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A Review of Critical Success Factors and Performance Metrics on Construction Projects

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Abstract: Owners make several important project delivery decisions in early planning and design phases of a project that impact project performance. Ideally, these decisions should be based on objective consideration and empirical evidence, but they are frequently based on an owner's level of comfort or prior experience. Due to the importance of making informed decisions, several academic studies have investigated the relationship between project performance and potential predictive variables including delivery method, contract type and procurement strategy. Many of these earlier studies have begun losing relevancy in a changing industry, through the introduction of new concepts such as team integration, teaming tools, building information modeling (BIM) and sustainable design. To address this growing knowledge gap, a study was conducted to: (1) identify key project success criteria from the owner's perspective; (2) determine suitable metrics for reliably measuring performance outcomes related to the established success criteria; and (3) consider new concepts such as project integration, BIM, team behavior and sustainability. The research team conducted an extensive literature review on studies exploring the relationship between project delivery and outcomes to generate a comprehensive listing of statistically relevant predictors of success and tested performance metrics. Validation of this compiled listing was performed through an advisory board of industry experts. The advisory board provided critical feedback and assisted in the development a survey instrument for collecting project-specific data. The results of this study will enhance our current understanding of project success criteria and tracking metrics to support decision-making processes. More importantly, it provides a basis for further study, data collection and the creation of a project performance database.

1. Introduction

Key owner decisions during the early stages of a project, such as delivery method, contract types and team selection process, have a role in determining project success (Konchar and Sanvido 1998). There is an interest among owners to understand the relationships between key decisions and their impact on typical definitions of project success, such as cost growth, schedule growth, and quality. In response, a number of studies have been conducted to inform decision makers by comparing the performance of common forms of project delivery (e.g. Molenaar and Songer 1998; Konchar and Sanvido 1998). The objective of these studies was to help owners to understand the implications of their decisions with more objectivity and based on sound empirical data.

While the contribution of the previous studies is frequently cited in literature and practice, they are beginning to losing relevancy for several reasons. First, while prior empirical studies considered the relationships between project organization, procurement, and payment, no single study has investigated the combined effect of these factors on project performance with a large number of projects. Second, new project delivery systems have developed in recent years, such as integrated project delivery (IPD) (Kent and Becerik-Gerber 2010). Finally, in the last decade, new evolutionary process improvements, such as sustainable design, building information modeling (BIM), and lean construction have gained traction. Case studies in literature suggest that adopting these concepts in construction projects can significantly affect the project performance (Korkmaz et al. 2010). Therefore, developing a new set of variables to address these limitations and establish an empirical project delivery database is promising.

To address this growing knowledge gap, a study was conducted to: (1) identify key project success criteria from the owner's perspective; (2) determine suitable metrics for reliably measuring performance outcomes related to the established success criteria; and (3) improve the robustness of performance measurement by considering new concepts such as project integration, BIM, team behavior and sustainability. The results of the study lead to the development of a comprehensive questionnaire that can be used to establish an empirical project delivery database. The database can be used to provide how-to-guidance for the project participants and support owners' decision-making to maximize the likelihood of success.

2. Background

Prior studies have established a framework, using statistical methods, to test for significant impacts of project delivery decisions on performance metrics (e.g. Konchar and Sanvido 1998). Two types of variables were identified from literature: dependent and independent. The dependent variables are project outcomes that reflect the measured performance or success of the project. The independent variables are those factors, including project delivery decisions, which can impact performance outcomes. The relationship between independent and dependent variables is depicted in Figure 1. As it is shown, independent variables (e.g. delivery methods) will be used to predict the amount of changes in dependent variables (e.g. cost, time, quality, etc). The notable results of the literature review and discussion of dependent and independent variables are provided below.

