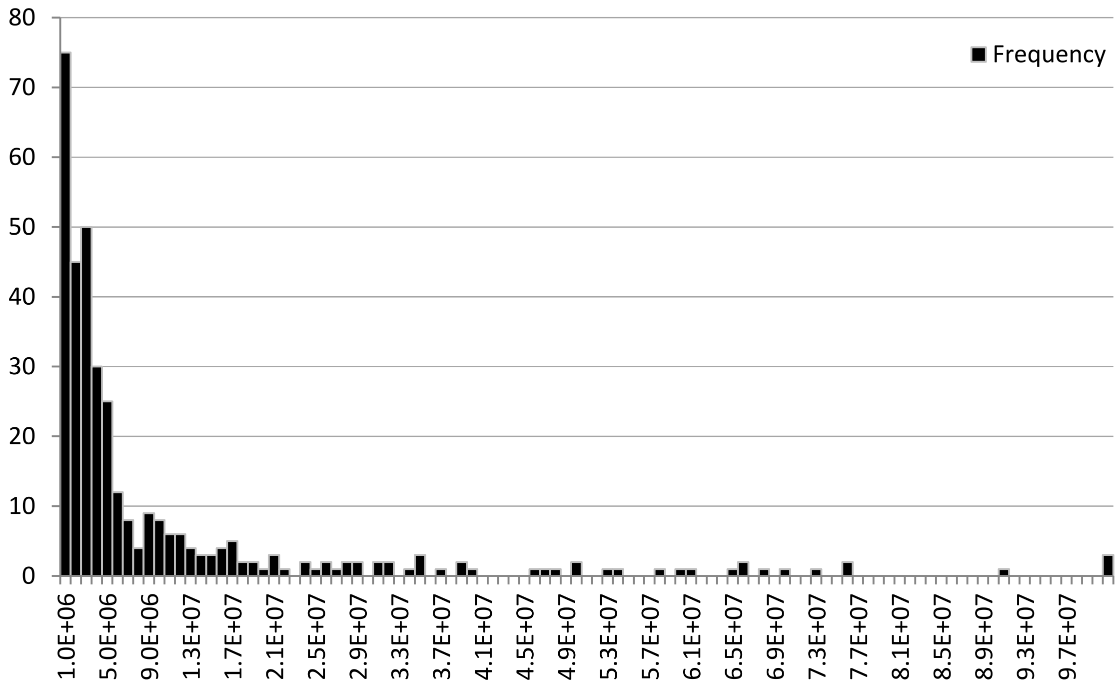

Figure 2-3. Distribution of adjusted contract amount (in dollars)

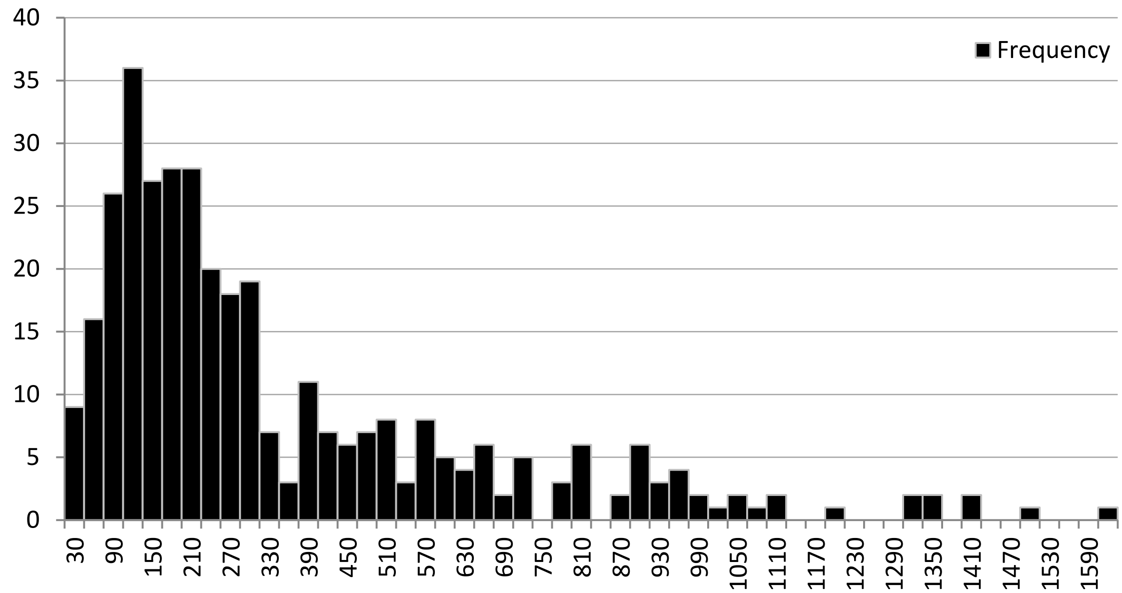

Figure 2-4. Distribution of original contract days

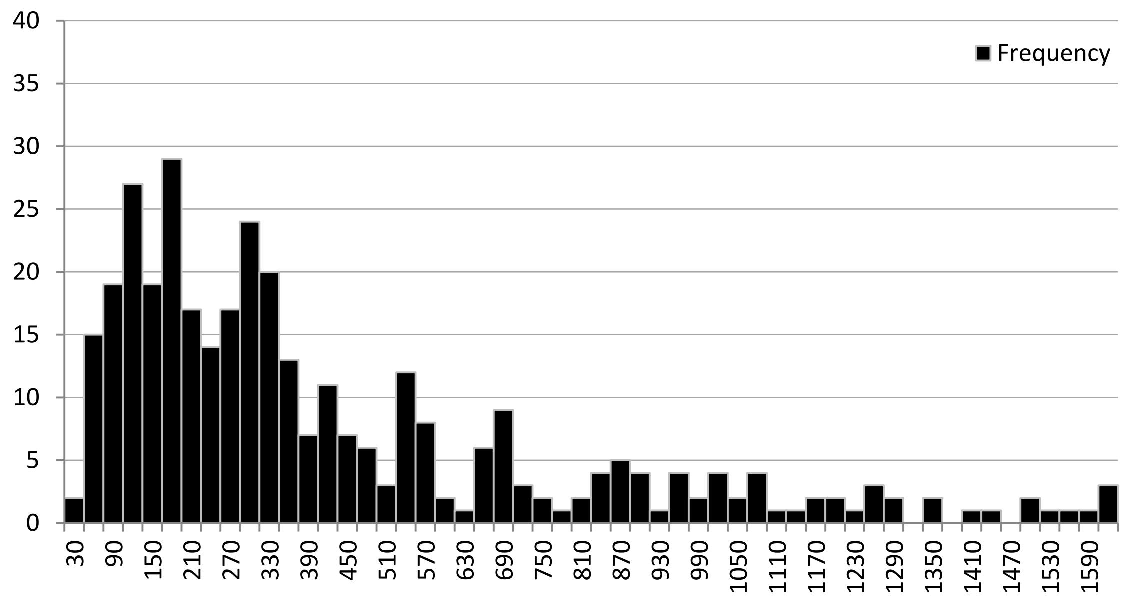

Figure 2-5. Distribution of adjusted contract days

Table 2-3 also shows the project costs and durations after contract changes, i.e., adjusted contract amount and adjusted contract days. Their sizeable deviations from the original values are in line with a notorious characteristic of construction projects reported in earlier studies (Bajari et al., 2001; Hwang, Thomas, Haas, & Caldas, 2009; Ibbs, 2005; Love, Holt, Shen, & Irani, 2002). The majority of sample projects appear to be completed with increased adjustments. 13% of the projects, on the other hand, had experienced negative cost adjustments, almost all of which are attributable to scope reductions. Apparently, the difference between adjusted contract duration and actual duration as well as that between adjusted contract amount and final payment is not as severe as those of contract adjustments. Presumably the FDoT lacks details in its project planning or is generous about *ex post* contract adjustments.

Table 2-4 summarizes the distribution of project types. Regarding work types, about 64% of the jobs are maintenance projects, whereas new construction and capacity addition account for about 12% and 24% of the jobs, respectively. New constructions are more likely to entail uncertainties related to designs, scopes, site conditions, and so on, for which they are usually considered more complex than others in terms of management as well as engineering techniques (Gkritza et al., 2008). With respect to structure types, road projects, including construction and maintenance of drainage, guardrail, landscaping, lighting, noise wall, sidewalk, and bike roads, etcetera, hold an absolute majority in 69% of the total. Overall, however, their practices are considered routine as opposed to those of bridges or operations projects that require more challenging technical as well as managerial skills (Gkritza et al., 2008).

Table 2-4. Types of projects

Work \ Structure	Roads	Bridges	Other	Total
New construction	6	0	35	41
Capacity addition	75	4	4	83
Maintenance	160	32	33	225
Total	241	36	72	349

5.1.3 Types of changes

Table 2-5 presents 7 types of causes that lead to contract changes and their summary statistics. The original FDoT data contains 49 types of causes. Based on the description of each cause provided by the FDoT[11], I grouped similar ones into the same type. First of all, it was determined whether the source of a change is internal or external. Internal sources are mainly project parties, whereas external ones are socioeconomic situations (Change 2) or environmental conditions (Change 3) both of which are a unique feature of construction as site production. Next, internal causes are further combined based on the main drivers. For example, material-related issues are categorized as on-site management issues (Change 1) with "deterioration of, or damage to, project after design" as both of them are mainly induced by the contractor as opposed to "changes result from engineering decision" by the owner (Change 6). Both plan errors or omissions (Change 4) and plan modifications (Change 5) can be directed either by the owner or by the contractor. However, they form separate groups due to the difference in the purposes of them. Finally, owner-requested changes for "partnering" and "value engineering" are coded in Change 7. Although they are different practices, they can be regarded as owner's efforts to increase the value of the project.

[11] Detailed descriptions are found in Appendix 1.

Table 2-5. Types of changes

Types \ Statistics	Obs.	Total amount	Average amount	Min	Max
1. On-site management issues	331	$13,362,421	$ 40,369.85	$- 128,546	$1,023,502
2. External situations	199	$ 9,456,972	$ 47,522.47	$- 487,563	$2,285,063
3. Weather or subsoil conditions	271	$13,025,117	$ 48,063.16	$- 13,252	$ 834,272
4. Plan errors or omissions	733	$42,280,847	$ 58,157.97	$- 117,037	$2,550,775
5. Plan modifications	737	$49,946,015	$ 67,953.76	$-1,411,748	$5,829,732
6. Engineering decisions	360	$28,691,762	$ 79,699.34	$-1,770,066	$8,260,000
7. Partnering or value engineering	68	$- 5,434,817	$-79,923.79	$-1,093,706	$ 292,966

5.2 Variables and summary statistics

5.2.1 Dependent variables

The focus of this study is cost performance of a project. To measure cost performance, I borrow the idea of cost performance index (CPI) from Earned Value Management (EVM) technique and compute the ratio of a baseline value to an actual one. In doing so, I decompose the actual value into the amount of contract adjustments and the cost above and beyond them to distinguish cost performance attributed to project from the one attributed to control. For the aspect of planning, the ratio of original contract amount to adjusted contract amount is computed and named planning performance index (PPI) in this study. The ratio of adjusted contract amount and actual payment to the contractor, which is named management performance index (MPI), would explain the control aspect of cost performance. Both indices are log-transformed for the consistency in the interval across ratios. Thus, values above or below 0 respectively mean cost underrun or overrun, while the value of 0 indicates the exact match between the amounts. Table 2-6 presents summary statistics of the dependent variables.

$$Planning\ Performance\ Index\ (PPI)\ = \frac{Original\ Contract\ Amount}{Adjusted\ Contract\ Amount} \tag{1}$$

$$Management\ Performance\ Index\ (MPI)\ = \frac{Adjusted\ Contract\ Amount}{Payment\ to\ a\ contractor} \tag{2}$$

Table 2-6. Summary statistics of cost and schedule variables

Variables \ Statistics	Obs.	Mean	Std. Dev.	Min	Median	Max
LN (Original/Adjusted)	349	-0.0381	0.0627	-0.3593	-0.0231	0.2692
LN (Adjusted/Payment)	349	0.0076	0.0579	-0.4119	0.0043	0.4252
LN (Project cost)	349	14.9424	1.6412	10.0951	14.9584	19.0771
LN (Project duration)	349	5.4486	0.8964	2.7081	5.4161	7.4483
Time extension	349	0.2227	0.4746	-0.8000	0.1371	5.0143

5.2.2 Independent variables

Type of a change

As described in section 4.1.3, a total of 7 types for project changes are established. Each project has different combinations of changes with respect to types and frequencies occurred during the execution. Some had undergone at least one of each change, others had experienced just some of the changes, and still others had encountered only a couple of changes over the project duration. Since the level of analysis is project, the frequency of each type under each project is counted and 7 variables representing the frequencies are included in the model even though more detailed information on individual changes is available. Average frequencies do not deviate from type to type, yet standard deviations, e.g., those of Change 4 (plan errors or omissions) and Change 5 (plan modifications), do from others. Also, Change 4 and Change 5 occurred more than others did (Table 2-7).

Table 2-7. Summary statistics of change variables

Statistics / Variables	Obs.	Obs. with Freq. > 0	Min	Max	Mean	Std. Dev.
Change 1	349	139	0	23	0.95	2.17
Change 2	349	88	0	11	0.57	1.44
Change 3	349	115	0	15	0.78	1.86
Change 4	349	198	0	58	2.10	4.70
Change 5	349	182	0	45	2.11	4.57
Change 6	349	151	0	17	1.03	2.07
Change 7	349	50	0	5	0.19	0.57

* Change variables are defined in Table 2-5.

Timing of a change

To explore how the relationship between the type of a change and cost performance differs by the timing that the change had occurred over the execution of the project, this study employs a continuous variable of timing not only as an independent term, but also as an interaction term with the type of a change. The timings of changes by the same type under the same project are averaged for the consistency in the level of analysis. Table 2-8 presents summary statistics for timing variables computed by the following formula[12]:

$$Timing = \frac{(Change\ order\ date - Work\ begin\ date)(days)}{Actual\ duration\ (days)} \tag{3}$$

[12] Values of timing below 0 or above 1 are respectively associated with changes processed before the project had begun or after the project had completed while final documentation not having been passed to the comptroller's office.

Table 2-8. Summary statistics of timing variables

Variables \ Statistics	Obs.	Obs. with Freq. > 0	Min	Max	Mean	Std. Dev.
Timing 1	349	139	-1.16	1.35	0.22	0.31
Timing 2	349	88	-0.17	0.90	0.13	0.25
Timing 3	349	115	-0.01	0.98	0.18	0.28
Timing 4	349	198	-0.46	0.98	0.31	0.31
Timing 5	349	182	-0.26	1.65	0.26	0.29
Timing 6	349	151	0.00	0.97	0.23	0.29
Timing 7	349	50	-0.46	0.88	0.06	0.18

* Timing 1 to Timing 7 respectively refer to the average timing of occurrence associated with each type of change.

Project cost* and *project duration

As discussed in section 3.5, project size appears to have a significant relationship with cost performance (Flyvbjerg, Holm, & Buhl, 2004; Gkritza et al., 2008; Korman & Daniel, 1998). I proxy for the size with two alternative measures (in the natural logarithmic scale), the original contract amount and the original contract duration[13], and test if each of them has a significant positive relationship with cost performance.

Project type

As discussed earlier, project type may also partially account for cost performance as distinct types of projects are involved in differing construction processes that varies with respect to the levels of manageability and technical difficulties (Gkritza et al., 2008). To account for this latent effect of project types, a discrete variable is included in the model. The original FDoT data categorizes projects into 11 types regardless of the kinds of

[13] Although adjusted contract amount (duration) and actual payment (duration) are also available in the data, this study uses the variables known at the time of contract award to prevent the project size variables from being correlated with the error of performance-related variables.

works or structures. Referring to Choi et al. (2011) and Gkritza et al. (2008), the types are regrouped depending on the 3 structure types, i.e., road, bridge, and miscellaneous structures, and 3 work types, i.e., new construction, maintenance, and capacity addition. Due to extremely small numbers or observations, however, bridge projects are merged into one, and maintenance absorbs capacity addition in the category of miscellaneous structures, resulting in a total of 6 project types.

Contractor's capability

Cost performance may vary to some extent depending on a contractor's capability of project management as the contractor, not the owner, is the party who actually performs the work. (Chan & Kumaraswamy, 1997). To control for this effect, this study employs two proxies for the capability: 1) whether or not a contractor is prequalified by the FDoT (Attar, Khanzadi, Dabirian, & Kalhor, 2013); and 2) whether or not a contractor had performed more than one projects with the FDoT prior to the current one (Bajari et al., 2014). Interestingly, contractors who are prequalified or had multiple collaborations are better in terms of planning performance, while those who are non-prequalified or had less than 2 collaborations exhibit better management performance (Table 2-9).

Table 2-9. Contractor characteristics

Criteria	Categories	# of contractors	Average PPI	Average MPI
Prequalified?	Yes	291	-0.0321	0.0037
	No	58	-0.0681	0.0271
Collaboration experience with the FDoT	0 or 1	232[1]	-0.0298	0.0068
	At least 2	117	-0.0545	0.0091

1. The number of contractors without any prior experience with the FDoT is 74.
2. Both indices are transformed into the natural-logarithmic scale.

Changes in duration

Schedule change in the middle of a project, regardless of whether it is compensable or not, is likely to increase or decrease project cost by affecting a normal flow of work. To control for any effect on cost performance attributed to unobserved consequences of schedule change, this study measures changes in duration (*CHGDUR*) as in Equation 4 and includes it as a control variable in the model:

$$Changes\ in\ duration\ (CHGDUR) = \frac{Actual\ duration - Original\ contract\ days}{Original\ contract\ days} \quad (4)$$

5.3 Analytic model

I conduct the analyses with some cross-section regressions of project *i*'s cost performance on aforementioned variables representing project characteristics and contractor capability, where cost performance is measured by two indices, $LPPI_i$ and $LMPI_i$. First, based on Gkritza et al. (2008), the original contract amount and original contract duration representing project size are included in the natural logarithmic scale. Next, an indicator variable of $PRJTYPE_i$ is added to the model since the cost performance is expected to vary across different types of projects. Third, the prequalification status of contractor *n*, $PREQUAL_i^n$, is employed to rule out any effect attributed to the expected managerial capability of contractor *n* who had supervised project *i*. Likewise, a dummy variable $NUMEXP_i^n$ is used to account for the asymmetry in contractor n's collaboration experience with the FDoT[14]. The regression equation proposed to be estimated is as follows:

$$COST\ PERFORMANCE_i \tag{5}$$
$$= \beta_0 + \sum_{j=1}^{3} PRJCHAR_i\beta_j + \sum_{k=4}^{5} CONCHAR_i\beta_k + \varepsilon_i$$
$$= \beta_0 + \beta_1 PRJCOST_i + \beta_2 PRJDUR_i + \beta_3 PRJTYPE_i + \beta_4 PREQUAL_i^n + \beta_5 NUMEXP_i^n + \varepsilon_i$$

Since the sample projects had awarded and executed over 10 years of time span, one may be concerned about any bias associated with different times of the projects, such as the influence of economic boom and recession. To address this concern additional models including 10 year-dummy variables are estimated, which confirm almost no year-specific effect on the performance. Thus, I would keep the year-dummies out of the analyses.

The regression in Equation (5) includes factors that are fixed from the time of work begin, but ignores the ones that emerge after then. To account for the effects of changes after the work begin, 7 variables each of which indicates the frequency of change j under project i are denoted by CHG_{ij} and added to Equation (5). Note that $CHGDUR_i$, is additionally employed to controls for the variations in the dependent variable explained by the changes in duration (Equation 6).

[14] The variables PREQUAL and NUMEXP contain a superscript, *n*, that specifies the contractor who had supervised a particular project in the data. However, the level of analysis should not be a problem because each project takes unique values of PREQUAL and NUMEXP depending on the dates of project award and work begin, respectively.

$$COST\ PERFORMANCE_i \quad (6)$$

$$= \beta_0 + \sum_{j=1}^{7} CHG_{ij}\beta_j + \beta_8 CHGDUR_i + \sum_{k=9}^{11} PRJCHAR_i\beta_k + \sum_{l=12}^{13} CONCHAR_i\beta_l + \varepsilon_i$$

Finally, I include 7 variables each of which represents the average timing of the occurrence associated with change j under project i, $TMNG_{ij}$ to test the effect of the timing of a change on cost performance. Particular interest in this study is to see if the effect of a change on cost performance differs by the timing of its occurrence. Thus, an interactive model that allows for the interaction between CHG_{ij} and $TMNG_{ij}$ is specified as in the following Equation (7):

$$COST\ PERFORMANCE_i \quad (7)$$

$$= \beta_0 + \sum_{j=1}^{7} CHG_{ij}\beta_j + \sum_{j=8}^{14} TMNG_{i(j-7)}\beta_j + \sum_{j=15}^{21} CHG_{i(j-14)} \times TMNG_{i(j-14)} \times \beta_j$$

$$+ \beta_{22} CHGDUR_i + \sum_{k=23}^{25} PRJCHAR_i\beta_k + \sum_{l=26}^{27} CONCHAR_i\beta_l + \varepsilon_i$$

6. Results and Discussion

6.1 Cost performance regression on project characteristics

Before turning to regression analyses, I first plot frequency distributions of management- as well as planning-performance (Figure 2-6 and 2-7). The distribution of planning performance is slightly skew to the left, indicating that the majority of contracts are adjusted upwards. An interesting message of the figures is that the distribution of cost performance is close to the normal distribution even after incorporating contract adjustments. Although cost overrun is considered a norm rather than an exception in the industry, these observations suggest a room for improvement in project performance.