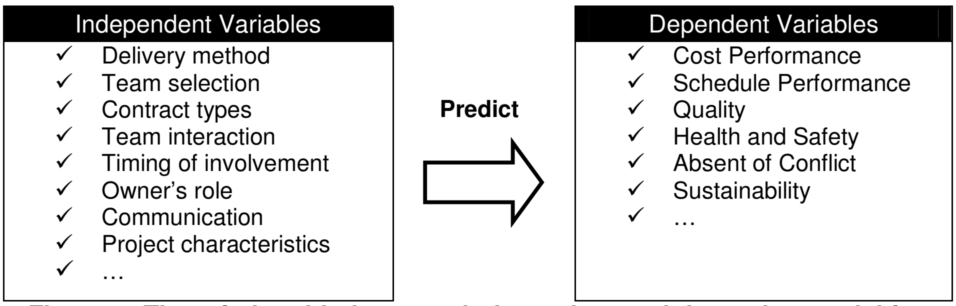

Figure 1. The relationship between independent and dependent variables

2.1 Dependent Variables

Quantifying project success is challenging because the definition of success often varies by stakeholder. For example, a contractor may consider construction speed and profitability as the most important measures of success, while an owner may emphasize on-budget completion or quality of construction. These conflicting views of success can result in poor overall project performance if expectations are not communicated. In literature and practice, the outcomes most frequently used to define project success are cost, time, and quality; also known as the iron triangle (Atkinson 1999). Other researchers have suggested more subjective outcomes such as functionality and participant satisfaction (e.g. Ashley et al. 1987), aesthetics (e.g. Sanvido 1992), safety records and flexibility to users (e.g. Kometa et al. 1995), the absence of legal claims (e.g. Pocock et al. 1996), friendliness of environment (e.g. Kumaraswamy and Thorpe 1996), and meeting specifications (Songer and Molenaar 1997) as additional indicators of project success. Recently, in addition to these success criteria, the "level of achievement in sustainable high-performance standards" is also considered important to measure outcomes of sustainable building projects (Korkmaz et al. 2010).

2.2 Independent Variables

Four independent variables were identified from the literature: (1) project delivery methods; (2) team selection methods; (3) contract types; and (4) team characteristics. These variables are explained in more details in the following sections.

2.2.1 Project Delivery Methods

In one seminal study, the Construction Industry Institute (CII) and Penn State University researched means of improving delivery method selection by providing practical decision guidelines backed by empirical evidence (CII 1998, Konchar and Sanvido 1998). To achieve this goal, performance metrics for cost, schedule, and quality for projects delivered under the three most common project delivery methods in the U.S. (design-bid-build, design-build, and construction management at risk) were compared for 351 building projects. The study concluded that design-bid-build projects showed statistically significant higher unit cost, and slower construction and delivery speeds. Additionally, the design-build projects had the lowest schedule and cost growth. While the unit cost, construction and delivery speed had higher level of certainty, cost and schedule growth explained a significantly lesser degree of variation. The most prominent contribution of the study was to provide guidance for owners on how to organize a successful project.

In another study, Ibbs et al. (2003) analyzed characteristics of 67 global projects and found that design-build does not outperform design-bid-build across all project performance criteria. The results indicated that design-build has a certain advantage on time savings, but a correlation with costs and productivity is questionable. They stated that the project management expertise and experience of the contactor may have a greater impact on project performance outcomes than project delivery strategy alone.

While most of the previous studies compared project performance of design-build and design-bid-build project delivery methods for building or industrial projects, there were limited studies to compare performance of these project delivery methods for highway projects. To expand delivery method research into the civil domain, Shrestha et al. (2012) investigated the relationship between project performance metrics (i.e., cost, schedule, and change orders) and project characteristics of 130 large highway projects (>$50 million) in Texas. The study concluded that the construction speed and project delivery speed per lane mile of design-build projects were significantly faster than of design-bid-build projects.

2.2.2 Team Selection

Several studies evaluated the impact of procurement methods on similar project performance metrics. For example, Molenaar et al. (1999) compared the performance of public design-build projects under three different procurement methods used by public owners: the one-step, two-step, and qualifications based. It was found that two-step method had the least cost growth (3%) and schedule growth (2%). The one-step projects were on the second place delivered on average 4% over budget and 3.5% behind the schedule. The qualifications based procurement method had the worst cost growth (5.6%) and schedule growth (3.5%). In another study, the data from 76 design-build projects was collected to develop a series of guidelines to help owners in selecting the design-build team aligned with their project goals (El Wardani et al. 2006). The performance metrics were based on the traditional outcomes of time, cost, and quality and the team selection methods were sole source, qualification-based, best value, and low bid selection. While the findings of the study illustrated that there were no specific team selection methods that outperform all others across every performance metric, the qualification-based selection method showed the lowest cost growth.

2.2.3 Contract Types

Bogus et al. (2010) compared the performance of public water and waste water projects procured under cost-plus fee (CPF) with and without a guaranteed maximum price (GMP) contract with traditional lump sum (LS) contract. The data was collected from 99 water or waste water infrastructure projects completed after 2003 and the results showed that the mean cost growth of projects procured under cost-plus fee with GMP contract was significantly less than projects procured under lump sum contracts.

2.2.4 Team Characteristics

Ling (2004) collected data from 42 public and private projects to identify key factors that affect performance of DB projects. His findings indicated that contractor characteristics are key determinants impacting many of the typical performance metrics. Other studies also found that the effective project management action, adoption of innovative management approaches, project team commitment, contractor's and client's competencies are success factors for projects (e.g. Lam et al. 2008). Team characteristics usually reference the following factors for the owners, designers, and contractors (Konchar and Sanvido 1998; Lam et al. 2008): experience with similar projects (i.e. size, type, etc); level of sophistication; communication among project team members; track record for successful completion of project; staffing level; adequacy of plant and equipment; key personnel's management ability; ability in financial management; quality control and management capacity; health and safety management capability; and magnitude of change orders, claims, and disputes in contractor's past projects.

3. Point of Departure

This study departs from the current body of knowledge by considering emerging issues and practices such as project integration, team selection, and team behavior as potential indicators of project success. The results of this study will be used to generate a questionnaire to collect project data and create a large, comprehensive, and reliable project delivery performance database to study relationships among project delivery decisions, team factors and project outcomes.

4. Research Methods

While, emerging concepts such as team integration, team behavior, and application of new processes and technologies are introduced to the construction industry, there are two main challenges in developing a questionnaire to measure those concepts in practice. First, there is a trade off between the length of the survey and the potential number of respondents providing project data. As the number of questions increases, the number of people who are willing to devote their time to complete the entire survey decreases. Therefore, the questions should first be prioritized according to their importance, ensuring that key measures and concepts are identified. Secondly, while specific variables may be found important, the same variables may also be impractical to record reliably and objectively. For example, to capture an abstract concept such as the level of trust among team members, a large number of project participants should be interviewed from different parties. In many cases, the data cannot be obtained in a reasonable time frame or is simply not available. To overcome these challenges, the research was conducted in two phases. In the first phase, a comprehensive literature review was implemented to make a list of dependent variables (performance metrics) and dependent variables (predictors). In the second phase, a research workshop was designed to further develop the identified list of variables and rank them according to their importance and availability. One should note that the goal of the study was to identify and validate the variables that should be included in a survey instrument tool to collect project data and establish an empirical project delivery database. In other words, the research team convened a workshop to make sure that no variable was missed from the analysis. The relative importance of variables and their impact on project outcome will be identified later by conducting robust statistical analysis on the data base created using the survey instrument.

4.1 Phase I: Literature Review

The first phase of the study involved conducting a comprehensive review of the literature about project performance over the past 25 years. The literature was selected mainly from the following sources: Journals of Construction Engineering and Management, Construction Management and Economics, Management in Engineering, and International Journal of Project Management. A rigorous content analysis was conducted on published papers relating to the measurement of project performance. The content analysis resulted in a comprehensive list of performance metrics and variables that may affect the performance. A summary of the content analysis on past studies was presented in the literature review section.