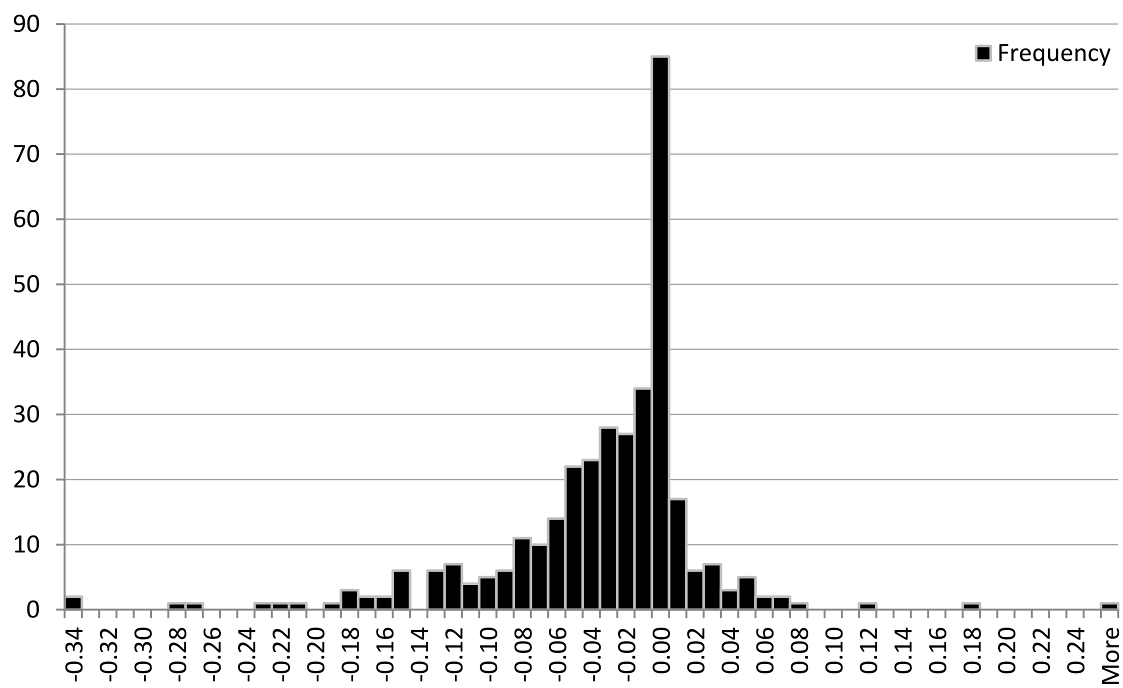

Figure 2-6. Distribution of natural-logged Planning Performance Index (LPPI)

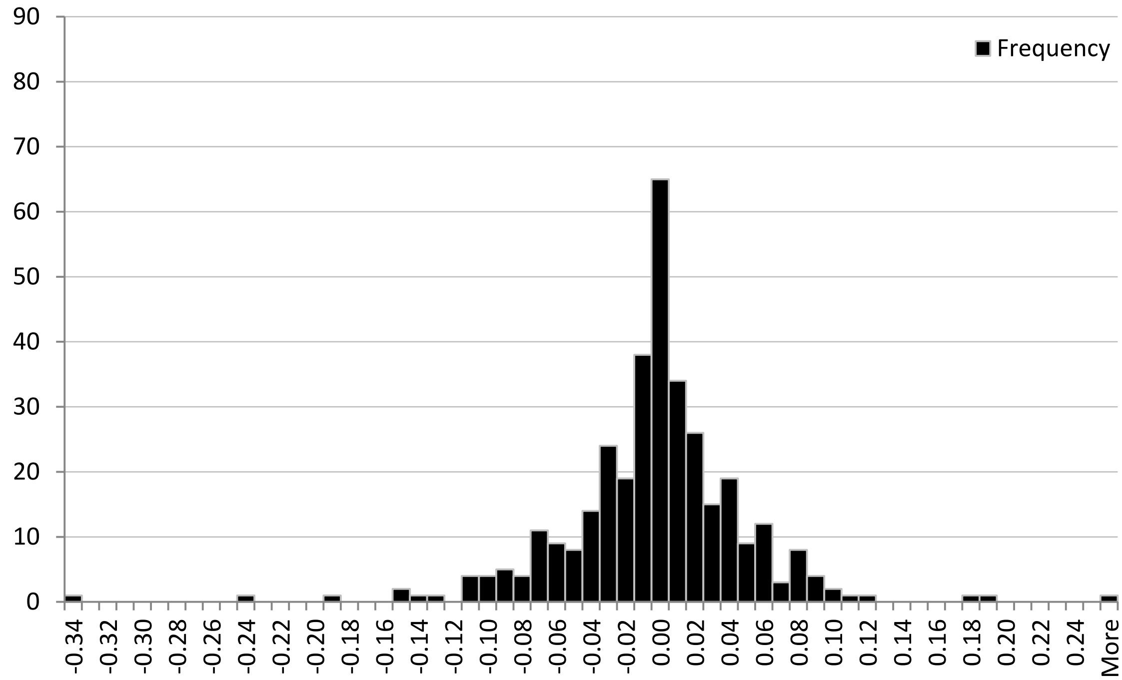

Figure 2-7. Distribution of natural-logged Management Performance Index (LMPI)

I begin the analyses by performing some cross-section regressions using aforementioned three project-characteristic terms that may affect project i's cost performance. Based on Gkritza et al. (2008), the first two terms are the original contract amount and the original contract duration at the onset of a project i, $COST_i$ and DUR_i, representing the size of the project. Also, an indicator variable of $PRJTYPE_i$ is used to measure the variance in performance that is attributed to various natures of construction processes and management practices associated with different types of projects. In doing so, I repeat the estimations with and without control variables of contractors' capabilities. Note that the analyses are conducted using two dependent variables, the ratio of original contract amount to adjusted contract amount in the natural logarithm scale ($LPPI_i$) as well as the ratio of adjusted contract amount to actual payment to the contractor ($LMPI_i$) to separate the effects of independent variables on management performance from those on planning performance.

Although the results shown in columns 1 and 2 of Table 2-10 generally reaffirm those reported in the literature, they are somewhat interesting. With respect to the project size, the amount of contract adjustments decreases (i.e., better planning performance) as the amount of contract awards increases, while the cost of works increases (i.e., worse management performance) as the cost of project increases. These might be puzzling at first glance, but are in line with mixed findings from the literature. As mentioned in the hypotheses section, Odeck (2004) asserts that percentage overruns from cost estimates tend to be higher for smaller projects because larger projects typically attract superior contractors who are deemed to be better at project planning. As for construction management, however, management problems associated with large projects might outweigh the benefits of using superior contractors as suggested in the literature (see Gkritza et al. 2008).

The results regarding the size of project duration are interesting as well. As opposed to the mixed findings on the project cost, it has been consistently argued that longer project durations could be translated to larger amounts of cost overruns. In terms of contract adjustments, the coefficients on DUR_i and $CHGDUR_i$ indicate that longer extended days as well as longer planned durations are associated with larger amounts of contract adjustments. However, I cannot be reasonably sure that either of them has a negative effect on management performance as the coefficients on both variables are not in the hypothesized direction. These counterintuitive results, particularly the relationship between the extended days and management performance might indicate that the FDoT had been generous about approving time extensions without compensating for contractors. This may also be a weak indication of additional costs incurred by schedule compression (Koskela, 2000). The fact that non-compensable time extensions account for on average 83% of the total extended days in the sample partially supports the first speculation, although the data set does not allow me to examine the effect of additional cost associated with schedule compression. Overall, the coefficients get slightly closer to zero with control variables, suggesting that larger projects attract more capable contractors.

Meanwhile, project types also significantly explain planning performance as well as management performance. As expected, Type 3 (bridge projects) is found to be harder in terms of planning as well as construction management than other types are. In this particular sample, their values of PPI_i and MPI_i are lower than those of Type 6 (road maintenance projects) approximately by 3.3% and 2.2%, respectively. The results for Type 1 (maintenance and capacity addition of traffic operations projects) are also worth noting. They involve smaller amounts of contract adjustments than others are as indicated by the largest positive coefficient of all. When it comes to construction management, however, they present worse performance than all but bridge projects with a negatively significant coefficient. These findings are consistent with those in the literature that it is harder to manage traffic projects as they are more likely to be affected by passing traffics than others, whereas it is easier to plan and schedule them due to their small sizes (Gkritza et al., 2008). Finally, the fact that the coefficients do not change severely with and without controlling variables may imply that the difference in performances are actually due to characteristics inherent in project types rather than the ancillary factor of contractor's managerial capabilities[15].

Table 2-10. Regression results with project characteristics variables

IV \ DV	1 LPPI	2 LPPI	3 LPPI	4 LMPI	5 LMPI	6 LMPI
COSTi	**0.0137**	**0.0096**	**0.0171**	**-0.0162**	**-0.0164**	**-0.0191**
	(0.003)	(0.040)	(<.001)	(<.001)	(<.001)	(<.001)
DURi	**-0.0220**	**-0.0170**	**-0.0190**	-0.0014	-0.0005	0.0024
	(0.008)	(0.042)	(0.021)	(0.835)	(0.946)	(0.736)
PRJTYPE1i	0.0104	0.0146	**0.0223**	**-0.0220**	**-0.0232**	**-0.0246**
	(0.377)	(0.210)	(0.050)	(0.027)	(0.020)	(0.015)
PRJTYPE2i	0.0013	0.0117	0.0178	0.0015	-0.0017	-0.0051
	(0.915)	(0.337)	(0.134)	(0.883)	(0.868)	(0.626)
PRJTYPE3i	**-0.0305**	**-0.0247**	**-0.0186**	**-0.0219**	**-0.0208**	**-0.0236**
	(0.009)	(0.035)	(0.099)	(0.026)	(0.037)	(0.018)
PRJTYPE4i	-0.0090	-0.0046	0.0043	0.0057	0.0053	(0.0033)
	(0.320)	(0.603)	(0.627)	(0.450)	(0.486)	(0.670)
PRJTYPE5i	0.0058	0.0203	0.0310	**0.0539**	**0.0520**	**0.0474**
	(0.837)	(0.466)	(0.249)	(0.023)	(0.030)	(0.046)
PREQUALi		**0.0298**	**0.0251**		**-0.0145**	-0.0131
		(0.003)	(0.009)		(0.088)	(0.123)
NUMEXPi		0.0081	0.0059		0.0082	0.0093
		(0.311)	(0.442)		(0.228)	(0.169)
NUMCOi			**-0.0029**			0.0006
			(<.001)			(0.284)
$CHGDUR_i$			**-0.0210**			**0.0144**
			(0.002)			(0.018)
CONSTANT	**-0.1188**	**-0.1179**	**-0.2015**	**0.2604**	**0.2646**	**0.2822**
	(0.001)	(0.001)	(<.001)	(<.001)	(<.001)	(<.001)
R^2	0.0595	0.0954	0.1684	0.2160	0.2238	0.2400
# of Obs.	349	349	349	349	349	349

1. *COSTi*, *DURi*, and $CHGDUR_i$ are transformed to the natural logarithmic scale.
2. In the parentheses, p-values are presented.

[15] We can also observe significantly positive coefficients on Type 5 (new road constructions) from columns 4 to 6, which is contradictory to conventional wisdom that new construction projects are more likely to be under-performed. Although the results are interesting, I would leave a more comprehensive interpretation until further analyses are conducted due to the low frequency of Type 5 in the data set.

6.2 Accounting for changes

6.2.1 Cost performance regression on the types of changes

While the analyses discussed in section 5.1 are typical reduced form regressions carefully studied in the literature, they just include factors known at the contract award phase without considering changes that are regarded as major factors influencing performance by interfering with the intended flow of work during the construction phase (Love et al., 2002). Apparently, not only the number of COs but also the number of CO days show significantly negative associations with discrepancy between contract amounts as reported in Table 2-3. To account for varying degrees of contributions that changes with different natures had made to cost performance, I now conduct analyses while including 7 change-variables described in section 4.2. As before, regressions are repeated using $LPPI_i$ as well as $LMPI_i$ so that factors affecting management performance on top of planning performance can be separately identified if there is any.

The estimated coefficients of the regressions are presented in Table 2-11. Turning first to the results of planning performance regressions in columns 1 to 4, we see significantly negative coefficients on CHG5 (plan modifications) and CHG6 (changes resulting from engineering decisions) while a significantly positive one on CHG7 (partnering or value engineering). In this particular sample, one more plan modification or engineer-driven change respectively increase the contract amount by 0.27% and 0.45% of the original amount when holding all other variables constant. In contrast, an additional practice of partnering or value engineering decreases the contract amount by 1.48% of the original amount, which suggests that FDoT's efforts to improve the coordination of project parties or the value of project outcome might be effective.

Although insignificant, coefficients on CHG 3 (changes due to environmental conditions) and on CHG 4 (plan errors or omissions) are negative as expected.

The results of management performance regressions are somewhat different. As columns 5 to 8 in Table 2-10 show, the results provide little evidence that any of the changes including CHG 5, CHG6 and CHG 7 are significant contributors to the performance. In addition, the sign of the coefficient on CHG6 is now positive and a negative effect of project duration also disappears. The results are consistent before and after controlling for capabilities of contractors. Also, the R-squared values are higher than those in columns 1 to 4 notwithstanding the insignificant explanatory powers of the change variables, suggesting that inherent characteristics of projects may explain more of the variations in management performance than changes do. Results are somewhat disappointing in terms of their support for existing theories, which may be a result of looking at the aggregated performance while failing to observe the activity-level performance in more detail.

The results of CHG 5 and CHG6 are worth discussing. Since these types of changes are likely to require subsequent changes (Dvir et al., 2004), they were expected to have negative relationships with planning performance as supported by the results. More important, they are also expected to have adverse effects on management performance by presenting extra challenges to contractors (Banaitiene & Banaitis, 2012). For instance, CHG 6-type changes are essentially induced by quality concerns from the owner side. Although they are usually expected to increase the value of the project to the owner (Perkins, 2009), they are merely less foreseeable and less controllable source of cost overrun to the contractor (Riley et al., 2005; USDoT, 2006). Moreover, contractors need to collaborate with other project parties including the owner when controlling these types of changes, meaning increased communication necessity. My data does not support this notion by yielding insignificant coefficients in the regression of $LMPI_i$ on CHG 5 and CHG6 holding all the other independent variables constant. Nevertheless, caution needs to be exercised in the interpretation and further examination is required given that the result is based on FDoT's expenditure rather than on the one that the contractor had actually ended up spending on the changed works.

Table 2-11. Regression results with change variables

IV \ DV	1 LPPI	2 LPPI	3 LPPI	4 LPPI	5 LMPI	6 LMPI	7 LMPI	8 LMPI
CHG1i	0.0015	0.0012	0.0014	0.0012	0.0007	0.0008	0.0006	0.0008
	(0.570)	(0.659)	(0.588)	(0.659)	(0.780)	(0.741)	(0.790)	(0.741)
CHG2i	0.0020	0.0028	0.0021	0.0027	0.0029	0.0026	0.0029	0.0026
	(0.502)	(0.353)	(0.483)	(0.361)	(0.270)	(0.318)	(0.265)	(0.326)
CHG3i	-0.0013	-0.0012	-0.0010	-0.0010	-0.0021	-0.0022	-0.0020	-0.0020
	(0.637)	(0.662)	(0.728)	(0.713)	(0.397)	(0.388)	(0.430)	(0.436)
CHG4i	-0.0005	-0.0004	-0.0005	-0.0004	-0.0007	-0.0007	-0.0007	-0.0007
	(0.720)	(0.789)	(0.720)	(0.780)	(0.560)	(0.535)	(0.560)	(0.526)
CHG5i	**-0.0029**	**-0.0027**	**-0.0029**	**-0.0027**	-0.0001	-0.0002	-0.0001	-0.0002
	(0.055)	(0.074)	(0.057)	(0.073)	(0.932)	(0.886)	(0.939)	(0.879)
CHG6i	**-0.0045**	**-0.0044**	**-0.0047**	**-0.0045**	0.0029	0.0029	0.0029	0.0028
	(0.038)	(0.044)	(0.032)	(0.039)	(0.128)	(0.136)	(0.136)	(0.152)
CHG7i	**0.0137**	**0.0144**	**0.0145**	**0.0148**	0.0022	0.0020	0.0026	0.0024
	(0.026)	(0.018)	(0.018)	(0.016)	(0.679)	(0.714)	(0.636)	(0.657)
$CHGDUR_i$	**-0.0208**	**-0.0201**	**-0.0200**	**-0.0198**	**0.0147**	**0.0145**	**0.0151**	**0.0149**
	(0.003)	(0.004)	(0.004)	(0.004)	(0.016)	(0.018)	(0.014)	(0.015)
COSTi	**0.0192**	**0.0163**	**0.0165**	**0.0151**	**-0.0180**	**-0.0169**	**-0.0190**	**-0.0182**
	(<.001)	(<.001)	(0.001)	(0.002)	(<.001)	(<.001)	(<.001)	(<.001)
DURi	**-0.0254**	**-0.0233**	**-0.0215**	**-0.02124**	0.0009	0.0001	0.0024	0.0023
	(0.002)	(0.004)	(0.010)	(0.011)	(0.904)	(0.990)	(0.742)	(0.754)
PRJTYPE1i	0.0173	**0.0200**	0.0179	**0.0197**	**-0.0239**	**-0.0247**	**-0.0236**	**-0.0246**
	(0.137)	(0.089)	(0.121)	(0.087)	(0.020)	(0.016)	(0.021)	(0.016)
PRJTYPE2i	0.0113	0.0187	0.0131	0.0188	-0.0015	-0.0041	-0.0008	-0.0040
	(0.333)	(0.115)	(0.264)	(0.113)	(0.886)	(0.697)	(0.939)	(0.705)
PRJTYPE3i	**-0.0250**	**-0.0223**	**-0.0210**	**-0.0203**	**-0.0226**	**-0.0235**	**-0.0210**	**-0.0214**
	(0.029)	(0.050)	(0.069)	(0.077)	(0.025)	(0.020)	(0.040)	(0.036)
PRJTYPE4i	-0.0016	-0.0002	-0.0002	0.0004	0.0048	0.0043	0.0054	0.0050
	(0.861)	(0.980)	(0.980)	(0.965)	(0.546)	(0.588)	(0.504)	(0.532)
PRJTYPE5i	0.0185	0.0268	0.0239	0.0289	**0.0463**	**0.0434**	**0.0485**	**0.0457**
	(0.493)	(0.319)	(0.378)	(0.284)	(0.052)	(0.070)	(0.043)	(0.057)
PREQUALi		**0.0262**		**0.0230**		-0.0093		-0.0127
		(0.005)		(0.019)		(0.259)		(0.142)
NUMEXPi			**0.0137**	0.0080			0.0054	0.0086
			(0.062)	(0.300)			(0.404)	(0.208)
CONSTANT	**-0.1745**	**-0.1679**	**-0.1665**	**-0.1641**	**0.2690**	**0.2666**	**0.2721**	**0.27078**
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
R^2	0.1620	0.1819	0.1708	0.1845	0.2403	0.2432	0.2419	0.2468
# of Obs.	349	349	349	349	349	349	349	349

*In the parentheses, p-values are presented.

6.2.2. Effect of a change depending on the timing of its occurrence

To see if the timing of a change matters to project performance, I now add seven variables, each of which represents the average timing of changes with the same cause under a project. In doing so, interactive models are estimated as well to examine whether or not the effects of changes on the performance differ by the timing of their occurrences. The regression results are shown in Table 2-12 and Table 2-13.

Turning first to the results of additive models (Table 2-12), a robust relationship is found between the average timing of changes due to environmental conditions and planning performance: the coefficient on TIMING3 is significantly negative before and after controlling for contractor's capabilities. In this sample, 1% late occurrence of a natural environment-induced change can be translated into an increase in contract amount of over 3%. Considering the average profit margin of less than 1% in the road works category, this effect is economically significant. While the coefficients on TIMING1 also appear to be significantly negative in columns 1 and 3, the effect diminishes if contractor's prequalification status is held constant. This implies that the advantage of selecting prequalified contractors outweighs the late occurrence of a contractor-controlled change. Contrary to my expectation, interactive models do not yield any significant results associated with the timing variables other than the coefficient on TIMING3.

Next, I repeat the analyses using management performance (LMPI) as the dependent variable. As can be seen in columns 5 to 8 of Table 2-12, none of the timing variables yields a significant result in the additive models. On the other hand, interactive models show evidence that changes due to natural environmental conditions and their timings have negative effects on management performance. Specifically, the coefficient on TIMING3 turns significantly negative while the coefficient on the interaction term between TIMING3 and CHG3 is significantly positive (columns 5 to 8 of Table 2-13). Holding all other variables constant in the full specification, 1% late occurrence of this change affects the performance by (-0.0315+0.0426*CHG3)*100%, which monotonically decreases with the frequency of CHG3 (column 8 of Table 2-13). However, this result indicates an improved performance with timing due to the large coefficient on the interaction term, which is counterintuitive and is not supportive of Hypothesis 1b. Results of hypotheses testing based on the regressions are summarized in Table 2-14.

Then why are most of the timing variables largely insignificant across specifications? I can think of at least two possible reasons, first of which is the use of average timing rather than individual values. The method enables this study to keep the level of analysis consistent. At the same time, however, that might mask variations across individual changes in terms of their timings and yield insignificant estimation results. A limitation inherent in the examination of aggregate-level data may be another possibility. The FDoT data lack detailed information at the activity level, which prevents me from observing how changes alter the level of resource requirements. Theoretically, changes to non-critical activities do not necessarily have severe influence on cost performance (Devaux, 2012). Although it is impossible to predict the consequence of analyses that exclude non-critical changes, I conjecture that failure in considering the criticality might lead to the insignificant results.

However, there is also a possibility that the timing of a change is not that crucial particularly in this category of construction projects. Unlike IT projects or new product development (NPD), road projects except for construction and management of bridges are regarded as routine rather than one-of-a-kind activities due to their less complex and less technically-challenging nature of works (Azadega et al., 2013). Also, it is widely believed in the industry that experienced contractors can foresee ex post changes based on the original drawings and specifications, and even reflect sizeable adaptation costs in their bids (Bajari et al., 2014)[16]. Given that roughly 85% of the sample projects had been performed by contractors with more than 10 years in business, it is reasonable to speculate that both contractors and experienced owners such as the FDoT are well aware of how to handle ex post changes, for which when a change had occurred might not be a serious issue. The analyses are inadequate to support this conjecture, though.

[16] For an example describing how contractors increase their expected total payment by manipulate bids upwards (or downwards) on items that are expected to overrun (or underrun), see Bajari et al. (2011).