4.2 Phase II: Research Charrette

For the second phase of the project, the research team used a structured workshop or "research charrette" to expand on and rank the preliminary list of variables. This technique is a useful method for facilitating data collection between industry respondents and academic researchers and combines the best tenets of surveys, interviews and focus groups in accelerated time frame (Gibson and Whittington 2010). Although survey research methods are employed extensively to study construction industry variables, they have several potential limitations such as low response rate, long response time, and possibility of miss-transferring the intended meaning to the respondent. On the other hand, the research charrette has several benefits over the traditional surveys (Gibson and Whittington 2010): providing an environment for industry experts to interact in a structured manner; using multiple data collection strategies in a single setting; obtaining the responses in a short amount of time; and forming a committee using non-random sampling method focused on volunteer experts. The research charrette has been successfully used in previous exploratory studies investigating project team alignment (Griffith and Gibson 2001) and developing project definition rating index (PDRI) for buildings (Cho and Gibson 2001). For example, Griffith and Gibson (2001) used multi-voting and small group breakouts to refine and narrow the list of key alignment strategies to the top issues affecting project team alignment during front end planning. For this study, the protocol provided by Gibson and Whittington (2010) was followed to enhance the success of charrettes.

A two-day charrette workshop was led to modify the preliminary list of performance metrics and influential variables and rank their importance and availability. A diverse panel of highly qualified experts attended, including two CM/GCs, two specialty contractors (one HVAC and one Electrical representative), three owners (two private and one public), two lawyers, and one architect. The panelists were selected from major industry groups (e.g. Design-Build Institute of America, Construction Management Association of America, Associated General Contractors of America, American Institute of Architects, and etc), qualified through a rigorous procedure, and had at least 10 years of experience in the construction industry.

The workshop had two phases, unstructured discussion and structured evaluation. The unstructured discussion focused on reviewing the list of performance metrics and critical predictors of project success obtained from the literature. The industry advisory board provided valuable insight on new concepts, such as team integration and technology. Then, structured evaluations were conducted to rate the importance and availability of performance metrics and critical predictors. The results of the evaluation were used to refine the scope of the data collection procedure and select the most important and reliable variables. The results assisted the team in identifying comprehensive variables and refining the list to a manageable number for data collection.

5. Results and Discussion

Dependent variables representing project performance, and independent variables that predict project performance were identified from the literature, supplemented by industry experts, and rated according to their importance and availability. The workshop resulted in thirty dependent variables (performance metrics) and 64 independent variables (predictors). In total, 1408 ratings were obtained from the industry panel to rate the importance and availability of variables. The medians of ratings were calculated to aggregate the industry panel's opinions of specific variables. As shown in Figure 2, the median importance of dependent variables is plotted against their median availability. For this study, the research team decided to focus on the upper right quadrant of this plot, which identified variables that are both very important and readily available for most projects.