Table 2-12. Regression results with timing variables: Additive model estimation

IV \ DV	1 LPPI	2 LPPI	3 LPPI	4 LPPI	5 LMPI	6 LMPI	7 LMPI	8 LMPI
CHG1i	0.0018	0.0014	0.0018	0.0015	0.0000	0.0002	0.00003	0.0002
	(0.551)	(0.622)	(0.540)	(0.605)	(0.997)	(0.948)	(0.992)	(0.926)
CHG2i	-0.0022	-0.0015	-0.0012	-0.0015	0.0019	0.0016	0.0020	0.0016
	(0.551)	(0.669)	(0.591)	(0.679)	(0.559)	(0.627)	(0.544)	(0.616)
CHG3i	0.0030	0.0027	0.0031	0.0028	-0.0014	-0.0012	-0.0014	-0.0011
	(0.346)	(0.405)	(0.333)	(0.387)	(0.634)	(0.681)	(0.641)	(0.707)
CHG4i	-0.0014	-0.0012	-0.0014	-0.0013	-0.0006	-0.0006	-0.0006	-0.0007
	(0.334)	(0.385)	(0.321)	(0.369)	(0.661)	(0.619)	(0.654)	(0.596)
CHG5i	-0.0024	-0.0021	-0.0023	-0.0021	-0.0001	-0.0002	-0.0001	-0.0002
	(0.142)	(0.185)	(0.158)	(0.191)	(0.953)	(0.883)	(0.972)	(0.898)
CHG6i	-0.0041	-0.0041	**-0.0044**	**-0.0043**	0.0036	0.0036	0.0035	0.0034
	(0.116)	(0.118)	(0.092)	(0.102)	(0.128)	(0.131)	(0.141)	(0.153)
CHG7i	**0.0146**	**0.0155**	**0.0149**	**0.0155**	-0.0015	-0.0020	-0.0014	-0.0019
	(0.083)	(0.066)	(0.076)	(0.064)	(0.839)	(0.795)	(0.850)	(0.802)
TIMING1i	**-0.0201**	-0.0182	**-0.0209**	-0.0190	-0.0006	-0.0016	-0.0009	-0.0023
	(0.095)	(0.128)	(0.082)	(0.113)	(0.953)	(0.882)	(0.933)	(0.828)
TIMING2i	**0.0314**	**0.0319**	**0.0307**	**0.0314**	0.0049	0.0047	0.0047	0.0042
	(0.063)	(0.057)	(0.068)	(0.061)	(0.743)	(0.757)	(0.755)	(0.782)
TIMING3i	**-0.0362**	**-0.0319**	**-0.0341**	**-0.0311**	-0.0099	-0.0121	-0.0092	-0.01143
	(0.010)	(0.024)	(0.015)	(0.027)	(0.430)	(0.337)	(0.467)	(0.366)
TIMING4i	0.0009	0.0017	0.0026	0.0027	-0.0094	-0.0098	-0.0088	-0.0088
	(0.935)	(0.877)	(0.815)	(0.809)	(0.354)	(0.332)	(0.388)	(0.384)
TIMING5i	-0.0111	-0.0108	-0.0126	-0.0118	0.0013	0.0011	0.0007	0.0001
	(0.359)	(0.367)	(0.297)	(0.326)	(0.907)	(0.917)	(0.947)	(0.991)
TIMING6i	-0.0097	-0.0076	-0.0077	-0.0067	-0.0060	-0.0071	-0.0054	-0.0062
	(0.449)	(0.549)	(0.545)	(0.600)	(0.599)	(0.537)	(0.642)	(0.592)
TIMING7i	-0.0126	-0.0128	-0.0100	-0.0111	0.0140	0.0141	0.0149	0.0158
	(0.617)	(0.609)	(0.691)	(0.658)	(0.536)	(0.533)	(0.511)	(0.487)
PRJCOSTi	**0.0201**	**0.0176**	**0.0176**	**0.0163**	**-0.0173**	**-0.0160**	**-0.0182**	**-0.0172**
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
PRJDAYSi	**-0.0210**	**-0.0197**	**-0.0173**	**-0.0176**	0.0011	0.0004	0.0024	0.0026
	(0.011)	(0.016)	(0.041)	(0.037)	(0.883)	(0.952)	(0.755)	(0.733)
PRJTYPE1i	0.0160	0.0181	0.0170	0.0185	**-0.0251**	**-0.0262**	**-0.0248**	**-0.0259**
	(0.168)	(0.118)	(0.142)	(0.111)	(0.016)	(0.012)	(0.018)	(0.013)
PRJTYPE2i	0.0100	0.0162	0.0117	0.0164	-0.0013	-0.0045	-0.0007	-0.0043
	(0.388)	(0.171)	(0.313)	(0.166)	(0.902)	(0.675)	(0.948)	(0.687)
PRJTYPE3i	**-0.0232**	**-0.0211**	**-0.0192**	**-0.0188**	**-0.0219**	**-0.0230**	**-0.0205**	**-0.0208**
	(0.043)	(0.064)	(0.099)	(0.104)	(0.033)	(0.025)	(0.050)	(0.047)
PRJTYPE4i	-0.0035	-0.0024	-0.0024	-0.0019	0.0061	0.0055	0.0065	0.0061
	(0.702)	(0.791)	(0.793)	(0.838)	(0.455)	(0.498)	(0.429)	(0.458)
PRJTYPE5i	0.0297	0.0354	0.0341	0.0373	**0.0491**	**0.0462**	**0.0507**	**0.0482**
	(0.272)	(0.190)	(0.208)	(0.167)	(0.043)	(0.057)	(0.038)	(0.048)
CHGDUR$_i$	**-0.0184**	**-0.0181**	**-0.0178**	**-0.0178**	**0.0151**	**0.0149**	**0.0153**	**0.0153**
	(0.008)	(0.009)	(0.011)	(0.011)	(0.016)	(0.017)	(0.015)	(0.015)
PREQUALi		**0.0218**		**0.0186**		-0.0112		**-0.0144**
		(0.020)		(0.058)		(0.182)		(0.105)
NUMEXPi			**0.0126**	0.0080			0.0044	0.0079
			(0.088)	(0.298)			(0.507)	(0.256)
CONSTANT	**-0.2018**	**-0.1929**	**-0.1942**	**-0.1894**	**0.2626**	**0.2580**	**0.2652**	**0.2615**
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
R^2	0.1992	0.2125	0.2064	0.2151	0.2466	0.2508	0.2477	0.2538
# of Obs.	349	349	349	349	349	349	349	349

*In the parentheses, p-values are presented.

Table 2-13. Regression results with timing variables: Interactive model estimation

IV \ DV	1 LPPI	2 LPPI	3 LPPI	4 LPPI	5 LMPI	6 LMPI	7 LMPI	8 LMPI
CHG1i	0.0006	0.0011	0.0016	0.0016	-0.0049	-0.0051	-0.0046	-0.0046
	(0.953)	(0.916)	(0.883)	(0.878)	(0.610)	(0.592)	(0.633)	(0.629)
CHG2i	-0.0004	-0.0015	-0.0009	-0.0017	0.01369	**0.0142**	0.0135	**0.0140**
	(0.970)	(0.877)	(0.928)	(0.864)	(0.111)	(0.098)	(0.116)	(0.102)
CHG3i	0.0037	0.0030	0.0040	0.0033	**-0.0224**	**-0.0221**	**-0.0223**	**-0.0218**
	(0.697)	(0.747)	(0.667)	(0.722)	(0.007)	(0.008)	(0.008)	(0.009)
CHG4i	-0.0037	-0.0039	-0.0038	-0.0040	-0.0030	-0.0029	-0.0031	-0.0029
	(0.336)	(0.295)	(0.319)	(0.291)	(0.366)	(0.388)	(0.361)	(0.383)
CHG5i	-0.0046	-0.0045	-0.0046	-0.0045	0.0027	0.0027	0.0027	0.0027
	(0.315)	(0.320)	(0.310)	(0.317)	(0.493)	(0.499)	(0.495)	(0.504)
CHG6i	0.0039	0.0040	0.0027	0.0033	0.0058	0.0058	0.0055	0.0051
	(0.593)	(0.580)	(0.712)	(0.654)	(0.365)	(0.369)	(0.400)	(0.433)
CHG7i	0.0170	0.0202	0.0183	0.0205	0.0004	-0.0011	0.0008	-0.0007
	(0.197)	(0.125)	(0.165)	(0.118)	(0.971)	(0.925)	(0.944)	(0.950)
TIMING1i	-0.0217	-0.0186	-0.0214	-0.0188	-0.0076	-0.0090	-0.0074	-0.0092
	(0.173)	(0.240)	(0.179)	(0.236)	(0.592)	(0.523)	(0.598)	(0.515)
TIMING2i	**0.0328**	0.0308	0.0310	0.0300	0.0127	0.0137	0.0122	0.0129
	(0.105)	(0.125)	(0.124)	(0.136)	(0.476)	(0.443)	(0.496)	(0.470)
TIMING3i	**-0.0399**	**-0.0359**	**-0.0374**	**-0.0349**	**-0.0306**	**-0.0325**	**-0.0298**	**-0.0315**
	(0.014)	(0.026)	(0.021)	(0.031)	(0.033)	(0.024)	(0.038)	(0.029)
TIMING4i	-0.0034	-0.0030	-0.0016	-0.0020	-0.0163	-0.0165	-0.0158	-0.0155
	(0.797)	(0.817)	(0.901)	(0.878)	(0.160)	(0.155)	(0.176)	(0.182)
TIMING5i	-0.0129	-0.0133	-0.0149	-0.0145	0.0007	0.0010	0.0001	-0.0001
	(0.345)	(0.324)	(0.276)	(0.286)	(0.951)	(0.937)	(0.992)	(0.991)
TIMING6i	-0.0007	0.0016	0.0001	0.0018	-0.0009	-0.0020	-0.0006	-0.0018
	(0.960)	(0.914)	(0.993)	(0.901)	(0.945)	(0.877)	(0.962)	(0.891)
TIMING7i	-0.0026	0.0031	0.0019	0.0051	0.0253	0.0226	0.0267	0.0245
	(0.939)	(0.927)	(0.956)	(0.880)	(0.396)	(0.449)	(0.372)	(0.413)
*CHG1i**	0.0028	0.0010	0.0008	0.00003	0.0110	0.0118	0.0103	0.0108
TMNG1i	(0.896)	(0.961)	(0.971)	(0.999)	(0.564)	(0.534)	(0.588)	(0.569)
*CHG2i**	-0.0043	-0.0002	-0.0027	0.0003	-0.0248	-0.0268	-0.0243	-0.0264
TMNG2i	(0.838)	(0.994)	(0.899)	(0.988)	(0.181)	(0.150)	(0.191)	(0.157)
*CHG3i**	-0.0005	-0.0002	-0.0013	-0.0007	**0.0432**	**0.0431**	**0.0430**	**0.0426**
TMNG3i	(0.976)	(0.992)	(0.940)	(0.968)	(0.006)	(0.007)	(0.007)	(0.007)
*CHG4i**	0.0055	0.0063	0.0056	0.0063	0.0067	0.0063	0.0067	0.0062
TMNG4i	(0.502)	(0.437)	(0.493)	(0.440)	(0.356)	(0.386)	(0.355)	(0.389)
*CHG5i**	0.0042	0.0048	0.0046	0.0050	-0.0051	-0.0054	-0.0049	-0.0052
TMNG5i	(0.639)	(0.588)	(0.604)	(0.574)	(0.523)	(0.498)	(0.534)	(0.513)
*CHG6i**	-0.0183	-0.0186	-0.0163	-0.0173	-0.0062	-0.0061	-0.0056	-0.0049
TMNG6i	(0.214)	(0.205)	(0.269)	(0.239)	(0.633)	(0.639)	(0.669)	(0.707)
*CHG7i**	-0.0102	-0.0181	-0.0131	-0.0189	-0.0123	-0.0085	-0.0132	-0.0093
TMNG7i	(0.739)	(0.555)	(0.669)	(0.538)	(0.649)	(0.754)	(0.627)	(0.733)
PRJCOSTi	**0.0202**	**0.0175**	**0.0177**	**0.0164**	**-0.0170**	**-0.0157**	**-0.0177**	**-0.0168**
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
PRJDAYSi	**-0.0207**	**-0.0193**	**-0.0170**	**-0.0172**	0.0006	-0.0001	0.0017	0.0018
	(0.013)	(0.020)	(0.048)	(0.044)	(0.940)	(0.986)	(0.824)	(0.809)
PRJTYPE1i	0.0173	**0.0199**	0.0183	**0.0202**	**-0.0245**	**-0.0257**	**-0.0242**	**-0.0254**
	(0.142)	(0.091)	(0.120)	(0.086)	(0.019)	(0.014)	(0.021)	(0.015)
PRJTYPE2i	0.0117	0.0184	0.0133	0.0185	0.0010	-0.0022	0.0015	-0.0021
	(0.322)	(0.127)	(0.262)	(0.125)	(0.922)	(0.838)	(0.885)	(0.846)
PRJTYPE3i	**-0.0235**	**-0.0211**	**-0.0195**	**-0.0190**	**-0.0230**	**-0.0241**	**-0.0218**	**-0.0221**
	(0.042)	(0.066)	(0.097)	(0.104)	(0.024)	(0.019)	(0.037)	(0.034)
PRJTYPE4i	-0.0027	-0.0014	-0.0017	-0.0009	0.0080	0.0074	0.0083	0.0078
	(0.773)	(0.879)	(0.860)	(0.920)	(0.339)	(0.378)	(0.321)	(0.034)
PRJTYPE5i	0.0313	0.0368	0.0347	0.0382	**0.0487**	**0.0461**	**0.0498**	**0.0474**
	(0.261)	(0.185)	(0.213)	(0.170)	(0.049)	(0.063)	(0.045)	(0.056)

Table 2-13. Regression result including timing variables: Interactive model estimation

IV \ DV	1 LPPI	2 LPPI	3 LPPI	4 LPPI	5 LMPI	6 LMPI	7 LMPI	8 LMPI
CHGDUR$_i$	**-0.0179**	**-0.0175**	**-0.0173**	**-0.0172**	**0.0154**	**0.0152**	**0.0156**	**0.0155**
	(0.011)	(0.012)	(0.014)	(0.014)	(0.013)	(0.015)	(0.012)	(0.013)
PREQUALi		**0.0230**		**0.0201**		-0.0111		-0.0139
		(0.016)		(0.044)		(0.189)		(0.119)
NUMEXPi			**0.0122**	0.0074			0.0038	0.0071
			(0.103)	(0.342)			(0.567)	(0.307)
CONSTANT	**-0.2037**	**-0.1955**	**-0.1971**	**-0.1925**	**0.2616**	**0.2576**	**0.2637**	**0.2605**
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
R^2	0.2052	0.2196	0.2118	0.2218	0.2703	0.2743	0.2711	0.2766
# of Obs.	349	349	349	349	349	349	349	349

*In the parentheses, p-values are presented.

Table 2-14. Summary of hypotheses testings

No.	Hypothesis statement	Supported?
H1a	A change is likely to be associated with worse cost performance if it is a) resulted from owner-side engineering decisions, b) induced by environmental conditions, or c) related to design or scope modifications. On the other hand, a change is likely to be associated with better cost performance if it involves: a) partnering or b) value engineering.	Yes
H1b	A negative association between a change and cost performance will be amplified as the timing of its occurrence gets delayed if it is: a) resulted from owner-side engineering decisions, b) induced by environmental conditions, or c) related to design or scope modifications.	No
H2a	Project cost representing the size of a project is negatively associated with cost performance.	Partially supported
H2b	Project duration representing the size of a project is negatively associated with cost performance.	Yes
H2c	Project type will have a significant relationship with cost performance. Specifically, new construction projects will show worse cost performance than maintenance or capacity addition projects, while road projects will show better cost performance than bridge or traffic operations projects.	Yes

7. Conclusion

7.1 Summary and implications

Using FDoT's data on their road projects over a 10-year time period, this study examines what best explains project cost in terms of planning and managerial performance. Contrary to the conventional wisdom that public ownership is a source of inefficiency in curbing cost increase, descriptive statistics indicate that the FDoT has not had a serious issue with respect to efficient management of their projects at least after incorporating contract adjustments. 39.3% of the sample projects turn out to be completed on or within budget based on the adjusted contract amount. With those completed within 5% increase in cost, the proportion reaches 85.1%. On the other hand, the distribution of the ratios between the original contract amounts and the adjusted amounts reveals lack of efficiency in planning, which seems to agree with the "planning fallacy" prevalent in the sector (Flyvberg, Holm, & Buhl, 2002). Thus, more interesting is to trace what triggers those changes.

The analysis finds that the effect of a change on planning performance of a project varies across changes rooted from different causes. Specifically, changes in design and specification, and those resulting from engineering decisions significantly explain planning performance. An implication from the finding that the incompleteness in design and specification is one of the major sources of the problem is obvious: project owners need to increase their efforts put into estimating and specifying projects before bid lettings. Admittedly, there is no way that I can conjecture the costs and benefits with associated additional efforts at this point. Moreover, there will always be unavoidable factors to be changed during execution regardless of the amount of efforts invested in design and planning. However, it seems reasonable for the owner to carefully evaluate the value added by extra upfront effort in engineering as the contribution of the incompleteness to cost performance is considerable.

The result also shows that changes resulting from engineering decisions are a significant source of variations in planning performance. In construction projects, the major role of project engineers is monitoring contractors' progresses and directing them to correct discrepancies from the plan and specification if there are any observed. Since those changes are to increase the value of the project, not all should be considered deleterious to project performance. Nevertheless, a vital issue is how to keep them to a minimum so as to prevent projects from over budget. Obviously, an accurate capture of the requirements and an effective flow-down of them to contractors are keys to that end, which necessitate fluid communication and coordination among project parties in addition to engineering efforts. This implies potential advantages of using alternative methods of project delivery or contract award, e.g., Design-Build over Design-Bid-Build or negotiation over competitive bidding. Hence, developing a system that balances ups and downs of each method would be an interesting direction for future research.

Further implication in the advantage of alternative methods is found in the significantly positive coefficient on the partnering and value engineering changes. These seemingly different two practices, in fact, share a core principle that aims at cost saving by reducing wastes in the process. In principle, partnering helps project parties avoid acrimonious negotiation process of change orders by mitigating the principal-agency problem (Godfrey, 1996). Value engineering changes encourage the parties to find ways to deliver a project outcome at a lower cost without sacrificing the quality requirements

(Kelly & Male, 1993)[17]. Both of them can be achieved by frequent coordination among the parties through fluid information and communication channels, which again, implies potential benefits of adopting a more flexible delivery method. Identifying conditions under which the benefits of DB outweigh those of DBB thus seems to be a critical issue for further research.

Meanwhile, the hypothesis that changes occurring later in a project are implemented less efficiently is supported only for changes due to natural environmental factors such as inclement weather or uncertain subsurface conditions. This unfavorable result is particularly relevant in this outdoor production where the production site usually encompasses a long range of the earth and has long been realized (see Bennett, 1991; Grimm & Wagner, 1974). However, it has attracted less attention from researchers as the old saying goes, "Everyone talks about the weather, but no one does anything about it." It is indisputable that the timings of these changes, especially those of weather-related ones, are difficult to be anticipated or controlled. Yet, this result underscores a consequence of neglecting uncertainty when configuring a project.[18] An implication is clear: the owner should take geotechnical engineering more seriously in project planning so that proper preparation, adjustment, and reaction to the local environment is possible during the execution.

Finally, previous studies enable me to conjecture a couple of reasons why the results for other types of changes are insignificant. First, the negative effect of timing on

[17] See Chung, Syachirani, Jeong, and kwak (2009) that supports the benefit of value engineering practices with respect to cost savings. Estimated return on investment reported in their paper ranges from 1,200% and 2,200%.

[18] Given that the majority of weather-related changes are addressed by non-compensable time extension, I suspect that they might mostly affect cost performance indirectly unlike subsurface condition-related ones did. Since this study does not distinguish between direct and indirect impacts of changes, however, I will leave a detailed discussion on this matter for future research.

cost performance may not be amplified linearly, rather the impacts of changes are the highest in the third quarter of the project duration (Bruggink, 1997; Coffman, 1997). Presumably this is related to manpower loadings in construction that are the highest between 60% and 80% of the progress[19]. FDoT data do not carry information on the resource loadings throughout projects that would have allowed me to test this notion precisely. Also, as discussed in section 5.2.2, it is possible that the actual effect of timing in the context of road projects is not as deleterious as the effect in more complex projects. That is, perhaps implementing changes, even if they occurred late, might not significantly harm project cost owing to less complex interdependency among different activities (Azadega et al., 2013; Lewis & Bajari, 2013). The projects of interest in this study are not heterogeneous enough to let me examine the effect of timing while concerning the level of complexity. Regardless, a constant endeavor is required to demonstrate the timing effect of a change if there is any. This will enable contractors as well as owners to estimate the expected result more precisely when planning to implement a change.

7.2 Caveats and future research

Besides the limitations mentioned above, this study has fundamental caveats that need to be addressed for a more complete analysis. First of all, the analyses are conducted at the macro (project) level notwithstanding that the primary focus is on the dynamics at a micro (change) level because of the limited data. Considering that the average profit margin of the sector is lower than the average contract adjustment of the sample projects, one may expect a sizeable deviation from FDoT's payment for a changed work to a

[19] See the trapezoidal distribution of the manpower loadings proposed by Bent and Thuman (1988) and the American Association of Cost Engineers (AACE).

contractor's actual expense on it. The FDoT data lack the information on the internal costs of contractors that would have been the response variable at the micro level, precluding this study from explaining multi-level dynamics with higher accuracy. Analyzing such data accompanied by another micro-level data on project progress could yield more meaningful implications regarding efficient management of project changes.

Regarding the data on timing, I use the change order approval dates. As mentioned in the data description section, the approval dates are the closest data available. Nevertheless, they are merely the best approximates based on which it is difficult to confirm exactly in what point of the project duration the change actually interrupted and affected the planned workflow. An effort should be made by researcher as well as by practitioners to keep a good record of the timing, e.g., the start and finish dates of a change implementation.

Meanwhile, this study focuses solely on road projects from a single owner. This might reduce extra needs to control for heterogeneity across projects from multiple owners. However, relying on the secondary data from a single source inflicts low external validity on this study. Moreover, the sample may not be representative of the whole FDoT projects, let alone the entire public procurement projects in the U.S. because I restrict the sample to the ones that contain relevant information on project changes. This leaves room for future research on similar cases from other major states in the U.S. such as California. A more comprehensive research would investigate projects related to less routine construction or military acquisition, which will enable us to observe how the function of project changes varies contingent on different contexts, e.g., the level of plan completeness, the level of task difficulty, or the level of uncertainty.

Finally, this study ignores the quality aspect of the performance while evaluating project performance. Some of the changes might be necessary to improve the quality of either the product or the process. However, adequate metrics for infrastructure quality has yet to be developed despite ongoing efforts, not to mention no information available from my data. Presumably this is in part related to the difficulty in assessment. Infrastructures, especially transportation facilities are built and operated to meet varied objectives of local, state, and national stakeholders as they affect a broad range of communities. Furthermore, consequences that were not intended at the completion of construction frequently emerge in the distant future. Quality assessment in this context, hence, necessitates a continuing performance measurement in the long term, which has not been rigorously undertaken by any agency (NRC, 1996).

A comprehensive evaluation of infrastructure quality is an essential step toward accomplishing performance improvement. Responsible agencies should be assiduous in collecting and managing data that coordinate varied social objectives across wide areas over a long period of time. Researchers should also continue to strive to develop metrics that help practitioners make effective decisions about infrastructure project management.

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Chapter 3: Design Completeness, Adaptability, and the Choice of Delivery System
An Empirical Study on Public Transportation Projects

1. Introduction

It is ironic that a phased "stage-gate" approach, which has been the professional standard of project management ever since the creation of the U.S. Project Management Institute in 1969, is now considered a potential obstacle to the successful delivery of construction projects (Lenfle & Loch, 2010). This is also the case in the public transportation sector where the project delivery method known as design-bid-build (DBB) is widely used with a strong tie to a fixed-price contract. As can be surmised from the name, the design and construction phases are clearly separated in DBB. Hence, a contractor is able to start the construction with a complete design of the project outcome created by the owner-side architect and engineer (A/E), which is the greatest advantage of this method. The initial design is, however, subject to change in almost all projects (Bajari, McMillan, & Tadelis, 2009). Once a need for change has been raised, the three parties, i.e., the owner, the architect, and the contractor, need to negotiate for compensating the change. But the adversarial nature of the separate-party method coupled with the stringent compensation agreements of fixed-price contracts diminishes flexible communication and interactive learning among them, leading to inefficiency in handling unforeseen circumstances (Perkins, 2009). This is considered the greatest disadvantage of DBB, which, in turn, triggers a continued growth of more flexible alternatives.

Design-Build (DB) is one of the alternatives that allows for overlap between the design and construction phases. In DB, a single entity called the design-build contractor is responsible for the design as well as the construction. This single point of responsibility not only enables the outset of the construction before the completion of the design, but also facilitates adjustment to design errors without formal contractual processes known as change orders. Since they are major sources of savings in project cost and schedule, hypothetically DB projects should outperform DBB projects in both aspects. Existing literature supports DB promoters by consistently arguing shortened delivery schedule of DB projects. Cost advantage of DB over DBB in the literature, however, lacks consensus. Oftentimes it is reported that a low level of design completeness at the beginning of construction may generate adverse results, i.e., a substantial cost growth attributed to a lot of changes during construction (Ibbs, Kwak, Ng, & Odabasi, 2003). In the same vein, it is also pointed out that shortened schedule may bounce back to public owners as a form of extra expenses if design information turns out to violate external obligations such as environmental requirements (Whittington, 2012).

Every time a public owner plans a project, she may ask herself a question when and why a certain type of delivery method to use for a particular project. This study extends the literature on the choice of delivery method in public-sector procurement projects by seeking to answer this question. Specifically, the following three research questions are set to be tackled on the basis of the fundamental decisions that every owner should make in the procurement process: 1) for what type of project a public owner is likely to employ one method or the other; 2) to whom a public owner tends to award each type of project; and 3) to what degree owner's decisions yield varying consequences under the two methods in terms of project cost and schedule. Borrowing economic theories of contract selection, these questions are addressed while a misfit between this study and their standard assumption of well-defined products being recognized.

To add literature on the public-sector construction project management, a comprehensive data set, which consists of road, bridge, and traffic operations projects delivered in Florida from 2001 to 2010, is collected. Characteristics of the projects are identified, collaboration histories of contractors with the owner (i.e., the Florida Department of Transportation: FDoT) are measured, and their relationships to the chosen delivery method are analyzed. Finally, the performance of projects delivered by each delivery method is assessed and compared. The results reveal that not all decisions in the project delivery had been made according to theoretical expectations. Large and environmentally uncertain projects were not always delivered by DB especially if they were assumed to have high impacts on the right-of-way or community. Moreover, it is observed that histories of successful project performance with the owner did not necessarily guarantee future business for DB contractors. The use of DB seems beneficial for schedule control despite these misfits. On the other hand, cost advantages of one method over the other cannot be supported by this study, triggering more comprehensive studies on how to enhance various benefits inherent in each delivery method.

This paper proceeds as follows. Section 2 gives an overview of project delivery methods used in public transportation projects. Section 3 reviews relevant literature and proposes testable hypotheses. Section 4 describes the analytic models and variables with a detailed description of the data set. Section 5 reports and discusses the results of analyses. Finally, section 6 recaps the findings of this study and provides implications for project deliveries in the public sector while discussing the limitations of this study. Topics considered for future research are also covered in this section.

2. Background: Delivery Methods in Transportation Projects

2.1 Overview

In 2013, there are roughly 730 thousand firms in the U.S. construction industry, which as a whole employ around 7.3 million workers and perform a value of $898.4 billion of works (U.S. Department of Commerce, 2014; US Department of Labor, 2014). Also, U.S. public construction spending has accounted for around 2% of GDP for the past few decades. As the blue line in Figure 3-1 shows, the spending relative to GDP from 2002 to April 2014 has dropped towards its lowest point in 20 years since 2009. People find one of the reasons from the decline in the spending for transportation, namely, roads and bridges (Plumer, 2013). Since state and local governments, who used to allocate the vast majority of their budget for transportation, have cut back on the spending, there has never been enough investment in this sector to fill the gap.[20] The red line in Figure 3-1 shows the trend of spending on roads and bridges as a percentage of GDP, which clearly indicates a trend in line with that of the total public construction spending.

[20] For instance, California government cut back transportation expenditure by 31% from 2007 to 2009 and so did Texas by 8%. Florida experienced less severe cutback with the decrease in the expenditure by 1.3% during the same period (Source: State expenditure report from the National Association of State Budget Officers).

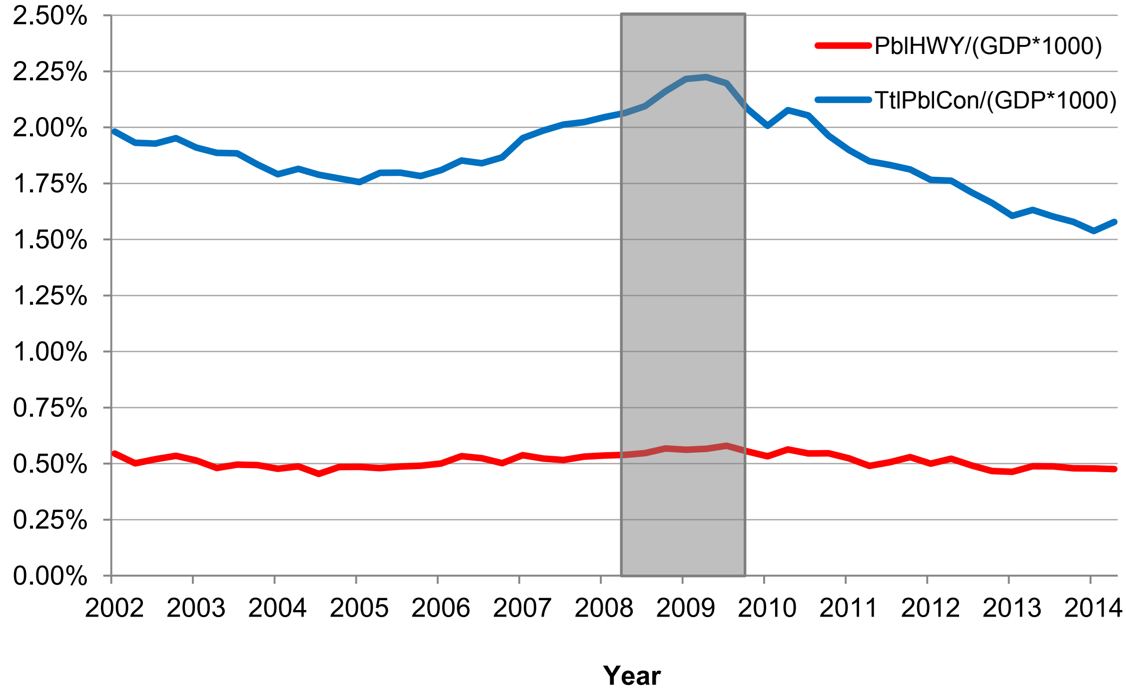

Figure 3-1. U.S. public construction spending relative to GDP

1. PblHwy: Total public construction spending for highway and street (millions of dollars).
2. TtlPblCon: Total public construction spending (millions of dollars).
3. Shaded area indicates the great recession lasted from December 2007 to June 2009[21].
4. Data source: Federal Reserve Economic Data (http://research.stlouisfed.org/fred2)

Recently, we can see a lot of reports calling for improvement in America's infrastructure. A well-known report is from the American Society of Civil Engineers that respectively gave roads and bridges the grades of D and C+ in 2013. While it is still an ongoing debate if governments should spend more money on transportation infrastructure, Florida plans to increase the spending to construct and fix the nation's aging roads and bridges (Van Sickler, 2013).

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[21] U.S. National Bureau of Economic Research, (2012). US Business Cycle Expansions and Contractions, (source: http://www.nber.org/cycles/cyclesmain.html).

2.2 Design-Bid-Build

The delivery of construction projects including road and bridge projects typically involve two major divisions of labor: designing projects and building them according to the designs. The root of the project delivery method is, in fact, Design-Build (DB) that goes back to the master builder approach in ancient Egypt (Perkins, 2009). Until early 1900s, the vast majority of built environment from buildings through landscapes to urban infrastructures had been delivered under the guidance of preeminent professionals known as master builders who were authorized to control the entire design and construction phases of the projects. Interestingly, the so-called "traditional" method is relatively new. Significant research, most of which are sponsored by the American Association of State Highway and Transportation Officials (AASHTO), led to a rapid growth in knowledge on construction materials and methods in the 1920s and 1930s (Minchin, Li, Issa, & Vargas, 2013). This, in turn, required two separate types of professionals, the architect and the general contractor, who are responsible for either design or construction without genuine knowledge about each other's work. As a result of this specialization, a project delivery method named Design-Bid-Build (DBB) had emerged and had been predominant in the procurement of public-sector construction projects for most of the 20th century.

A DBB project goes through three separate phases of design, bidding, and construction in order. A project owner first procures an architect/engineer (A/E) to prepare the design drawings and tender documents of the project, based on which it starts advertising the request for proposal (RFP). The RFP could be open to any interested contractor or often advertised only to a limited number of pre-selected contractors invited to bid. In any case, a contractor is selected via competitive sealed bidding due to the nature of public sector where the virtue of "accountability, transparency, equity, and fair dealing" is highly regarded in the procurement process (Perkins, 2009). Once bids are received, the owner reviews the bidders and their proposals with the assistance of the architect. The owner does not have any obligation to award the contract to the lowest bidder. There are certainly other crucial factors to be considered in the selection process such as past performance and financial stability (FDoT, 2012). But it is customary that the lowest-bidding contractor wins the project in the end. The selected contractor becomes the major source of input in the construction phase, being responsible for managing construction processes or making daily decisions about construction activities. Meanwhile, the role of A/E is reduced to monitoring the progress of work or reviewing change order documents on the owner's side (Molenaar, Songer, & Barash, 1999).

Most of the advantages associated with DBB are from its open and fair processes assured by multiple procurement cycles. It assists owners to make better decision by having a range of options. For designers and general contractors, it offers fair opportunities to participate in the public procurement. Owners can have chances to identify potential contractors from multiple bidders, which are chances for new or less-experienced contractors to enter the public-sector construction market. With respect to performance, owners are able to insure contractors' works to some extent by requiring them to submit surety bonds (Perkins, 2009). In the cases of transportation-related projects in Florida, for example, contractors are required to submit the so-called bid bonds in the bidding process to ensure that "the winning bidder will undertake the contract under the terms at which they bid." Once contracts are awarded, the winning contractors are required to commit themselves to the faithful completion of the contract by furnishing the FDoT with the payment and performance bonds equal to each year's annual contract amount every twelve-month period of the contract[22] (FDoT, 2012).

In traditional DBB where cost is generally the only criterion to determine the contractor, however, no "fast-tracking" process is available (Shrestha, O'Connor, & Gibson, 2012). On top of that, projects delivered by DBB have high potential to involve in costly and prolonged disputes while coping with change orders due to adversarial relationships among contractual parties (Perkins, 2009). Suppose that a design included in the contract failed in the field. If it has to be altered significantly, the original contract also has to be amended to compensate for it. None would want to take the responsibility and pay for it unless it is definite who should. The owner would blame the contractor for mismanagement on the site, whereas the contractor would argue against poor designs by the A/E. The owner, however, cannot perfectly monitor the construction process since it has delegated on-site decision making to the contractor (McAfee & McMillan, 1986: Muller & Tunner, 2005). Suppose also that the owner is not satisfied with the works done by the contractor. The owner may request for changes in scope with extra cost or time as small as possible. The contractor, on the other hand, may request extra payment or time extension by attributing the changes to inadequate specifications by the owner. The negotiation for pricing such changes is asymmetric in that the contractor knows more about the method, cost, and time associated with the changes (Bajari & Tadelis, 2001), leading to conflict between them.

[22] A performance bond is a surety bond required to be issued to guarantee the contractor's obligations to complete the project in strict conformity with the designs, specifications and conditions of the contract. A payment bond is also a surety bond issued to assure that the contractor will pay his subcontractors and suppliers the labor and material costs.

2.3 Design-Build

DB, which is called a "non-traditional" or an "innovative" method, is essentially the same as the ancient master builder approach in the fundamentals. As mentioned earlier, DB differs from DBB in that it involves only one procurement cycle without a clear separation between the design and construction phases. In Florida, for example, once the FDoT decides that delivering a certain project through DB rather than DBB would be beneficial to both the public and the department, it starts developing an RFP package including the design and construction criteria using in-house staffs knowledgeable of the contracting requirements. The design and construction criteria contains key information based on which DB contractors can prepare bid proposals, where a DB contractor may take any form of legal entity comprised of the designer and builder, e.g., firm, partnership, association, joint venture[23]. The prepared RFP is advertised to pre-qualified DB contractors for 60 to 90 days[24]. As soon as the advertisement period ends, the evaluation team starts reviewing the proposals that contain the qualification of contractors (i.e., past experience and performance, and resources), and project approach and understanding of critical issues (i.e., preliminary design, plan for completing the work, etc.). The final selection is made based on the scores weighting criteria or group discussion among the evaluators (FDoT, 2012).

[23] According to the Design-Build guidelines provided by the FDoT, "criteria may include geo-technical analysis, surveying, permitting, right of way mapping, title searches, utility coordination, etc. The design and construction criteria shall state the specifications, design criteria, and standards to be used in the design and construction of the project (FDoT, 2012)."

[24] The FDoT states that "the advertisement will include, as a minimum, the name and description of the project, the District and County location of the project, the major type(s) of work required, any minor types of work that are required for the project (but not normally associated with the major work), the estimated construction cost of the project (if applicable), how and where Design-Build Firms can respond, any additional technical qualifications desired," etc (FDoT, 2012).

The DB method is advantageous to the owner in that the selection process is essentially based on the qualification of contractors rather than based solely on low bid (Molenaar et al., 1999). Also, the method relieves the owner of legal and managerial responsibilities related to design errors as the responsibilities are clearly on the DB contractor (Perkins, 2009). However, perhaps the greatest advantage of DB is its potential to deliver projects more efficiently by integrating the design and construction services effectively. First, there should be a significant time-saving associated with the number of procurement cycle reduced from the DBB method (Songer & Molenaar, 1996). Second, now that the designer and builder are in a collaborative relationship, it is possible to involve construction experts in the design process, resulting in not only a more efficient project plan with respect to material purchase and labor input, but also a more constructible design (Molenaar et al., 1999). Even if there is a need for design change, the relationship allows for adjustment through fluid channels rather than litigations (Perkins, 2009). Finally, construction works can be initiated even without the complete design as long as the design necessary for the groundwork is available, from which substantial time-savings can be expected (Molenaar et al., 1999).

DB also suffers from problems of changes notwithstanding the fact that those associated with design errors and omissions can potentially be decreased as a source of change. According to a study conducted by the U.S. DoT (2006), 81% of the surveyed projects showed the level of preliminary design completion prior to contract award 30% or less with the average of 27%. Since DB projects usually start with a bare minimum of specification rather than a well-defined design and scope, they in fact involve more uncertainties than DBB projects do. Thus many additional changes in design and scope are likely to occur, resulting in project cost growth as the project advances (Ibbs et al., 2003). Another issue comes from the fact that the owner does not participate in the design process once the project is awarded to the contractor. This makes hard for the owner to get informed of the final outcome of the project from the point of contract award. Therefore, DB projects are always accompanied by problems associated with owner-generated changes that arise when the owner does not agree with the design features or scope of the outcome (Riley, Diller, & Kerr, 2005). This type of changes is considered to be particularly damaging if they occur in the late phase of project after the realization of the outcome. Figure 3-2 describes typical bar chart schedules of DB and DBB, and Table 3-1 summarizes comparative features of the two methods discussed so far.

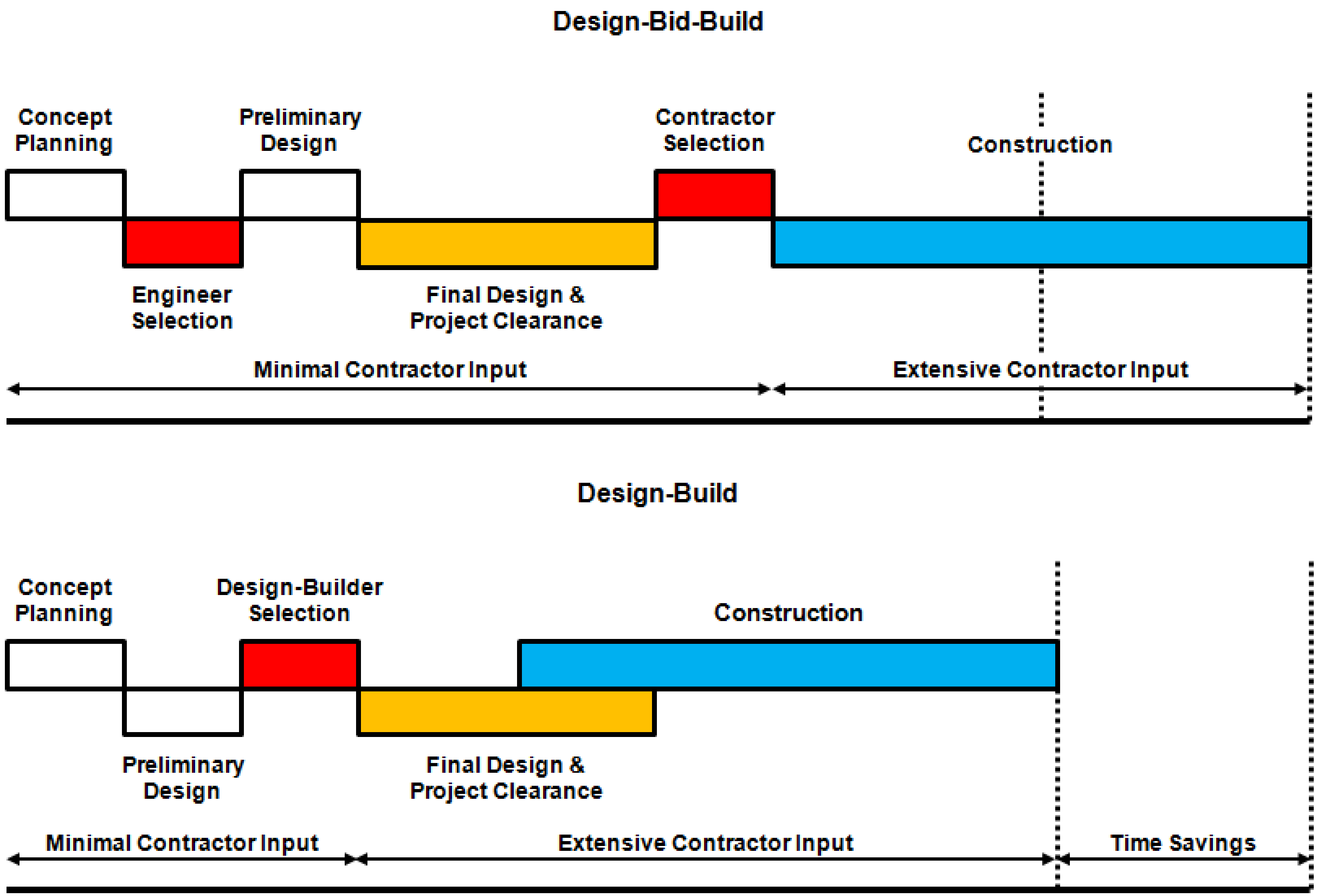

Figure 3-2. Typical bar chart schedules of DB and DBB (Source: Dr. Keith Molenaar, University of Colorado at Boulder)

Table 3-1. Comparison between Design-Bid-Build and Design-Build

Method / Descriptions	Design-Bid-Build	Design-Build
Characteristics	▪ Characterized by two procurement cycles with the separation of design and construction.	▪ Characterized by one procurement cycle with the overlap between design and construction.
Advantages	▪ Best-understood method for all stakeholders from contractual parties to auditors and the public. ▪ Offers open and fair opportunities for more firms to participate. ▪ Can produce highly competitive pricing. ▪ Defines roles and responsibilities for the participants clearly. ▪ Well-suited to projects with straightforward objectives and outcome.	▪ Allows for fast-tracking process. ▪ Relieves the owner of legal and managerial responsibilities related to design errors or designer-contractor relationship. ▪ Can expect a more constructible design owing to early contractor involvement. ▪ Allows for creative design and construction. ▪ Allows for flexibility if project scope needs to be changed.
Disadvantages	▪ No fast-tracking process available. ▪ High potential for change orders due to the low bid. ▪ Adversarial relationships among contractual parties. ▪ Can be difficult to accomplish scope changes. ▪ Can be involved in costly and prolonged legal issues where changes occur. ▪ Encourages cost-cutting; may result in quality loss especially in periods of material-cost inflation.	▪ Limited involvement of the owner. ▪ May result in many owner-generated changes if the owner refuses to accept some uncertainties. ▪ Requires extensive pre-project communication and competent bridging documents. ▪ Cannot guarantee the best designer and contractor combination. ▪ Can be weak in quality control due to owner's limited involvement. ▪ Few legal precedents when problems arises (AIA).

3. Literature Review and Hypotheses

This section reviews the literature related to the choice of contractual arrangement to gain some insights that suggest testable predictions for the choice of public-sector project delivery method. Background information provided in Section 2 suggests two prominent features of DB compared to DBB. First, one entity is authorized to perform the two major tasks of any construction project, enabling close interactions between designers and constructors. Second, construction commences before the final design is complete, enabling schedule compression. Thus, transition from one way to the other is essentially a tradeoff between *ex ante* set-up cost and *ex post* adaptation costs where responsibilities associated with the tasks are also redistributed accordingly. Reviewing the nature of the outcome to be delivered and the characteristics of the parties to be involved allows us to estimate the relative magnitude of these costs, which, in turn, partially answers the question which method to use. Analytic framework proposed for this study is displayed at the end of the review (Figure 3-3).

3.1 Characteristics of projects

In organization theory, Levitt and March (1995) postulate:

> *The problem of organizing is seen as one of transforming a conflict (political) system into a cooperative (rational) one. A conflict system is one in which individuals have objectives that are not jointly consistent. It organizes through exchanges and other interactions between strategic actors. A cooperative system is one in which individuals act rationally in the name of a common objective.*

To create "a cooperative project organization" pursuing a common objective, owners need an appropriate governance structure (Turner et al., 2001). A project delivery method is the structure for owners to organize and finance a process that the components of design and construction are combined to deliver a project, where the components include roles and responsibilities, activities, and resources (Loulakis & Hoffman, 2000; Miller, 1999).

The problem of contract choice has attracted much attention in the economic literature. The primary concern in this literature is how to screen the seller who has superior information on the production costs. Under the assumption of *ex ante* asymmetric information, this literature believes that sellers get to reveal their private information by choosing a particular contract that buyers offered in the bidding process (Bajari et al., 2001). However, the E&C literature suggests the importance of *ex post* adaptation as much as *ex ante* set-up in construction projects. Actually both parties share uncertainty about significant changes in design and specification arising after the contract execution as not all future aspects of works can be envisaged in advance. Thus, the problem of contract choice in the E&C projects is primarily about whether to safeguard against ex post adaptations or to facilitate them.