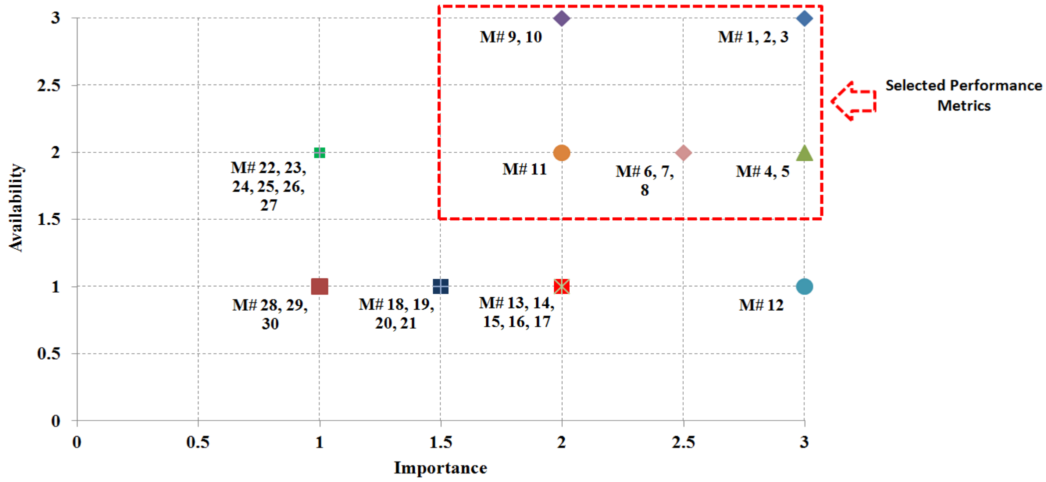

Figure 2. Representative importance and availability of dependent variables

The data needed to calculate the project performance metrics is shown in Table 1. Performance metrics usually measure change from the original contract's time and cost. As it was expected, cost, schedule, and quality are among the most important performance metrics. Another important measure is intensity that combines cost, time, and size into a single metric. In addition, to obtain a more accurate picture of the real cost of projects, unresolved claims and change orders should be tracked. Measuring these metrics is critical to compare the project performance among different delivery methods.

Similar to performance metrics, the variables that may affect or predict project performance were identified from the literature, complemented by industry experts, and rated according to their importance and availability. Then, the median of ratings were calculated to rank the variables. From the 64 identified variables, 45 were selected to be included in the survey as shown in Table 2. Many of these variables are explained in previous studies; however, there are three new categories that have not been investigated sufficiently: (1) team integration, (2) team behavior, and (3) process and technology.

5.1.1 Team Integration

One of the challenges with the potential to limit project performance in the construction industry is the fragmentation of parties in different phases of the project. In addition, the ability to influence project performance decreases dramatically as the project proceeds. Therefore, it is often rewarding to involve all team members that influence project performance in the early stages of the project. To facilitate such team integration, practitioners began to use innovative project delivery systems such as Integrated Project Delivery (IPD). The common principals of IPD are described by Kent and Becerik-Gerber (2010) and include a multiparty agreement, shared risk and rewards, and early involvement of all parties. To increase collaboration among key players in IPD projects, one contract is used for entire project that is entered by the owner, architect, general contractor and other parties. In addition, to focus on project success, risk and rewards of all team members are shared and the contract encourages collaboration among team members to fulfill common project goals. Furthermore, one of the main benefits of IPD is to involve all parties from the earliest design phase of the project. Such an early involvement can lead to innovative solutions brought up by designers or contractors to avoid inefficient work practices and costly changes late in construction phase. Therefore, several questions were designed to capture the indicators of team integration such as the presence of a multi-party contract, shared risk and rewards, and early involvement of all parties. For example, the percentage of design completion when each stakeholder was involved was described as a predictor of project success.

Table 1. Representative project outcomes (dependent variables)

#	Metrics	Importance	Availability	Data Needed
1	Unit cost ($/SF)	3	3	Final project cost (Design + Construction) Gross square footage (SF)
2	Schedule growth (%)	3	3	As-built design start As-built substantial completion
3	Intensity ($/SF/Month)	3	3	Gross square footage (SF) Final project cost (Design + Construction) As-built design start As-built substantial completion
4	Quality (turnover, system, and design)	3	2	Start-up difficulty Call back frequency O&M costs Structure & envelope expectations met Interior expectations met Environmental system expectations met Aesthetic expectations met Functional expectations met
5	Unresolved claims and change orders (%)	3	2	Estimated cost of unresolved claims and change orders Final project cost (Design + Construction)
6	Cost growth (%)	2.5	2	Final project cost (Design + Construction) Awarded project cost (Design + Construction)
7	Delivery speed (SF/Month)	2.5	2	Gross square footage (SF) As-built substantial completion
8	Construction speed (SF/Month)	2.5	2	Gross square footage (SF) As-built construction start
9	LEED award	2	3	Sustainability certification level Expected number of credits planned vs. Actual number of credits received
10	Recordable incidents	2	3	Number of recordable incidents
11	Energy utilization index (kBtu/SF/Yr)	2	2	Gross square footage (SF) Total energy consumed in one year (kBtu/Yr)