This notion is well explained in a series of studies conducted by Turner and colleagues who realized that a transaction cost economics (TCE), a widely-accepted theory for contract selection, did not fully explain modern construction projects. While seeking the answer to the question when each type of contracts, e.g., fixed-cost[25], cost-

[25] The contractor is paid a pre-specified price for the entire job regardless of future events.

plus[26], or re-measurement[27], should be used and why, they observed from three case studies that transaction costs were, in fact, very small. Instead, the differences in project outturn costs across different contract types were found to be large, suggesting that contract types need to be flexible enough to cope with uncertainties arising as the project proceeds. Consequently, they argued that contract types need to be chosen according to the level of uncertainty in the project outcome and in the delivery process at least in the context of E&C projects.

Let us translate the decisions on the choice of contract method into economic cost. When contemplating any construction project, the owner must first decide whether to outsource design and construction separately (DBB) or together (DB). The former requires a formal contract with an A/E to develop a complete design and specification (design, hereafter) that explicate the tasks and associated quantity of each work item. On the other hand, the owner simply needs to provide the design criteria using an in-house staff or outside A/E for the latter. Hence, the choice between the two delivery methods can be interpreted as the decision on the degree of design completeness at the outset of the project. A rational owner would pick out a particular delivery method for any given project in a way that reduces the expected cost associated with differing degrees of design completeness.[28]

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[26] The contractor is reimbursed for all the costs plus a stipulated profit margin. The profit margin can be a percentage of the out-turn cost (cost plus percentage fee), or a fixed amount (cost plus fixed fee).

[27] The contractor is refunded their costs at agreed unit rates. The most widely used one is based on a schedule of rates.

[28] In practice, construction usually begins at the point that the design has progressed approximately 30% to complete in DB projects (Green, 2003).

Perhaps the primary costs[29] associated with developing a design is the cost of identifying contingencies that can occur *ex post*, where contingencies would include the type of foundation given the soil conditions on site, alternative materials in case of industry-wise material shortage, a backup plan in case of changes in regulations, and so forth. If it is possible to anticipate all the contingencies *ex ante*, the occurrence of *ex post* changes and resulted renegotiations between the parties can perfectly be prevented. Holding other conditions unchanged, however, the more the contingencies are identified, the higher the cost of initial design is. In the circumstance that the initial design turns out to be inadequate and fails to be realized at some point in the execution, the owner may incur additional costs for renegotiations as well as modifications depending on the party mainly responsible for the defect.

The cost of design never decreases with the increase in the number of contingencies as it takes time, money, and efforts to identify and document them regardless of how trivial they are. Intuitively, the outcome as well as the process of larger project is likely to entail more numerous possibilities than those of smaller one is, demanding more costs to be invested to increase the degree of design completeness. Savings from going with a less complete design will, however, incur extra costs associated with inefficient ex post renegotiations attributed to contingencies that had not been considered during design. Therefore, a rational owner who admits limits to human knowledge and costs of information would seek to save the costs of a large project by facilitating interactions while relaxing ex ante design completeness, deciding on DB.

[29] By cost, I mean not only direct cost, e.g. payments to the A/E, fees associated with field survey, etc., but also indirect cost such as time spent for risk identification, drawing, documenting, and so on (Bajari et al., 2006). Thus, it is reasonable to assume that the cost of specification is positive regardless of what the contingency is (Bajari et al., 2001).

Conversely, the owner will benefit more from protecting against foreseeable hazards by specifying utmost contingencies ex ante if the outcome and the process of a project are relatively simple, preferring DBB.

A similar idea is widely recognized in the literature on contractual selection. For example, Bajari et al. (2001) write that "simple projects (which are cheap to design) will be procured using fixed-price contracts and will be accompanied by high levels of design completeness (that is, a low probability that adaptations are needed). More complex projects will be procured using cost-plus contracts and will be accompanied by low levels of design completeness (that is, a high probability that adaptations are needed)." Turner et al. (2001) also posit that fixed-price contracts would be more appropriate if the owner has a highly predictable project outcome, whereas cost-plus contracts would be a better choice for the owner without a clearly-defined project outcome. Contracts may not perfectly dictate constraints on delivery methods. Yet DBB involves tight contractual agreements with a complete design, whereas DB allows for flexibilities in dealing with adaptations. Hence, it seems reasonable to assume a strong correlation between fixed-price contract and DBB while cost-plus contract with DB. Konchar and Sanvido (1998) in the E&C field actually recognize this and suggest that "the DB project delivery method is more effective in large and complex projects." In sum, the reasoning behind the choice of contracting method may pass through to the choice of delivery method, suggesting DBB should be the choice for smaller projects while DB being for larger ones.

***H1**: The degree of project scope is positively related to the choice of Design-Build over Design-Bid-Build, which involves less degree of design completeness while high degree of managerial flexibility. Specifically, the more expensive the estimated cost of a project is, the more likely that a public owner would choose Design-Build for the delivery method.*

In addition to the nature of project outcome, the possibility of unforeseen circumstances raised by the external environment, e.g., changing economic conditions, generates uncertainties in the delivery process. Crocker and Reynolds (1993) assumed "the task becomes more daunting when the possibilities are more numerous and the time of performance remote." Their empirical analysis on the Air Force engine procurement supports the hypothesis that the higher the level of environmental uncertainty, e.g. technological difficulty or remote time for contract performance, the more likely the owner is to adopt less restrictive arrangements such as fixed-price incentive contracts. In other words, the owner reflects her desire to minimize costs and maximize benefits associated with governing projects by choosing a certain type of contract that not only safeguards against risks identified in advance, but facilitates adaptations arising as events unfold (Crocker et al., 1993). Accordingly, I anticipate that the owner is likely to choose DB for an environmentally uncertain project, e.g., the one in lengthy duration, as the cost of crafting a more complete design ex ante is increasing while additional contingencies being more hypothetical.

H2: *The expected level of environmental uncertainty is positively related to the choice of Design-Build over Design-Bid-Build.*

Specifically, the longer the estimated duration of a project is, the more likely that a public owner would choose Design-Build for the delivery method. Similarly, the more technically-challenging a project is, the more likely that a public owner would choose Design-Build for the delivery method.

3.2 Characteristics of contractors

Once a delivery method is chosen, the owner needs to start searching for a contractor who will actually execute the project. While the owner is responsible for defining the project outcome and providing financial resources, it is the contractor who is authorized to be responsible for daily on site management all the way through the implementation (Gil, 2009). Just because the contractor conducts tasks on behalf of the owner does not necessarily mean the contractor holds the same business interest with the owner. Also, there is information asymmetry between the owner and contractor regarding the optimal cost and method of construction (Bajari et al., 2001). Thus, outsourcing is, by nature, prone to accompany opportunistic behaviors of the contractor. In this case, the owner would be reluctant to hire an unproven contractor to perform a project over which she merely has limited control. Presumably the expected cost associated with managerial opportunism decreases as the degree of design completeness increases (Muller et al., 2005). Besides, large-scale projects usually require more capabilities to be completed. Contractor's collaboration experience with the owner is a part of such capability that reduces potential costs of ex post renegotiations (DBIA, 2014). Thus, I would expect DB to be awarded to a more experienced contractor while DBB to whom with the lowest bid through competitive bidding regardless of the experience.

> ***H3***: *Design-Build projects are more likely to be awarded to more experienced contractors.*
>
> *Specifically, Design-Build projects are more likely to be awarded to contractors who have performed a greater number of projects with the owner.*

Along with the possibility of opportunistic behaviors, contractor's managerial capability also leads to differing level of efficiency over the project execution, where managerial capability encompasses from general administration to resource management. In the case that unintended consequences are likely to arise as a result of incomplete design, a precaution to protect against the unintended is to entrust a contractor from whom a high level of efficiency is predicted. A manifest history of success in terms of managing cost and schedule would be a reliable source of information. The benefit from the increasing level of capability is, however, likely to diminish with increasing level of design completeness (Muller et al., 2005). That being the case, I would anticipate a contractor having a successful collaboration history with the owner to be selected when the project is decided to be delivered by DB all else being equal. This is irrelevant to the selection of DBB contractor, where almost all the time the winner is the lowest bidder. In fact, the construction industry is very competitive (Horta & Camanho, 2014), suggesting contractor selection may be sensitive to past performance if non-financial criteria is allowed to be considered.

H4: *Design-Build projects are more likely to be awarded to more reputable contractors.*

Specifically, Design-Build projects are more likely to be awarded to contractors who have better cost- or schedule- performance in the past projects with the owner.

3.3 Performance comparison between Design-Bid-Build and Design-Build

There are quite a few studies attempting to compare performance of construction projects delivered by DBB or DB (Table 3-2). Although the degrees vary from study to study, DB projects characterized by single procurement cycle and schedule compression in design and construction phases clearly show a schedule advantage over DBB projects regardless of project size or type. With respect to changes in schedule, for example, Konchar and Sanvido (1998) find that schedule growth was 11.4% less in DB projects than in DBB studied. Ibbs et al. (2003) also report that DB projects overall experienced less changes in schedule with the rate of 7.7% compared to 8.4% in DBB projects. Similar results are found from studies by U.S. DoT (2006) and by Shrestha (2007), where schedule growths were less in DB projects than in DBB by 9% and 5.3%, respectively. Finally, Minchin et al. (2013) argue "minimal differences and a slight edge for DB" projects based on various statistical tests conducted.

These results, however, need to be interpreted with caution mainly due to two reasons. First, as can be found in Table 3-2, most of them are based on small-sized, thus, non-representative samples. Second, the interplay of other factors that presumably influenced schedule performance differently under two methods, e.g. project's characteristics, contractor's managerial capabilities and experience, contracting methods, and so on, were not considered at all in those performance comparisons. Yet, I would expect a positive relationship between the choice of DB and schedule performance in line with conspicuous features of the DB method discussed in Section 2 as well as those results from previous studies.

> ***H5**: Design-Build projects are likely to outperform Design-Bid-Build projects in terms of schedule: the choice of Design-Build is likely to be related to less Schedule overrun.*

Regarding cost performance, in theory DB projects should outperform DBB projects as the one-team system offers designer and builder cost-sharing opportunities, The results regarding the link between delivery method and cost performance are mixed, though. Some studies present a finding in common that DB projects showed less cost growths compared to those delivered by DBB (e.g., CII, 1997; Konchar and Sanvido, 1998; Molenaar et al., 1999), others suggest that cost advantage of DB over DBB was unclear (e.g., Ibbs et al., 2003; Hale, Shrestha, Gibson, and Migliaccio, 2009), still others even advocate for DBB with an argument that DBB, rather than DB, is “a more consistent and reliable method in matters of cost” (e.g., US DoT, 2006; Minchin et al., 2013). Meanwhile, Shrestha and his colleagues, who reported a significant lower average cost change in DB projects (-5.5%) than in DBB projects (4.1%) using 15 highway projects in 2007, replicate their study after collecting several more projects in 2012. At this time, however, they failed to obtain a consistent result as the difference in average cost changes was statistically insignificant.

Then why DB projects do not clearly indicate a cost advantage over those delivered with the traditional method? Obviously, the degree of overlap among activities increases as the degree of schedule compression increases. This, in turn, makes the project more complex as the number of activities that the contractor should concurrently handle increases (Love, 2002). Beyond the limited number of activities that a project team can undertake at a time (Hoedemaker, Blackburn, & Van Wassenhove, 1999), a shortened duration may bounce back to the owner in the form of reworks at great expense (Love, 2002). The consequence of this issue may rely on the level of contractor's competence, as is the case with ever-present risks associated with incomplete design at the outset of the project. Therefore, I believe that the choice of DB should be related to a better cost performance if the qualification of contractor is considered. Specifically:

H6*: Design- Build projects are likely to outperform Design-Bid-Build projects in terms of cost when contractor's qualification is considered: the choice of Design-Build is likely to be related to less cost overrun because the choice of Design-Build is likely to be related to the selection of a better-qualified contractor, which, in turn, leads to less cost overrun.*

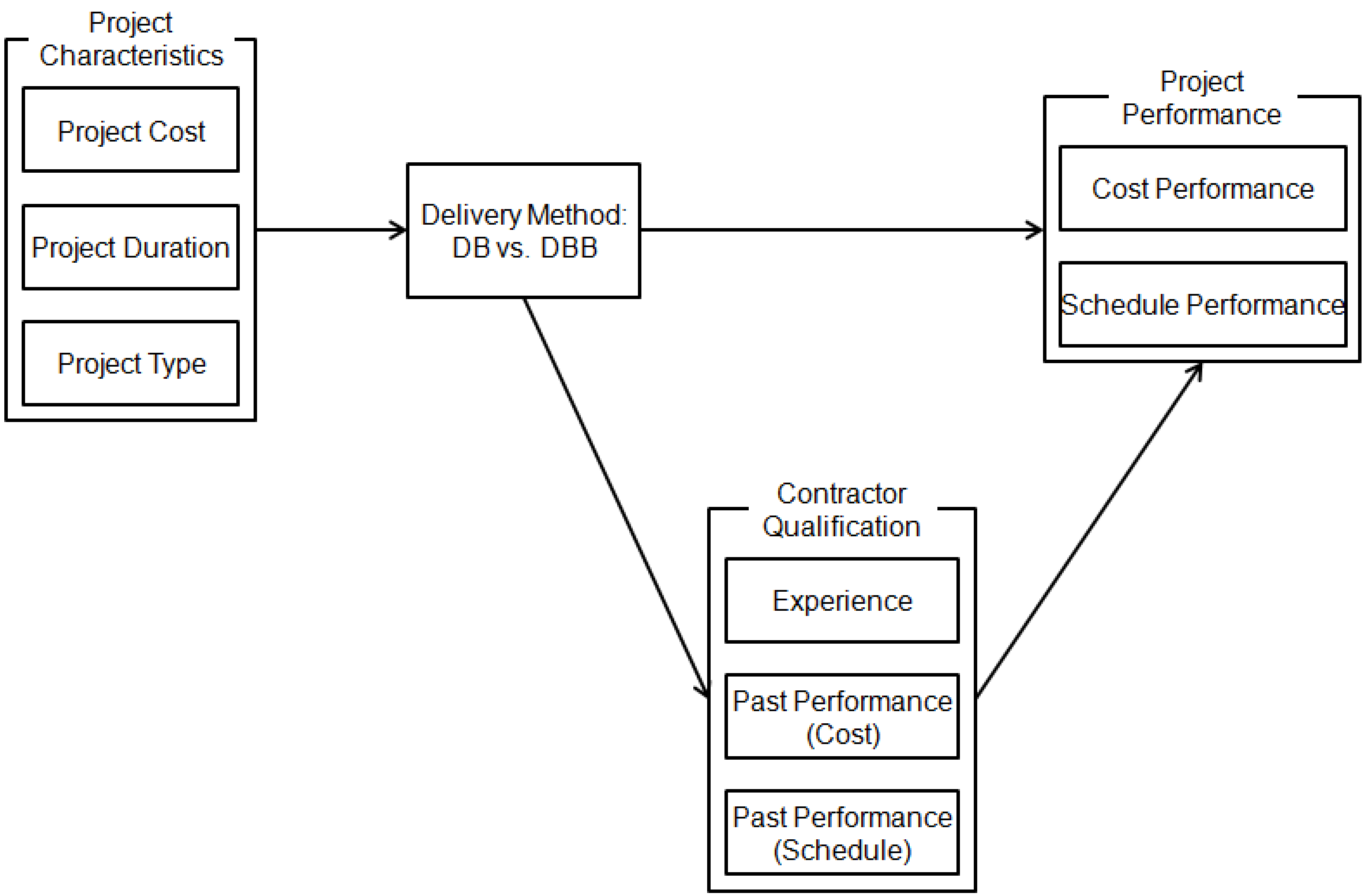

Figure 3-3. Analytic framework of this study

Table 3-2. Overview of the studies comparing performance of DB and DBB methods in construction projects

Authors	Data & Method	Sample size	Project type	Project size	Findings
Songer & Molenaar (1996)	▪ Survey ▪ Independent samples t-test	Respondents: 108	N/A	N/A	▪ Owners choose DB to take advantage of the time savings inherent in the process. ▪ Establishing cost, reducing cost, constructability/innovation, establishing schedule, and reducing claims are considered in the choice of DB.
CII[1] (1997)	▪ Survey ▪ Descriptive statistics	DB: 154 DBB: 116 CM@risk: 81	Buildings	N/A	▪ The median cost growth of DBB and that of DB were 4.8% and 2.2%, respectively. ▪ 49% of DBB projects had design and construction cost growth greater than 5% while 34% of DB projects did.
Songer & Molenaar (1997)	▪ Survey ▪ Interview	Respondents: 88	Buildings Industrial Highways	N/A	▪ The following factors were found critical in successful DB projects: adequate owner staffing, established budget, owner's construction sophistication, shared understanding of scope, and well-defined scope.
Konchar & Sanvido (1998)	▪ Survey ▪ Independent samples t-test ▪ Regression	DB: 154 DBB: 116 CM@risk: 81	Buildings Industrial	N/A	▪ Construction speed was at least 12% and 7% faster in DB projects than in DBB and in CM@Risk projects, respectively. ▪ Delivery speed was at least 33.5% and 23.5% faster in DB projects than in DBB and in CM@Risk projects, respectively. ▪ Cost growth was 5.2% and 12.6% less in DB projects than in DBB and in CM@Risk projects, respectively. ▪ Schedule growth was 11.4% and 2.2% less in DB projects than in DBB and in CM@Risk projects, respectively.
Gransberg & Senadheera (1999)	▪ Survey	Respondents: 15 DoTs	Highways	N/A	▪ A careful analysis of the project must be made before deciding on a DB system and all possible contracting methods should be also considered in accordance with DB. ▪ Qualification -basis contactor selection will increase the probability that the project will be completed successfully.
Molenaar et al. (1999)	▪ Survey	Respondents: 104	N/A	N/A	▪ 59% of DB projects were completed within at least 2% of budget. ▪ 77% of DB projects were completed within at least 2% of schedule.

Table 3-2. Overview of the studies comparing performance of DB and DBB methods in construction projects

Authors	Data & Method	Sample size	Project type	Project size	Findings
Chan et al. (2002)	▪ Survey ▪ Regression	Respondents: 53	Buildings	N/A	▪ Project team commitment, client's competencies, and contractor's competencies are important to the success of DB projects. ▪ Contractor's competencies contributed to project time performance.
NIST[2] (2002)	▪ Survey ▪ Correlation	DB: 210 DBB:116	Industrial	N/A	▪ DB projects had significant less schedule growth, change orders, and reworks than DBB projects did.
Ibbs et al. (2003)	▪ Survey ▪ Regression	DB: 24 DBB: 30 Others: 13	Buildings	Total cost: $25 - $75 million	▪ Cost advantage of DB over DBB was not clear. ▪ DB projects experienced fewer changes in schedule than DBB projects (7.7% versus 8.4%).
Ling et al. (2004)	▪ Survey ▪ Regression	DB: 33 DBB: 54	Buildings	Original contract value > $5 million	▪ Gross floor area of the project is the most significant factor affecting the speed of both DB and DBB projects. ▪ The following variables are significant in predicting the speed of DB projects: level of project scope completion when bids are invited, extent to which the contract period is allowed to vary during bid evaluation, and level of design completion when the budget is fixed.
Riley et al. (2005)	▪ Survey ▪ Descriptive statistics	DB: 65 DBB: 55	Mechanical	Original contract value >= $50,000	▪ The results indicate advantages of DB over DBB in cost control. ▪ The average size of all change orders was found to be 50% smaller and cost growth due to change orders was found to be 71% smaller in DB projects. ▪ The average size of unforeseen changes was found to be 77% less and cost growth due to unforeseen changes was found to be 98% less in DB projects.
Warne (2005)	▪ Descriptive statistics	DB: 21 DBB: 39	Highways	Total cost: $83 - $1,300 million	▪ 76% of DB projects were completed ahead of schedule. ▪ 100% of the comparable projects were built faster using DB.
US DoT (2006)	▪ Survey ▪ Descriptive statistics	DB: 11	Highways	Total cost: $5 - $20 million	▪ Cost growth was 3.8% more in DB projects than in DBB projects. ▪ Schedule growth was 9% less in DB projects than in DBB projects.

Table 3-2. Overview of the studies comparing performance of DB and DBB methods in construction projects

Authors	Data & Method	Sample size	Project type	Project size	Findings
Shrestha et al. (2007)	▪ ANOVA	DB: 4 DBB: 11	Highways	Total cost > $50 million	▪ Cost growth of DB projects was 9.6% less than that of DBB projects. ▪ Schedule growth of DB projects was 5.3% less than that of DBB projects.
Hale et al. (2009)	▪ ANOVA	DB: 38 DBB: 39	Military facilities	N/A	▪ DB projects were significantly superior to DBB projects in terms of schedule performance. ▪ Cost advantage of DB over DBB was unclear.
Perkins (2009)	▪ Independent samples t-test	DB: 14 DBB: 20	Housing[3] Industrial Other[4]	Average cost: $15.9 million	▪ DB projects had less construction cost growth. ▪ There are fewer and less costly changes, especially the lower number and cost of engineering changes, in DB projects.
Shrestha et al. (2012)	▪ ANOVA	DB: 6 DBB: 16	Highways	Total cost > $50 million	▪ In cost-related metrics, no significant difference in means was found. ▪ DB projects were found to be constructed and delivered faster than DBB projects.
Minchin et al. (2013)	▪ Independent samples t-test ▪ Mann-Whitney U-test	DB: 30 DBB: 30	Bridges Roads	Original contract value >= $7 million	▪ DBB was found to be the same or superior to DB in terms of cost performance. ▪ DB showed little or no difference from DBB in terms of schedule performance.

1. Construction Industry Institute
2. National Institute of Standards and Technology
3. This includes barracks and dormitory as well as family housing.
4. This includes utilidor, ordinance ranges, animal kennels, a flight simulator, and a physical fitness center.

4. Data and Analytic Method

4.1 Data

4.1.1 General description

The data includes construction and maintenance projects of road and bridge works in Florida let and completed between the years of 2001 and 2010. In addition to cost and time reports publicly available on the website,[30] the spreadsheets containing basic information on the projects as well as contractors are gained from the State Construction Office in the FDoT. The projects are advertised and awarded by either the central contract administration office or the District Contract Offices,[31] of which only those by the district offices are addressed in this study as the FDoT has let all their D/B projects through the district offices ever since D/B method was authorized for federal projects based on the Federal Acquisition Reform Act in 1996. The total number of projects studied is 1,512.

The unit of analysis in this study is a roadwork project under which information on project characteristics, project outcomes, contractor characteristics, and the form of the delivery method (D/B/B or D/B) is available. Specifically, project characteristics include a description of the work to be executed, and the project value and duration estimated by FDoT's project engineers, while actual cost and duration, the number of change orders, extra costs and durations caused by change orders are provided for the variables representing project outcomes. In addition, the data contain identification

[30] The cost and time reports are posted on the following webpage: (http://www.dot.state.fl.us/construction/CONSTADM/reports/cost&timeNEW/ConstructionOfficeReport.shtm).

[31] The FDoT consists of a total of 8 District Contracts Offices, each of which handles most of the construction contracts less than $10 million and maintenance contracts. According to a specialist in the State Construction Office, that is simply a function of how the organization is decentralized.

numbers of the general contractors that had performed the projects as well as their prequalification status, which allows for the analyses on the dynamics behind the choice of the contractor conditioned on the delivery system.

4.1.2 Summary statistics

Table 3-3 and Figure 3-4 present the distribution of delivery methods based on the year let. During the period, an absolute majority of the projects (83%) had been delivered by D/B/B, while the projects delivered by D/B account for just about 17% of the total.[32] However, the proportions of D/B projects, which had been consistently around 10% until 2008, have displayed a sharp increase starting from 2009. Apparently, the increase is mainly attributable to the increase in the number of DB Minor[33] projects. According to a construction administration specialist in the FDoT, the primary reason for the spike is related to how the Department delivered its American Recovery and Reinvestment Act (ARRA) projects. The FDoT has seen funding advancements for those projects and determined one of the best ways to deliver them to be D/B.

Table 3-3. Distribution of delivery methods by letting year

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
DB	12	29	18	12	26	15	17	12	56	58	255
	(7%)	(16%)	(10%)	(8%)	(16%)	(12%)	(13%)	(10%)	(34%)	(43%)	(17%)
DBB	157	159	157	140	141	110	112	114	109	79	1278
	(93%)	(84%)	(90%)	(92%)	(84%)	(88%)	(87%)	(90%)	(66%)	(57%)	(83%)
Total	163	179	174	150	167	125	128	125	165	136	1512

[32] These proportions are based on the number of projects let by the District Contract Offices only. Projects let by the State Construction Office are not considered as they are not included in the analysis.

[33] What distinguishes between DB Major projects and DB Minor projects is whether the estimated cost is $10 million or more or less than $10 million. Also, DB Minor projects are accounted for in the annual innovative contracting statutory cap ($120 million) that prohibits the Department from entering more than $120 million in contracts annually (FDoT, 2012).

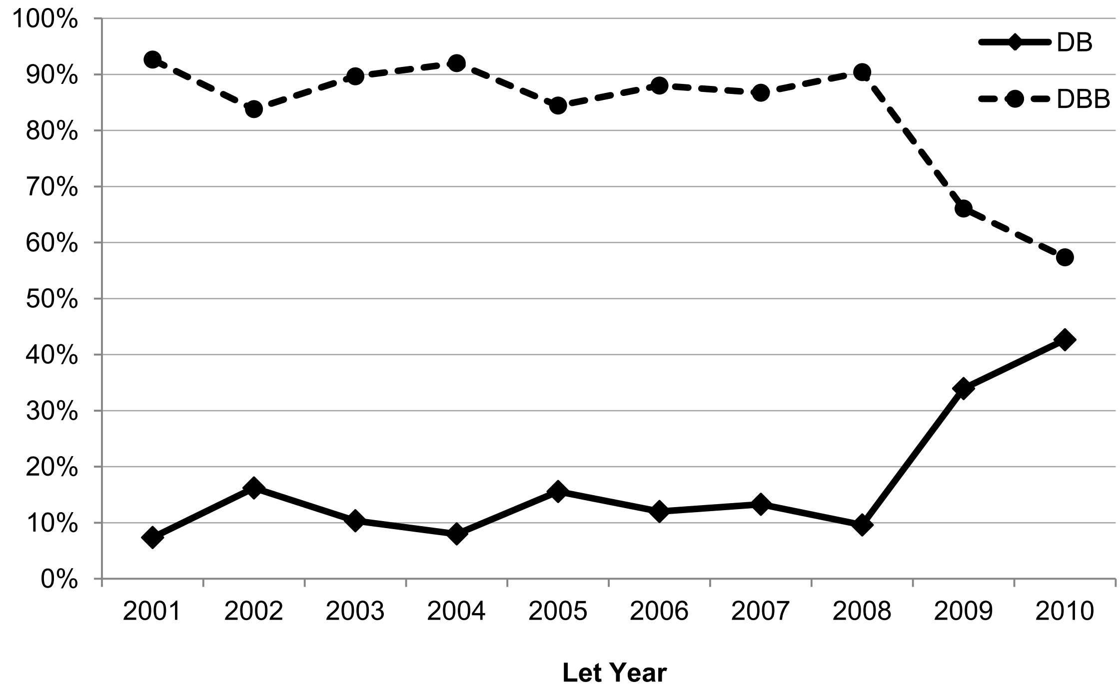

Figure 3-4. The proportion of projects by the delivery methods

Table 3-4 summarizes the distributions of project costs and durations, where project cost is represented by the original contract amount instead of engineer's estimate because the estimates of some projects in the early 2000s are not available. The statistics indicate that the data consist of a diverse set of projects. Project cost ranges from $4,000 to $243 million with the average of around $3.4 million and the standard deviation of $12 million. The distribution of durations also confirms a great deal of heterogeneity across projects. Meanwhile, the joint distribution of the costs versus delivery methods shows that projects delivered by D/B are overall more expensive than those by D/B/B. In terms of schedule, it is apparent that D/B bids had been awarded to the projects requiring relatively long durations regardless of the costs based on which we can get a sense that the FDoT desired to expedite the project deliveries by using the D/B method.

Table 3-4. Distribution of project size

	Total		DBB		DB	
	Cost	Duration	Cost	Duration	Cost	Duration
Average	$3,361,432.88	189	$2,006,742.06	151	$10,039,261.74	378
Std.Dev.	$11,961,227.14	201	$7,113,707.85	162	$23,388,400.40	261
Min.	$4,000.00	10	$4,000.00	10	$24,447.22	60
Median	$510,912.13	120	$384,512.47	100	$2,673,642.28	310
Max.	$242,787,000.00	1,622	$96,822,143.45	1,622	$242,787,000.00	1,592

Table 3-5 presents the distribution of the number of projects performed by each contractor in the data. Nearly 50% of the contractors conduct only one project with the FDoT as a general contractor. This is consistent with the reports from other studies, e.g., Bajari and Ye (2003), and Bajari et al. (2014), and reflects an extremely competitive situation of the construction industry that can be characterized by high entry and exit rates of the contractors due to the low entry costs. On the other hand, the number of contractors who had delivered D/B projects for the FDoT is quite low, implying that there are not a fair number of contractors who are capable of providing integrated design and construction services. Given that the FDoT is considered one of the most pioneering owners in the transportation sector, the lack of capable D/B contractors may be an issue from which a lot of owners in the sector are commonly suffering.

Table 3-5. Distribution of contractors by number of jobs done

# of jobs	DBB	DB	Total
1	169	46	179
2-5	109	35	119
6-10	27	10	32
11-20	17	3	19
> 20	11	0	17
Total	333	94	366

4.2 Analytic model and variables

To evaluate the hypotheses that describe the relationships among a series of decisions and the consequential performance in the project delivery process, this study uses discrete choice models as well as ordinary least squares (OLS) regressions. First of all, the choice of delivery method as a function of project characteristics is analyzed using the following binary logistic regression:

$$P(DELIVERY_i = 1) = \Phi(\alpha + \theta CHAR_i), \quad (1)$$

where P denotes the probability, $DELIVERY_i$ is an indicator function of project delivery method, and ϕ denotes the logistic function. $DELIVERY_i$ takes the value of 1 if a project is determined to be delivered with DB. Independent variables, $CHAR_i$, are project-specific characteristics that are supposed to proxy for the size, the extent of scope, and the level of environmental uncertainty associated with each project. Specifically, the size is represented by original contract amount and original contract days (both in the natural logarithmic scale). In particular, original contract days are expected to capture varying levels of environmental uncertainty on top of the size as a project with a longer execution period is more likely to be influenced by changing external conditions in material prices, exchange rates, laws and permits, and so on. Finally, projects are grouped into 8 types depending on the structure to be built and the work to be performed (i.e., new construction, reconstruction, and maintenance). This categorical variable, $TYPE_i$, is included in the model to proxy for the extent of scope.

Next, the relationship between the delivery method chosen for a particular project and the qualification of the contractor to whom the project was awarded is examined using both OLS and logistic regressions. Three dependent variables measuring contractor's qualification are utilized: 1) the cumulative number of FDoT projects a contractor had performed prior to the current one; 2) mean cost performance from the past FDoT projects; and 3) mean schedule performance from the past FDoT projects. The first variable, which is named as $EXPERIENCE_i$ in the model, is an ordinal variable, where $EXPERIENCE_i = 2$ if a contractor had performed at least three projects, $EXPERIENCE_i = 1$ if one or two projects, and $EXPERIENCE_i = 0$ if none. I regress this variable on $DELIVERY_i$ and the three project-characteristics variables using an ordered logistic regression. The model passed a chi-square test for proportional odds that assumes the effect of the predictors to be identical across different levels. The general form of the regression equation is as follows:

$$P(EXPERIENCE_i = 2) = \Phi(\alpha + \theta_1 DELIVERY_i + \theta_2 CHAR_i) \quad (2)$$

The second and third variables are the averages of proportional increases in project cost and in project duration from the past FDoT projects, where the baselines are respectively original contract amount and original contract duration. These variables are measured following the way that FDoT evaluates cost- and schedule performance of their own projects (FDoT, 2012). I assign 1 to both of the variables for a contractor who had no prior experience, signifying a neutral status without either good or bad indication. These dependent variables are separately regressed on the same set of independent variables with the ordered logistic model described above. The general form of the OLS regression models is shown in the following equation:

$$PAST\ PERFORMANCE_i = \beta_0 + \beta_1 DELIVERY_i + \beta_2 CHAR_i + \varepsilon_i \quad (3)$$

Finally, a series of OLS models are used to compare the performance of DB and DBB projects in terms of cost and schedule. In doing so, five performance measures are derived for each element to identify where each type of projects were generally in trouble with meeting the objectives. The first measure of cost performance compares FDoT's budget estimate to original contract amount, which reflects the difference in the estimated project costs between the public-sector owner and the private-sector contractor[34]. The second measure is the difference between original and adjusted contract amounts. By this one, we can see under which delivery method costs associated with change orders were controlled better. Thirdly, total production cost that is paid to the contractor is compared to original contract amount to see how accurate the originally agreed production costs were and under which method production costs were controlled better. Lastly, two components, the difference between FDoT's actual expenditure and original contract amount and the difference between FDoT's actual expenditure and production cost, are computed to account for the amount incurred above and beyond production cost, which mainly consists of costs for preliminary engineering, bid and contract administrations, fees and taxes, ancillary studies, and so forth.

[34] Perhaps bid amounts is a better measure for contractor's project cost estimate. However, this study uses original contract amount that can be considered an adjusted budget based on contractor's bid amount as the use of bid amount significantly drops the number of observation available for the analyses.

In a similar manner, schedule performance is decomposed into five measures. First, the number of days from bid let to contract execution is calculated to see if there is any difference in the amount of time that the owner invested to prepare for each type of project. To explain overall amount of time saved by design-construction compressions in DB projects, the numbers of days from bid let to work begin for both types of projects are obtained as the next measure. The third one compares original and adjusted contract days, based on which we can learn which method is more effective in handling schedules associated with change orders. Then the difference between original contract days and actually-used days is measured to check under which method project schedule was controlled better over the project execution. To capture the amount of schedule overrun mainly attributed to managerial inefficiency, the increase from adjusted contract days to actually used days is employed as the fifth measure of schedule performance.

Measures for cost and schedule performance introduced so far are separately regressed on contractor's level of experience and project characteristics as well as the chosen delivery method. Note that estimations are conducted with or without $EXPERIENCE_i$ to test if $EXPERIENCE_i$ suppresses the relationship between $DELIVERY_i$ and $OVERRUN_i$ following the method proposed by Baron and Kenny (1986). The regression models can collectively be written as Equation (4):

$$OVERRUN_i = \beta_0 + \beta_1 DELIVERY_i + \beta_2 EXPERIENCE_i + \beta_2 CHAR_i + \varepsilon_i \tag{4}$$

For all the specifications, $LETYEAR_i$ and $DISTRICT_i$ are included as control variables. $LETYEAR_i$ is used to control for the variations attributed to macroeconomic conditions, which is 1 if a project was let in 2008 and 0 otherwise considering the great recession in 2008 affecting the construction industry immensely. Also, projects in the sample are let by 8 different districts, implying a potential bias from owner's characteristics, e.g., administrative policies, experience, spatial locations, and so on. To control for these variations, $DISTRICT_i$ is included in the models. All the variables used in the analyses are summarized in Table 3-6.

Table 3-6. List of variables

Outcome variables		Mean	S.D.
$COST1_i$	=Difference between budget and original contract amount	-9.10%	27.92
$COST2_i$	=Difference between original and adjusted contract amount	3.37%	13.68
$COST3_i$	=Difference between original contract amount and production cost	-0.32%	15.23
$COST4_i$	=Difference between original contract amount and DoT's expenditure	-0.81%	20.29
$COST5_i$	=Difference between production cost and DoT's expenditure	0.02%	4.72
$SCHEDULE1_i$	=Number of days from letting date to contract execution date	38.16	19.23
$SCHEDULE2_i$	=Number of days from letting date to work begin date	101.44	55.53
$SCHEDULE3_i$	=Difference between original and adjusted contract days	21.50%	37.59
$SCHEDULE4_i$	=Difference between original contract days and actual days	14.94%	50.32
$SCHEDULE5_i$	=Difference between adjusted contract days and actual days	-6.84%	22.85

Exogenous variables		Freq.	%
$DELIVERY_i$	=0 if a project was delivered by Design-Bid-Build	1,257	83.13
	=1 if a project was delivered by Design-Build	255	16.87
$EXPERIENCE_i$	=0 if a contractor has no history of collaboration with the FDoT	260	17.20
	=1 if a contractor had performed 1 or 2 projects with the FDoT	220	14.55
	=2 if a contractor had performed more than 2 projects with the FDoT	1,032	68.25
		Mean	S.D.
$PASTCST_i$	=Mean difference between original contract amount and actual expenditure from the previous projects	1.07	0.3862
$PASTSCH_i$	=Mean difference between original contract days and actually used days from the previous projects	1.34	6.6384

Table 3-6. List of variables

Exogenous variables		Freq.	%
$COST_i$	=Original contract amount of each project (in a logarithmic scale)	13.29	1.76
$DURATION_i$	=Original contract days of each project (in a logarithmic scale)	4.82	0.92
$TYPE_i$	=0 if Type = 1 (Road Maintenance)	305	20.17
	=1 if Type = 2 (Road Construction or Reconstruction)	210	13.89
	=2 if Type = 3 (Bridge Maintenance)	343	22.69
	=3 if Type = 4 (Bridge Construction or Reconstruction)	27	1.79
	=4 if Type = 5 (Intelligence Transportation System Installation)	95	6.28
	=5 if Type = 6 (Miscellaneous Structures Maintenance)	129	8.53
	=6 if Type = 7 (Miscellaneous Structures Construction)	346	22.88
	=7 if Type = 8 (Facility Construction or Renovation)	57	3.77

Control variables		Freq.	%
$LETYEAR_i$	=1 If a project was let in 2008 (the time of financial crisis)	125	8.27
	=0 Otherwise	1,387	91.73
$DISTRICT_i$	=0 if a project was let by District 1	215	14.22
	=1 if a project was let by District 2	299	19.78
	=2 if a project was let by District 3	192	12.70
	=3 if a project was let by District 4	150	9.92
	=4 if a project was let by District 5	176	11.64
	=5 if a project was let by District 6	129	8.53
	=6 if a project was let by District 7	167	11.04
	=7 if a project was let by District 8	184	12.17

5. Results and Discussion

This section presents and discusses the results of hypotheses testing in three separate subsections. The first two subsections focus on the two sequential decisions that owners need to make on their projects, namely, the choice of delivery method and the choice of qualified contractor. And they are followed by the last subsection that examines the consequences of those decisions in terms of project cost- and schedule performance.

5.1 Choosing the delivery method

I start the evaluation of the hypotheses using a discrete choice econometric model. The question, what type of project a public owner is likely to employ one method or the other, is analyzed by logistic specification that regresses the choice of delivery method on the variables representing project characteristics such as original contract amount and duration, the types of structures and works to be performed. Here, the event of the binary dependent variable ($y_i = 1$) is defined as the case that the owner chooses DB over DBB. Table 3-7 presents parameter estimates from the logistic regressions before and after including control variables. All three measures of project characteristics appear to have significant relationships with the likelihood of selecting the DB method while original contract amount and the type of project showing interesting results with respect to the directionalities of the parameter estimates.

Specifically, the parameter estimate associated with the intercept is -8.78, the definition of which is the estimated logit[35] for a Road Maintenance project with 0 cost and 0 duration. For one unit increase in the original contract duration, the logit will increase by 1.63 (without holding all the other variables constant), while the logit will decrease by 0.10 for one unit increase in the original contract amount (before controlling for all the other variables in the model). Since the smallest-sized project in the data is a road maintenance project with the original contract amount of $4,000 and the original contract duration of 10 days, it would be more realistic to interpret that the estimated logit for the reference group is -5.35. Thus, the odds of choosing DB over DBB for the

[35] Odds in the logarithmic scale, where odds = $\hat{\pi}/(1-\hat{\pi})$ when $\hat{\pi}$ is the probability of an event to occur.

reference group is approximately 0.0047[36], meaning that it is very unlikely for the FDoT to deliver a small-sized road maintenance project using the DB method.

Looking into each variable, the chance that a project will be delivered by the DB method is predicted to increase with estimated duration getting longer. The coefficient for the natural log of original contract duration is 1.63, which means that there is a 410% increase in the odds with every percent increase in duration. Although the coefficients slightly vary, I can see that this positive relationship between the estimated project duration and the likelihood of choosing DB is robust to changes in specifications, such as ruling out any potential variations attributed to external economic conditions. This sizable positive effect may reflect owner's desire to achieve the objective of time by compressing design and construction schedules.

Meanwhile, the small, but negative coefficient associated with original contract amount implies that a higher estimated cost does not necessarily lead to the choice of DB. Theoretically DB can be more suitable for more expensive projects that are generally more complex and hard to be administered as discussed in Section 3. According to the industry literature, practitioners also seem to be well aware of this (NIST, 2002; Molenaar et al., 1998). Failure in supporting the hypothesized relationship may be attributable to the huge difference in sample sizes between DB and DBB projects in the data. However, from the review of the industry literature that reveals the extensive use of DB for medium or smaller (<$50 million) projects (USDoT, 2006), it is my impression that owners would rather not choose DB for too expensive projects. It would be hard for

[36] $\text{Odds} = e^{(b_0+\sum_{i=1}^{4} b_i X_i)}$ and $\text{Probability} = e^{(b_0+\sum_{i=1}^{4} b_i X_i)}/\{1 + e^{(b_0+\sum_{i=1}^{4} b_i X_i)}\}$ (Neter, Wasserman, & Kutner, 1989).

owners to find an established contractor who has deep pocket enough to compete for a large project while being capable of providing adequate levels of design and construction services. I conjecture that owners, particularly those from the public sector, may not be bold enough to deliver large projects by DB under which they have limited involvement from design to quality control. My data supports FDoT's active use of DB for less expensive projects (see Figure 3-5 and Table 3-8), whereas it does not allow me to provide any further insight regarding this phenomenon.

Turning to the type of projects, the result identifies the following three types indicating significantly higher chance to be delivered by DB[37]: new- or re-construction of bridges (Type 4); installation or upgrade of ITS (Type 5); and construction of miscellaneous structures (Type 7). Construction or maintenance of facilities (Type 8) and new- or re-construction of roads (Type 2) also show higher chances to be delivered by DB than the reference group, while the coefficients are significant at 10% level. Specifically, the coefficient for Bridge construction projects is the largest with the value of 1.26, which is equivalent to 3.51 in odds scale. This means that the odds of being selected as a DB project are roughly 2.5 times higher for bridge new- or re-construction projects than for road maintenance projects. ITS projects follow with the odds roughly 1.8 times higher than those of the baseline projects. In contrast, projects performing maintenance of bridges (Type 3) or of miscellaneous structures (Type 6) show lower probabilities of being delivered under DB with the odds of 0.25 and 0.63, respectively.

Although the results clearly reveal FDoT's DB selection criteria, not all of them appear as expected. For instance, the results associated with Type 4 and Type 5 can be

[37] Road maintenance projects (e.g., resurfacing) are the most frequently observed type in the data, as such it was set to be the reference group of the categorical variable representing the type of project.

assumed to support the hypothesis, suggesting a positive relationship between the choice of DB and the measure of scope, given that those projects usually involve complex processes with higher level of technical challenges than other roadwork projects do (Gkritza & Labi, 2008). On the other hand, higher odds for Types 7 and lower odds for Type 3 are quite unexpected. It is often suggested in the industry guidelines that DB is appropriate for projects with high potential for innovation in the process or those without major unknowns, serious utility relocations or subsoil problems, significant right-of-way acquisitions or complex environmental permitting requirements (FDoT, 2012). While these guidelines does not help clarify the inconsistency in the decisions, it leads me to suspect that public transportation agencies like FDoT focus more on mitigating negative externalities for surroundings than on maximizing benefits from innovative processes. Urban projects are actually subject to approval by the state design engineer to be delivered by DB in Florida, which is in line with the suspicion. Unfortunately, the data do not contain the information on the project location that might have enabled me to explore the mechanism behind the choice in further detail.

Results are overall robust even after controlling for potential effect of economic condition and variations from district to district. Significantly negative coefficients associated with let year indicate that DB was less used during the nation-wide financial crisis. In terms of the institutions governing project deliveries, significant variations are found in the likelihood of using DB across districts. Since this is beyond the scope of this study, however, I leave a more detailed discussion on public entity in the project management role for future research.

Table 3-7. Results of logistic regressions for delivery method (DBB = 0, DB = 1)

Dependent Variable: Delivery Method	1	2	3	4
Cost	-0.1039	-0.1033	0.0849	0.0946
	(0.211)	(0.216)	(0.389)	(0.347)
Schedule	**1.6283**	**1.6231**	**1.7960**	**1.7866**
	(<.001)	(<.001)	(<.001)	(<.001)
Type 2	**0.4689**	**0.4752**	**0.6393**	**0.7136**
	(0.083)	(0.079)	(0.036)	(0.021)
Type 3	**-1.3952**	**-1.388**	**-1.6308**	**-1.5927**
	(<.001)	(<.001)	(<.001)	(<.001)
Type 4	**1.2569**	**1.2828**	0.8233	0.8655
	(0.01)	(0.008)	(0.157)	(0.135)
Type 5	**1.0123**	**1.0754**	**2.2788**	**2.4158**
	(0.001)	(0.001)	(<.001)	(<.001)
Type 6	-0.4569	-0.4558	-0.5647	-0.5693
	(0.308)	(0.310)	(0.230)	(0.229)
Type 7	**0.5534**	**0.5472**	**0.6938**	**0.7060**
	(0.034)	(0.037)	(0.016)	(0.015)
Type 8	**0.6792**	**0.6586**	**0.9037**	**0.9046**
	(0.077)	(0.088)	(0.045)	(0.048)
Let Year		**-0.8429**		**-1.2142**
		(0.021)		(0.005)
District 2			-0.7063	-0.7065
			(0.016)	(0.017)
District 3			0.6576	0.6449
			(0.054)	(0.059)
District 4			-0.9475	-0.9418
			(0.006)	(0.007)
District 5			0.2783	0.2956
			(0.441)	(0.420)
District 6			-2.6031	-2.6478
			(<.001)	(<.001)
District 7			-1.6474	-1.6198
			(<.001)	(<.001)
District 8			-3.3762	-3.465
			(<.001)	(<.001)
Constant	**-8.7792**	**-8.7100**	**-11.5177**	**-11.5492**
	(<.001)	(<.001)	(<.001)	(<.001)
Likelihood Ratio	400.8694	406.9726	558.4477	567.8922
Adjusted R-squared	0.3905	0.3956	0.5177	0.5250
Observations	1512	1512	1512	1512

Table 3-8 Distribution of project cost (Design-Build projects only)

Project Cost	Frequency	Percent	Total cost	Average cost
< $2 Million	110	43.1%	$ 75,093,248.81	$ 682,665.90
$2 - 10 Million	88	34.5%	$ 423,483,585.60	$ 4.812.313.47
$10 - 50 Million	47	18.4%	$ 1,064,804,633.00	$ 22.655.417.72
$50 - 100 Million	7	2.7%	$ 458,078,277.60	$ 65.439.753.95
> $100 Million	3	1.2%	$ 538,552,000.00	$ 179.517.333.30
Total	255	100.0%	$ 2,560,011,745.00	$ 10,039,261.74

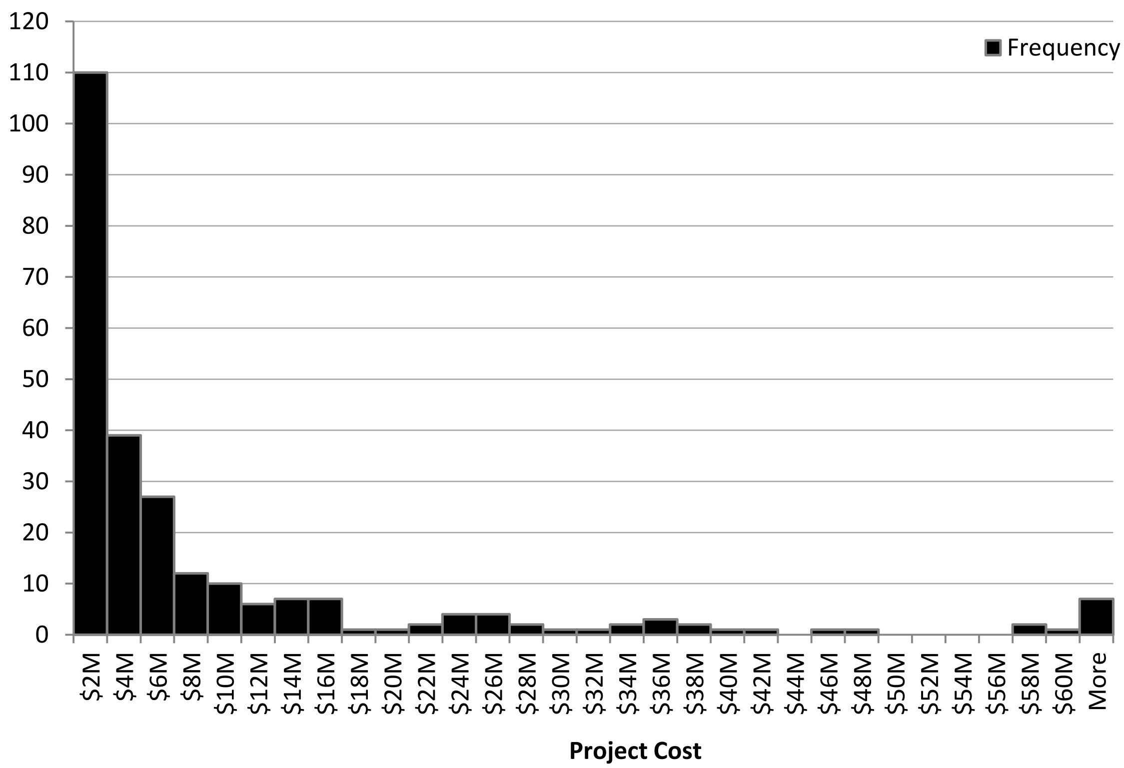

Figure 3-5. Distribution of Project Cost (Design-Build Projects Only)

5.2 Choosing the contractor

Once a delivery method is determined for a given project, owner's next step is selecting the best contractor. This section reports parameter estimates from a series of ordinary least square (OLS) and ordinal logistic specifications to see if the data can shed light on the relationship between the delivery method and contractor's qualification. Notice that the type of delivery method chosen is now an independent variable because the choice precedes the selection of contractor while being independent of the set of available contractors. Also note that for contractor's qualification, three proxies are used as the dependent variables: cumulative number of FDoT projects; average cost performance from previous projects; and average schedule performance from previous projects, where the first one is an ordinal variable as described in Section 4.3.

Table 3-9 presents estimates from proportional odds model for ordinal logistic regressions, where the dependent variable is an ordinal variable based on the cumulative number of FDoT projects that a contractor had performed prior to the current one. We see significantly positive coefficients associated with the delivery method across specifications (except for the case that only Let Year dummy is included in the model as a control variable). Thus, going from DBB to DB, the odds of winning a project is 53% higher for contractors with experience of more than 2 FDoT than those of at most 2 projects given that all of the other variables in the model are held constant. Because of the proportional odds assumption[38], the same amount of increase (53%) is found between no collaboration and the combined category representing at least 1 collaboration, supporting the hypothesis that awarding a DB project is likely to lead to selecting a contractor with the history of more frequent collaborations.

[38] All specifications passed chi-squared tests for the proportional odds assumption required for describing cumulative models.

Table 3-9. Results of logistic regressions for collaborations (None = 0, 1 or 2 = 1, >2 = 2)

Dependent Variable: # of Collaborations	1	2	3	4
Delivery	**0.3302**	0.2857	**0.4800**	**0.4269**
	(0.066)	(0.112)	(0.013)	(0.027)
Cost	-0.4580	-0.4602	-0.4837	-0.4862
	(<.001)	(<.001)	(<.001)	(<.001)
Schedule	0.2420	0.2391	0.2267	0.2242
	(0.031)	(0.033)	(0.052)	(0.055)
Type 2	1.0404	1.0578	1.0515	1.0640
	(<.001)	(<.001)	(<.001)	(<.001)
Type 3	1.1338	1.1571	1.1189	1.1390
	(<.001)	(<.001)	(<.001)	(<.001)
Type 4	1.5381	1.5769	1.5142	1.5473
	(0.001)	(0.001)	(0.001)	(0.001)
Type 5	0.9536	1.0716	0.8908	1.0359
	(0.002)	(<.001)	(0.006)	(0.002)
Type 6	1.7454	1.7810	1.7345	1.7612
	(<.001)	(<.001)	(<.001)	(<.001)
Type 7	0.9000	0.9275	0.8495	0.8722
	(<.001)	(<.001)	(0.002)	(0.001)
Type 8	1.6556	1.6812	1.6008	1.6342
	(<.001)	(<.001)	(<.001)	(<.001)
Let Year		-0.9862		-1.0075
		(<.001)		(<.001)
District 2			0.4646	0.4695
			(0.027)	(0.026)
District 3			0.2708	0.2516
			(0.244)	(0.281)
District 4			0.5118	0.5266
			(0.038)	(0.034)
District 5			0.5803	0.6073
			(0.011)	(0.008)
District 6			0.7878	0.7928
			(0.002)	(0.002)
District 7			0.5424	0.5268
			(0.027)	(0.032)
District 8			0.5119	0.4648
			(0.053)	(0.081)
Constant 1	2.1609	2.2428	2.1216	2.2117
	(<.001)	(<.001)	(<.001)	(<.001)
Constant 2	3.0526	3.1439	3.0205	3.1205
	(<.001)	(<.001)	(<.001)	(<.001)
Likelihood Ratio	199.0881	217.2762	212.4409	231.151
Observations	1512	1512	1512	1512

Table 3-10 and Table 3-11 show estimates from OLS regressions that analyze the relationship between the delivery method and contractor's performance from the past projects with the FDoT. Unlike the results associated with the cumulative number of projects, these results do not support the hypothesis that DB projects are generally awarded to better-qualified contractors. Looking at the coefficients associated with the variable "Delivery," they are all found positive, meaning that the mean past cost performance of DBB contractors is rather higher than that of DB contractors. A similar conclusion can be drawn regarding past schedule performance. Positive coefficients for "Delivery" reported in Table 3-10 indicate that on average, DBB contractors than DB ones had performed better in terms of completing projects on time. I included variables representing project characteristics to account for any effects that difference in scopes inherent in them might have on the selection of contractors (from column 2 in both tables). In addition, 8 districts or let year dummy are controlled for as were in the previous analyses (from column 3 in both tables). Apparently, the results are robust regardless of whether or not they are included. Hence, it may not be reasonable to argue that contractor's qualification plays a significant role in matching the type of chosen delivery method to the selected contractors.

Table 3-10. Results of OLS regressions for past schedule performance

Dependent Variable: Past Schedule Performance	1	2	3	4	5
Delivery	0.4121	**0.9714**	**0.9806**	**1.4492**	**1.4676**
	(0.366)	(0.064)	(0.062)	(0.010)	(0.009)
Cost		-0.4191	-0.4185	-0.3737	-0.3726
		(0.001)	(0.025)	(0.053)	(0.054)
Schedule		1.1565	1.1558	1.2332	1.2328
		(0.024)	(0.001)	(0.001)	(0.001)
Type 1		0.1467	0.1474	-0.0340	-0.0411
		(0.879)	(0.879)	(0.967)	(0.966)
Type 2		0.0791	0.0815	-0.2757	-0.2742
		(0.936)	(0.934)	(0.782)	(0.783)
Type 3		0.0393	0.0422	-0.1664	-0.1645
		(0.967)	(0.965)	(0.863)	(0.865)
Type 4		0.0409	0.0470	-0.2582	-0.2518
		(0.979)	(0.976)	(0.869)	(0.872)
Type 5		-0.0791	-0.0607	-0.0669	-0.0351
		(0.943)	(0.957)	(0.953)	(0.975)
Type 6		0.2956	0.3000	-0.0625	-0.0605
		(0.781)	(0.778)	(0.954)	(0.955)
Type 7		1.0197	1.0237	0.8648	0.8686
		(0.286)	(0.284)	(0.368)	(0.366)
Let Year			0.1612		0.2553
			(0.795)		(0.681)
District 2				2.0067	2.0221
				(0.006)	(0.006)
District 3				0.1520	0.1634
				(0.824)	(0.811)
District 4				0.4559	0.4602
				(0.570)	(0.567)
District 5				-0.0124	-0.0007
				(0.987)	(0.999)
District 6				0.7217	0.7413
				(0.353)	(0.341)
District 7				-0.3209	-0.3139
				(0.687)	(0.694)
District 8				0.1450	0.1540
				(0.849)	(0.840)
Constant	1.0022	0.2286	0.0651	-1.3819	-1.6570
	(0.016)	(0.905)	(0.974)	(0.542)	(0.484)
R-squared	0.0005	0.0133	0.0134	0.0233	0.0233
Observations	1512	1512	1512	1512	1512

Table 3-11. Results of OLS regressions for past cost performance

Dependent Variable: Past Cost Performance	1	2	3	4	5
Delivery	**0.0729**	**0.0671**	**0.0674**	**0.0546**	**0.0550**
	(0.006)	(0.027)	(0.027)	(0.092)	(0.091)
Cost		-0.0358	-0.0358	-0.0385	-0.0385
		(0.001)	(0.001)	(0.001)	(0.001)
Schedule		0.049088	0.0491	0.0453	0.0453
		(0.015)	(0.016)	(0.030)	(0.030)
Type 1		-0.08033	-0.0803	-0.0631	-0.0632
		(0.151)	(0.152)	(0.266)	(0.266)
Type 2		-0.08772	-0.0876	-0.08644	-0.0864
		(0.127)	(0.127)	(0.135)	(0.135)
Type 3		-0.04733	-0.0472	-0.0377	-0.0377
		(0.394)	(0.395)	(0.501)	(0.502)
Type 4		0.032241	0.0324	0.0344	0.0345
		(0.722)	(0.720)	(0.705)	(0.704)
Type 5		-0.07138	-0.0708	-0.0867	-0.0861
		(0.268)	(0.273)	(0.185)	(0.190)
Type 6		-0.10166	-0.1015	-0.1015	-0.1014
		(0.099)	(0.100)	(0.104)	(0.104)
Type 7		-0.13709	-0.1370	-0.1317	-0.1316
		(0.013)	(0.014)	(0.018)	(0.018)
Let Year			0.0051		0.0054
			(0.888)		(0.882)
District 2				-0.0200	-0.0197
				(0.638)	(0.644)
District 3				-0.0920	-0.0918
				(0.021)	(0.021)
District 4				-0.0692	-0.0691
				(0.137)	(0.138)
District 5				-0.0412	-0.0410
				(0.359)	(0.363)
District 6				-0.0102	-0.0097
				(0.822)	(0.829)
District 7				0.0094	0.0096
				(0.839)	(0.836)
District 8				-0.0295	-0.0293
				(0.506)	(0.509)
Constant	1.0057	1.3327	1.3275	1.4286	1.4228
	(<.001)	(<.0001)	(<.001)	(<.001)	(<.001)
R-squared	0.0050	0.0209	0.0209	0.0283	0.0293
Observations	1512	1512	1512	1512	1512

It is worth noting that frequent collaborations are observed to be highly regarded in the selection process while histories of successful collaborations are not. According to Performance and Production Review published by FDoT every year, projects caught its attention are those completed at least 10% over budget or at least 20% behind schedule. These generous criteria for performance evaluation are not surprising given that public-sector organizations generally do not aim at profit-maximization. Considering the scale of production in this sector, however, a small amount of cost overrun or a short period of schedule delay from each project would collectively result in significant wastes of taxpayers' money or commuters' time. Findings of this study may be in line with the generosity and imply that to some degree public-sector owners might have been overlooking the importance of non-financial qualifications in selecting contractors.

Care must be taken not to jump to a conclusion that public-sector owners do not appraise contractors' qualifications other than bid amounts in the proposal evaluation process. The FDoT is in fact one of those states that awards DB projects based on what is called "best-value" to both the public and the department. Evaluation criteria for the best value consist of three components: qualification of DB firms; technical approach; and price estimate, where the qualification criteria addresses "performance history" and "similar types of work experience" (FDoT, 2012)[39]. Once DB firms submit proposals containing information on all those components, a score is given to each criterion and the total scores are calculated by the weighted scoring method. The proposal with the lowest weighted score is deemed "best value" and becomes the winner of the project.

[39] Other important criteria include "organization and staffing plan of the proposed design-build firm and subcontractors," "environmental compliance record," and "project approach and understanding of critical issues." Depending on the characteristic of each project, additional criteria deemed relevant by the public authority can also be considered.

However, best-value selection is sometimes disputed by lowest bidders. Since evaluations of the set of criteria are conducted by selection committee members, they entail subjectivity and discretion even though the relative importance of each criterion is stipulated in the request for proposal (RFP). Moreover, public-sector projects are more prone to be awarded to lowest bidders compared to private-sector ones due to their procurement process that strongly favors the use of open competitive bidding. It is impossible to demonstrate that regardless of the delivery method, projects had typically been awarded to lowest bidders in the public sector due to the lack of data. Yet the result of this study, which fails to support the relationship between the choice of DB and the selection of better-qualified contractor, may imply qualification criteria devalued in the selection process. This may also be in line with industry sources admitting that least reputable contractors are awarded projects in the public sector, which is very rare in the private sector (Bajari et al., 2009: Halsey & Quatman, 2014).

5.3 Performance

Now that two biggest decisions for a project are made, a question naturally raised to be answered is whether the decisions actually led to desirable consequences. This section seeks to answer this question by looking into cost and schedule performance of projects delivered under two different methods. To that end, cost and schedule of each project are decomposed into several components, respectively, and where the most serious cost escalation or schedule delay had occurred for each type of projects is identified.

5.3.1 Schedule performance

Five schedule components are examined to compare schedule performance associated with two delivery methods, from which a significant schedule effectiveness of DB projects is captured. The first one analyzed is the number of days from the date of contract letting to that of contract execution. As we can see in Table 3-12, DB projects overall required slightly longer days between the two events. One might want to interpret this as owner's investment in preliminary administrations to prepare downstream risks associated with incomplete design at the time of contract execution. However, the difference in mean days drops to close to zero after project characteristics, governing units, and let years are taken into account. Therefore, it can be inferred that longer durations needed for administering DB projects can be offset by managerial capabilities of governing units for the same size and type of projects let in the same year.

Next, the mean number of days from contract let to work begin is significantly less for DB projects, indicating design-construction schedule compression in them. For the same size and type of projects in this particular sample, those delivered by DB save roughly 30 days up to the start of construction. It appears that the average duration of DB projects is 24 days longer than that of DBB projects when all else being equal. Hence, saving about a month seems considerable. Interestingly, however, there is a previous study arguing that the bulk of time savings in DB projects is not attributed to schedule compression, but to the industry norm that allocates funds up front. In DBB projects, funding is usually allocated for discrete phases over the project execution, which is likely to cause inefficiency in project schedule by repeatedly generating work stoppages and subsequent revisions in plan in the middle of the project (Whittington, 2012).

Turning to the central premise of this study that close interactions between designers and constructors will help expedite the execution of DB projects, mean schedule overruns for the two types of projects are assessed (Table 3-12). It is obvious that DB projects, overall, experienced significantly less changes in schedule compared to DBB projects in all three aspects examined. When looking at the changes attributed to change orders specifically, the difference in mean schedule changes between the two types of projects is over 10% with and without control variables. Once contract days are adjusted, on average both projects spent less than them to be completed. However, the degree of decrease is at least 5% higher for DB than DBB projects with and without control variables. Now that designers and constructors belong to one team, there should be less design changes. Even if changes are required, the handling process should be facilitated. These results strongly support for the schedule effectiveness of DB.

Finally, it was analyzed if contractor's qualification contributes to explaining the relationship between the chosen delivery method and the amount of schedule change. Section 5.2 reports that DB projects are more likely to be awarded to the contractors with larger numbers of collaborations with the owner, which, in turn, is expected to lead to a less degree of schedule overrun. Hence, I anticipated observing a larger difference in mean schedule overruns between the two types of projects after accounting for contractor's experience. The results in Table 3-12 consistently present slightly larger differences after including the contractor variable. However, the differences are too marginal to allow me to argue that contractor's intervening effect actually exists with this particular sample. Findings of this study clearly suggest the major sources of time savings associated with the DB method: concurrent engineering coupled with an efficient process.

Table 3-12. Comparisons of schedule performance between DBB and DB projects

Schedule	Contractor Experience	Raw values			With Project Characteristics			With Project Characteristics and Control Variables		
		DBB	DB	Diff.	DBB	DB	Diff.	DBB	DB	Diff.
Let Date ↓ Execution Date	Before adjustment	37.2 days	43.1 days	**-5.9 days** (<.01)	38.0 days	40.3 days	-2.3 days (0.14)	38.5 days	37.6 days	0.9 days (0.42)
	After adjustment	38.1 days	44.1 days	**-6.0 days** (<.01)	39.2 days	41.2 days	-2.0 days (0.18)	39.9 days	38.7 days	1.2 days (0.42)
Let Date ↓ Work Begin Date	Before adjustment	103.9 days	89.0 days	**14.9 days** (<.01)	105.3 days	75.5 days	**29.8 days** (<.01)	107.9 days	77.7 days	**30.2 days** (<.01)
	After adjustment	103.1 days	88.1 days	**15.0 days** (<.01)	105.4 days	75.6 days	**29.8 days** (<.01)	107.8 days	77.7 days	**30.1 days** (<.01)
Original Contract Days ↓ Adjusted Contract Days	Before adjustment	21.6%	21.0%	0.6% (0.82)	23.0%	11.8%	**11.2%** (<.01)	20.2%	5.9%	**14.3%** (<.01)
	After adjustment	23.5%	23.2%	0.3% (0.92)	24.7%	13.3%	**11.4%** (<.01)	22.2%	7.6%	**14.6%** (<.01)
Original Contract Days ↓ Actual Used Days	Before adjustment	14.3%	18.2%	-3.9% (0.26)	17.5%	0.6%	**16.9%** (<.01)	13.4%	-8.9%	**22.3%** (<.01)
	After adjustment	16.9%	21.3%	-4.4% (0.20)	19.7%	2.5%	**17.2%** (<.01)	16.2%	-6.6%	**22.8%** (<.01)
Adjusted Contract Days ↓ Actual Used Days	Before adjustment	-7.5%	-3.2%	**-4.3%** (<.01)	-5.9%	-11.0%	**5.1%** (<.01)	-7.0%	-14.2%	**7.2%** (<.01)
	After adjustment	-7.1%	-2.6%	**-4.5%** (<.01)	-5.6%	-10.7%	**5.1%** (<.01)	-6.6%	-13.9%	**7.3%** (<.01)

1. Diff. = DBB - DB, hence, a positive value of Diff. indicates a better performance of DB project.
2. P-values are in the parentheses.

5.3.2 Cost performance

A similar procedure was carried out using five components of cost overrun and the results are presented in Table 3-13. The first component examined is the change from FDoT's budget estimate to original contract amount. It is observed that on average original contract amount is lower than budget estimate for both types regardless of other factors considered. This is supposedly a result of open competitive bidding that is actively used in the public sector procurement. However, it is widely believed in the industry that contractors generally submit low bids on purpose to win the projects and aggressively seek change orders during execution to recoup profits (Bajari et al., 2009). If that is the case, the overrun from original contract amount to production cost should be lower for DB projects where contractors are the major responsible party for risks associated with design changes.

As expected, overall percent cost changes from original contract amount to production cost are lower for DB projects than for DBB projects, although the differences are too small to be statistically significant. It is as if production costs are controlled better in DBB projects when the focus is on the raw values. However, the results have been reversed after adjusting for the means with project characteristics and external conditions held constant. Increases in costs attributed to change orders are additionally examined, which also shows a weak advantage of DB over DBB. Results associated with Hypothesis 6, expecting cost advantages of DB over DBB while holding contractor's experience constant, are exhibited in the rows titled "After adjustment" of Table 3-13. As can be seen, however, the differences between the means that contractor's experience might bring about are too small to be significant.

Finally, to shed light on extra costs[40] (e.g., administrative costs) that might have incurred above and beyond production cost, the percent difference between the actual expenditure of the FDoT and original contract amount is calculated for both types of projects. Interestingly, DBB projects are found to have overall better performance in this regard, while the differences are not statistically significant. I can conjecture that the FDoT tends to spend more money on preparing and administering external requirements as well as contractual arrangements for DB projects to safeguard against uncertainty and opportunism that would possibly be generated by bidding with less-completed design (Whittington, 2012). Unfortunately, any further breakdown of these transaction-cost type of expenditure is impossible at this phase, preventing me from investigating the reasons for the variations in greater depth.

Meanwhile, it seems worth noting the changes in adjusted mean percentages before and after variations across districts and let years are controlled for, although not all of the differences are statistically significant (last 3 columns in Table 3-12 and Table 3-13). For instance, the difference in mean cost changes between budget estimate and original contract amount becomes larger by approximately 3% after the control. In the case of extra costs, performance for DB projects turns to favorable with the adjustment. These results imply the importance of characteristics related to owners, e.g., experience in administering similar projects, capabilities of handling change orders and claims, geographic location, and so on, in achieving cost objectives. The number of projects performed across 8 districts for the last decade quite varies as shown in Table 3-3, not to mention their wide-spread geographic locations. Since these factors are beyond the

[40] These costs include those necessary for preliminary administration, ancillary studies, bid administration, outside agreements, DoT engineering, and so on (Whittington, 2012).

original scope of this study, they will not be addressed any further than the effects being noticed for future consideration.

In sum, what I can conclude at best with this particular sample of road, bridge, and traffic operations projects performed with the FDoT is that DB projects are not inferior to DBB projects in terms of cost performance unlike some of previous studies, including a report to the Congress on SEP-14, argue. In my opinion, cost advantages of DBB over DB corroborated by them might stem from their approach that merely compares performance indicators without considering other critical factors. This study could have drawn the same conclusion by applying the approach (first three columns in Table 3-13). However, this study also omits a number of factors assumed to affect cost control, most prominently contract type, procurement process, contractor's characteristics[41], besides owner's characteristics discussed above. This is why the results of this study are not able to elucidate whether one method is superior to the other with respect to cost control or the difference in cost overruns between the two types of projects is a function of ancillary factors that had not been considered in this study. Thus, this topic begs for more serious research to enhance cost-wise benefits that the DB method is expected to generate.

Table 3-14 presents the results whether or not each of the six hypotheses in this study is supported by the regression analyses discussed throughout Section 5.

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[41] In addition to contractor's characteristics analyzed in this study, i.e., the cumulative number of repeated business with the owner and the average performance from past projects, characteristics to be considered in future research may include contractor's financial stability, resource capacity, technical expertise, and current workload (Attar, Khanzadi, Dabirian, & Kalhor, 2013; Lewis & Bajari, 2014).

Table 3-13. Comparisons of cost performance between DBB and DB Projects

Cost change	Contractor experience	Raw values			With Project Characteristics			With Project Characteristics and Control Variables		
		DBB	DB	Diff.	DBB	DB	Diff.	DBB	DB	Diff.
Budget estimate ↓ Original Contract Amount	Before adjustment	-9.5%	-7.8%	-1.7% (0.44)	-7.2%	-8.4%	1.2% (0.62)	-9.6%	-13.8%	4.2% (0.10)
	After adjustment	-11.4%	-9.6%	-1.8% (0.40)	-7.9%	-9.0%	1.1% (0.66)	-10.6%	-14.5%	3.9% (0.13)
Original Contract Amount ↓ Adjusted Contract Amount	Before adjustment	3.4%	3.2%	0.2% (0.85)	3.4%	2.2%	1.2% (0.26)	1.9%	0.0%	**1.9%** (0.09)
	After adjustment	4.1%	4.0%	0.1% (0.94)	4.0%	2.6%	1.3% (0.21)	2.7%	0.6%	**2.1%** (0.06)
Original Contract Amount ↓ Production cost	Before adjustment	-0.8%	1.6%	**-2.4%** (0.03)	0.1%	-1.4%	**1.5%** (0.20)	-0.7%	-3.7%	**3.0%** (0.02)
	After adjustment	-0.2%	2.3%	**-2.5%** (0.02)	1.2%	-0.5%	**1.7%** (0.19)	0.5%	-2.6%	**3.1%** (0.01)
Original Contract Amount ↓ FDoT's Expenditure	Before adjustment	-1.4%	1.9%	**-3.3%** (0.02)	-0.6%	-0.9%	0.3% (0.85)	-2.6%	-4.9%	**2.3%** (0.15)
	After adjustment	-1.4%	2.0%	**-3.4%** (0.01)	0.2%	-0.2%	0.4% (0.79)	-1.6%	-4.0%	**2.4%** (0.12)
Production cost ↓ FDoT's Expenditure	Before adjustment	-0.0%	0.2%	-0.2% (0.48)	-0.3%	0.1%	-0.4% (0.35)	-0.6%	-1.0%	0.4% (0.33)
	After adjustment	-0.1%	0.2%	-0.3% (0.49)	-0.3%	0.1%	-0.4% (0.35)	-0.6%	-1.0%	0.4% (0.33)

1. Diff. = DBB - DB, hence, a positive value of Diff. indicates a better performance of DB project.
2. P-values are in the parentheses.

Table 3-14. Summary of hypotheses testings

No.	Hypothesis statement	Supported?
H1	The degree of project scope is positively related to the choice of Design-Build over Design-Bid-Build, which involves less degree of design completeness while high degree of managerial flexibility. Specifically, the more expensive the estimated cost of a project is, the more likely that a public owner would choose Design-Build for the delivery method.	No
H2	The expected level of environmental uncertainty is positively related to the choice of Design-Build over Design-Bid-Build. Specifically, the longer the estimated duration of a project is, the more likely that a public owner would choose Design-Build for the delivery method. Similarly, the more technically-challenging a project is, the more likely that a public owner would choose Design-Build for the delivery method.	Yes
H3	Design-Build projects are more likely to be awarded to more experienced contractors. Specifically, Design-Build projects are more likely to be awarded to contractors who have performed a greater number of projects with the owner.	Yes
H4	Design-Build projects are more likely to be awarded to more reputable contractors. Specifically, Design-Build projects are more likely to be awarded to contractors who have better cost- or schedule- performance in the past projects with the owner.	No
H5	Design-Build projects are likely to outperform Design-Bid-Build projects in terms of schedule: the choice of Design-Build is likely to be related to less Schedule overrun.	Yes
H6	Design- Build projects are likely to outperform Design-Bid-Build projects in terms of cost when contractor's qualification is considered: the choice of Design-Build is likely to be related to less cost overrun because the choice of Design-Build is likely to be related to the selection of a better-qualified contractor, which, in turn, leads to less cost overrun.	No

6. Conclusion

6.1 Summary

As a result of growing impatience on the part of the public with the lengthy construction process, an innovative form of delivery method, DB, has been instituted in the public transportation sector. The primary purpose of using DB is to expedite the process through concurrent engineering. The public also expected cost savings from the use of DB based on the cost-sharing opportunities inherent in the process as well as on the widely-accepted notion that longer projects cost more.

Inspired by some disagreements in the existing literature, this study attempted to tackle public perception concerning putative advantages of DB over DBB. In doing so, the two critical decisions made by owners in the procurement process, namely the selections of project type and of contractor, were incorporated in the analyses and the consequences driven by those sequential decisions were examined with respect to cost and schedule performance.

One cannot argue that public perception with respect to cost performance is correct: DB projects do not generate significant cost savings in any aspect (at least in this particular sample) in spite of the early establishment of guaranteed maximum price, while this does not necessarily mean that DBB is more effective at controlling project cost. DB projects tend to be awarded with lump sum contracts, where contractors are allowed to keep their books closed without sharing cost breakdown structures. In this situation, cost savings are likely to be passed on to contractors, while owners may not know how much of the funds paid out to DB contractors are for real expenses, buffers against uncertainties, and higher margins, respectively. Given the inherent feature of DB that restricts owners' involvement, they may unwittingly be dealing with the risks attributed to contractor's opportunistic behavior coupled with information asymmetry.

On the other hand, this study corroborates a positive schedule implication of DB that has constantly been reported in the literature. While it was impossible to compare construction-phase schedule overruns between the two types of project directly, the mean schedule overruns for DB projects were consistently (and significantly) observed to be lower than those for DBB projects from all the components examined.

Meanwhile, It was unsuccessful to verify a significant role of contractor's experience in explaining a better performance of DB projects. Even though the differences in means became larger after controlling for the contractor variable, they were too small to support for the effect. In contrast, considerable differences were generated after including a variable in the model that was intended to control for variations in performance associated with heterogeneous governing units. As mentioned in Section 5.3.2, a more complete analysis would identify and endogenize the full menu of owner characteristics, e.g., the experience and capability of conducting similar projects, the implications of which will assist public-sector owners in making better use of DB.

However, success is in the eye of the beholder. Unlike private sector businesses, fairness and openness virtues in the procurement process are as important as savings in cost or schedule for public-sector owners (Perkins, 2009). At the same time, public-sector owners concern more about public perception than private-sector owners do (Shrestha et al., 2012). These differences seem to be reflected in the procurement process currently in use. Regardless of project size and scope, for instance, it was found that the FDoT was unlikely to transfer risks to DB contractors for the projects that were assumed to have a high impact on the right-of-way or environment. It was also found that DB contractors having demonstrated histories of successful collaborations with the FDoT did not necessarily grab a high chance of winning projects in the future. Perhaps costs do not drive every project especially in the public sector. However, public owners should remember that saving taxpayers' money is also a way of pursuing public welfare, which would be enhanced by taking full advantage of various benefits inherent in each delivery method.

6.2 Implications for public-sector project delivery

Findings of this study suggest rooms to improve the delivery process in the public transportation sector. One is an active incorporation of various contractual forms or award mechanisms in each delivery method. For example, public owners are able to alleviate the lengthy delivery process from which DBB usually suffers by rewarding contractors for accelerated delivery. Lewis et al. (2011) actually show faster project completions and less negative externalities on commuters that explicit time incentives had induced in highway constructions. In the case of DB, it seems hard for owners to control costs associated with uncertainty and opportunism while using it coupled with the lump sum contract. To overcome this weakness, public-sector bureaucrats may need to consider an alternative award mechanism, e.g., negotiation, which allows for *ex ante* information sharing between the two parties before designs are complete and construction begins. While not addressing construction delivery methods, we can find some previous studies in economics that suggest the use of negotiations for complex projects rather than open competitive bidding (Bajari et al., 2001; Bajari et al., 2009; Clough & Sears, 1994;

Goldberg, 1997; and Hinze, 1993). Their conclusions are rooted in the downside of open competitive bidding that hinders project parties providing each other enough inputs at the design phase.

Meanwhile, there is also room to consider an alternative delivery method for owners who are concerned about the fragmented process in DBB and their limited involvement in DB at the same time. Construction Management at Risk (CM at-Risk) is one of them. In this method, the owner hires not only an A/E but construction manager (CM) who manages the project from its kickoff to closeout as an agent of the owner. The CM engages in the design process as a design consultant for the owner and performs "value engineering or constructability reviews" during preconstruction. Later in the construction phase, the CM takes the role of contractor and provides construction service. Although the A/E and the CM are needed to work in an interactive manner to deliver the project, the latter is the one placed in the position of managing most of the project risks (Strang, 2002).

Of various benefits associated with this method, the most prominent one for the owner is that it protects the owner from cost overrun beyond a certain point. In Florida, for example, CMs are required to submit a Guaranteed Maximum Price (GMP) at about half point in the contract phase, by which they warrant to the FDoT that the project will be delivered at a cost within the GMP. Since the A/E and the CM work together from early phases of the project, this method also offers opportunities for cost sharing. With respect to schedule performance, a project can be delivered at a fast-tracked schedule if a cost guarantee gives the owner the confidence to begin construction before having a complete design. Finally, qualifications-based selection and better quality control throughout all aspects of the project increase the potential for a high-quality outcome to be delivered at a low cost.

This method, of course, has some drawbacks. Qualification-based selection of A/E and CM may generate a perceived lack of open and fair price competition. Also, there are always risks that the A/E and CM fail to reach consensus during the design process. Moreover, CM at-Risk's personnel may feel closer to subcontractors rather than the owner by habit even though they are supposed to represent the interests of the owner. Above all, field personnel who are under a great deal of pressure to meet the GMP may be less enthusiastic about thorough inspections in close situations because a big field problem would tend to increase the cost over the guaranteed price causing the CM at-Risk firm to make up the difference. Hidden defects of which the owner was unaware until the end of the project may be discovered dearly months or years later (Strang, 2002). In sum, none of the delivery method should be exercised at random. Making strategic decisions in the project delivery process clearly beg for more serious research.

6.3 Caveats and future research

This study contributes to the literature on the choice of delivery method particularly in the public transportation sector by identifying where improvement is possible in the delivery process. With that goal, this study borrows theories from other fields (mainly from economics) and endeavors to overcome the lack of theoretical foundation that most of descriptive engineering management studies suffer from, and analyzes direct or indirect impact of the choice on project performance. This is one of the few studies on this topic that analyzes an objective dataset with a large sample size over a long span, therefore, excels at external validity compared to previous empirical studies.

The use of secondary data, however, imposes limitations as well. First, there might be a problem of endogeneity as I cannot rule out the existence of omitted-variable bias. Even worse, it is hard to identify what those omitted variables might be given the lack of theoretical foundation on this topic. From reviewing the industry literature, I believe that the error term may be related to owner characteristics, including experience, bureaucratic process, organizational environment toward innovation, team building strategy (Mahdi & Alreshaid, 2005). Unfortunately, there is nothing at hand available for measuring them. In this regard, a single source of data sets is also problematic. The FDoT is especially famous not only for overall good performance, but for its innovation-oriented culture that is reflected in the longer use of DB than any other state. Thus, the results of this study must be interpreted with caution in consideration of any bias that unobserved traits of the owner might have caused. Generalizability to other states or other sectors should not be ascertained, either.

Meanwhile, this study may suffer from selection bias. I was not able to construct all the variables for all the 1,512 projects in the dataset due to missing values. As a result, some of the results lack the full support of the data. For example, engineer's budget estimate was unavailable for a total of 498 projects, which affected the specification of models testing cost performance. Furthermore, most of missing values are from projects awarded by District 3 in the early 2000s, which is an initial phase that the FDoT started managing its project data in a digitalized manner. To deal with this issue, I conducted the analyses while controlling for the variables representing award year as well as district.

Also, the data still contained more than a thousand of observations even after excluding incompletely specified projects. Hence, I believe that there were a sufficient number of well-specified projects enough to answer the questions of this study.

The starting point of the next step will be a more complete analysis that would address aforementioned caveats. As discussed above, various owner characteristics are themselves choice variables that should be endogenized in the model. Then, the first action to this end is collecting similar data sets from other major states in the U.S. and construct measures that would account for those characteristics, which will resolve the issue of generalizability to some extent. Given that this study failed to observe a significant difference in cost performances between delivery methods, another direction for future research is to look into the difference from a fit perspective. That is, it would be interesting to see if a fit of project characteristics or contractor characteristics with a particular delivery method would lead to superior performance. For further extension, project costs can be examined more thoroughly by being decomposed into several important components associated with design, construction, administrations, changes and reworks, dispute resolutions, external permits and compliances, and so on. In theory, projects under the two delivery methods should present different patterns of changes in costs over the life of a project (Whittington, 2012). This approach will address the drawback of this study lacking direct comparison of construction-phase performance between the two methods. More important, it will guide practitioners to a better use of project delivery methods by identifying where each of them was unsuccessful in achieving cost objectives.

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Chapter 4: Conclusion

The objective of this dissertation, which is comprised of two independent essays, was to address some limitations from the construction management literature and provide governmental owners guidance regarding what they can do to improve project performance particularly in the public infrastructure sector. To overcome lack of theoretical background in the existing literature, I borrowed theories from academic fields out of construction project management, such as economics and production management. I then gathered and analyzed an extensive data set of public transportation projects awarded by the Florida Department of Transportation between 2000 and 2010 to see if theories held in practice.

The first essay was on project changes that had been considered a major source of poor performance. To identify where improvement is possible, I categorized changes into 7 types based on the nature of them and found that a great portion of increases in project cost could be attributed to owner-directed changes. In addition to the nature of changes, the timing of their occurrence during the life of project was analyzed if later changes were actually more detrimental to cost performance. As was the case from most of previous studies, however, this essay failed to support any significant effect of timing. To determine whether this result was due to incomplete specifications of the models or timing not actually affecting project cost, non-linear form of the relationships or omitted variables, e.g., the level of project complexity, can be considered in the future works.

A finding from the first essay also implied that governmental owners might benefit from implementing a more flexible delivery method. As such, the second essay focused on comparing two project delivery methods, Design-Bid-Build and Design-Build, that are distinct from each other with respect to the levels of design completeness at the outset of the project and flexibility in adaptations. The analyses revealed that the virtues of fairness and openness still seemed to be prevalent in the decisions on the selections of projects or contractors. Also, the results did not allow me to conclude that one method is superior to the other in terms of cost performance. In particular, the greatest increases in costs were attributed to change orders for both methods. Finally, an obvious advantage of Design-Build over Design-Bid-Build with respect to schedule control was confirmed by the analyses.

These two essays together reaffirm the importance of project planning from the owner-side to meet project cost objectives regardless of delivery methods. For schedule control, on the other hand, delivery methods did matter. Projects requiring expedited completion would benefit from using what enables concurrent engineering and fluid channel of communication. For further extension, one can consider looking deeper into the right fits between project characteristics (or contractor characteristics) and a particular delivery method to help governmental owners fully enjoy various benefits inherent in each delivery method. Incorporating the two essays, that is, investigating different change-handling mechanisms under different delivery methods would also yield meaningful implications in regard to project control.

Appendix 1. Descriptions of reasons for contract changes

No.	Description
1	Subsurface material or feature not shown in plan.
2	Harmonize project with adjacent projects or right of way.
3	Design standards, specification or policy change after contract letting.
4	Utility adjustment delays w/ no JPA[42] (should be premium Avoidable 3rd party).
5	Work added to or deleted from 3rd party agreements.
6	Contract changes at Right of Way Office's request (litigation, court orders, negotiations etc.).
7	Permit-related issues.
8	Weather-related new work, repairs, overruns or contract changes due to weather.
9	Deterioration of, or damage to, project after design (not weather-related).
10	Test features not included prior to letting.
11	Contract changes to utility JPA work (should be no cost to FDOT).
12	Materials acquisition-related issues.
13	Impacts from special events or excessive traffic (e.g., delays for Super Bowl).
14	Conflicts between contractors, from overlapping project limits, pay items, schedules etc.
15	Increase in steel material prices.
16	Necessary pay item(s) not included in contract.
17	Incorrect or insufficient subsoil information.
18	Incorrect pay items for earthwork, embankment and excavation jobs on one contract.
19	Discrepancies between plan notes, plan details, pay items, standard indexes and specifications.
20	Utility work w/ no JPA: conflict, wrong size, wrong location, proposed or existing.
21	Modification of MOT[43] for pedestrians, boats, cars, bikes, etc.
22	Plans do not describe scope of work.
23	Phasing or plan components not constructible as shown in plans.
24	Modification to pavement design required.
25	Required drainage modifications.
26	Inadequate Right of Way to construct project as shown on plans.
27	Access management issues.

[42] JPA: Joint Participation Agreement
[43] MOT: Maintenance of Traffic

28 Improper or inadequate signing, signalization or pavement marking design or features.
29 Revisions required related to major structural component changes.
30 Hazardous materials encountered requiring contract changes.
31 Bike, pedestrian, ADA[44] or other public transit requirement not properly addressed: not MOT-related.
32 Landscaping issues not adequately addressed.
33 Computation errors in pay item work amounts.
34 Inaccurate or inadequate survey information used in plans preparation.
35 Indecision or delayed response by or on behalf of FDoT causing contract delay.
36 Architectural feature related issue (generally for building modifications).
37 No specification provided for item of work.
38 Value Engineering change proposal.
39 Partnering.
40 DRB[45] Member Fees
41 Inaccurate directions given to contractor by or on behalf of FDoT during construction.
42 Change resulting from engineering decision
43 Overrun of existing pay items: when overruns will exceed 5% of original contract amount.
44 Defective materials.
45 Contingency Supplemental Agreement.
46 FDoT determined risk avoidance cost paid solely to avoid risk in failing to settle disputes.
47 DRB recommended cost in excess of engineer's estimate and entitlement analysis.
48 Arbitration board. recommended costs in excess of engineer's estimate and entitlement analysis.
49 Court ordered costs in excess of engineer's estimate and entitlement analysis.

[44] ADA: Americans with Disabilities Act
[45] DRB: Disputes Review Board

Appendix 2. Correlation coefficients between continuous independent variables (Essay 1)

	PRJCOSTi	*PRJDAYSi*	*CHGDURi*	*TMNG1i*	*TMNG2i*	*TMNG3i*	*TMNG4i*	*TMNG5i*	*TMNG6i*	*TMNG7i*
PRJCOSTi	1.0000									
PRJDAYSi	0.8758	1.0000								
	(<.001)									
CHGDURi	-0.0850	-0.1581	1.0000							
	(0.113)	(0.003)								
TMNG1i	0.3704	0.3654	-0.0266	1.0000						
	(<.001)	(<.001)	(0.621)							
TMNG2i	0.2459	0.2668	-0.0319	0.1695	1.0000					
	(<.001)	(<.001)	(0.553)	(0.002)						
TMNG3i	0.3495	0.3638	0.0841	0.1914	0.2218	1.0000				
	(<.001)	(<.001)	(0.117)	(<.001)	(<.001)					
TMNG4i	0.2461	0.1793	0.0429	0.0757	0.1240	0.1790	1.0000			
	(<.001)	(<.001)	(0.424)	(0.158)	(0.021)	(<.001)				
TMNG5i	0.3047	0.3267	0.0550	0.2255	0.1016	0.2121	0.2115	1.0000		
	(<.001)	(<.001)	(0.305)	(<.001)	(0.058)	(<.001)	(<.001)			
TMNG6i	0.2077	0.1935	-0.0178	0.0808	0.0009	0.0895	0.0580	0.0670	1.0000	
	(<.001)	(<.001)	(0.740)	(0.132)	(0.987)	(0.095)	(0.280)	(0.212)		
TMNG7i	0.2230	0.2034	0.0280	0.1141	0.1483	0.1074	0.0628	0.0661	0.0659	1.0000
	(<.001)	(<.001)	(0.603)	(0.033)	(0.006)	(0.045)	(0.242)	(0.218)	(0.219)	

Appendix 3. Correlation coefficients between continuous independent variables (Essay 2)

	COSTi	*DURATIONi*	*PASTCSTi*	*PASTSCHi*
COSTi	1.000			
DURATIONi	0.8177	1.000		
	(<.001)			
PASTCSTi	-0.0727	-0.0335	1.000	
	(0.005)	(0.193)		
PASTSCHi	-0.0135	0.0396	0.0171	1.000
	(0.599)	(0.124)	(0.507)	