5.1.2 Team Behavior

The main indicators of team behavior are the effectiveness of communication and the transfer of knowledge among team members. Successful completion of a project requires extensive knowledge exchange among different project parties. In addition, due to mutual dependent nature of construction activities, timing and quality of communication and knowledge exchange significantly affect project performance (Rojas and Soneger 1999). The lack of strong communication can lead to misleading and unclear perception of the design drawings, reports, contracts and work orders which can negatively affect the project performance (Oberlender 2000). Therefore, by improving the frequency and quality of communication, the probability of satisfying the client's requirements and priorities increases. To measure team behaviour, questions were developed to ask about the quality of knowledge sharing, communication latency and open book accounting policy.

5.1.3 Process and Technology

Resulting from workshop discussions, several new major processes and technologies were identified with an impact on project performance: design charrettes; off-site manufacturing; using BIM execution planning; and using lean tools. First, a design charrette is an intensive brainstorming activity in which participants collaborate to complete a design project in a finite amount of time. Questions were developed to ask whether design charrettes were used in the project and who were involved in the process. Second, the industry panel stated that using off-site manufacturing can affect project performance. There are several advantageous to using off-site manufacturing (Ting 1997, Tam et al. 2007): better supervision on improving the quality of prefabricated products; reduce overall construction costs; shorten construction time; environmental performance improved for waste minimization; integrity on the building design and construction; aesthetic issues on the building; and reducing the waste. To consider the effect of off-site manufacturing, a question was included in survey to ask the number of hours devoted to off-site work.

Table 2. List of predictors (independent variables)

Categories	Predictor
Delivery Method	Project delivery methods (e.g. DBB, CMR, DB, IPD, etc.) Specific type of contract used (AIA, ConcensusDocs, etc.) Time of involvement of key project participants
Team Selection	Proposal solicitation method (open call, prequalified bid, RFP, etc.) Selection method (low bid, negotiated, best value) Selection criteria in negotiated or best value (price, prior experience, Interview performance, etc.)
Contract Types	Payment terms (e.g. lump sum, GMP, cost plus fee, etc.) Incentives Alternative dispute resolution Partnering Multi-party contract Regulatory/legal constraints Onerous contract clauses
Team Characteristics	Scope definition and flexibility Team experience with similar building type and delivery system Owner relationship with other team members (first time vs. repeat) Team's prior experience as a unit Project team chemistry Work split (direct hire/subcontracted) Owner decision making process and ability Turnover rate End user involvement
Team Behavior	Information sharing Communication between team members Communication latency Contingency management Open book accounting policy Joint project manager
Process And Technology	Using design charrettes Off-site manufacturing Co-location Using BIM execution planning Using Lean tools (e.g. Last Planner)

The third element was using Building Information Modeling (BIM) in the project. BIM is defined by the National Institute of Building Sciences as a “digital representation of physical and functional characteristics of a facility,” that is, a shared knowledge resource for facility information that facilitates decision making throughout the project life cycle (National Institute of Building Sciences 2007). BIM is a process that enables the project team members to collaborate in project life cycle from early design to occupancy which can result in increased building value, shortened project schedule, reliable and accurate cost estimation, program compliance, market-ready facilities, and optimized facility management and maintenance (Eastman et al. 2008). The findings of the workshop indicated that the ownership of the intellectual property of BIM, application of the BIM (e.g. clash detection, 4D scheduling, and etc), and frequency of updating execution plans are critical in project performance.

The last influential element under the process and technology category was lean construction, which is defined as “a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value" (Koskela et al. 2002, p. 221). Lean production focuses on the reduction of waste, increase of value to the customers, and continuous improvement. Questions were developed to ask whether lean tools were used in the project. Some of the lean tools include but not limited to (Antillón 2010): look-ahead process; constraint analysis; backlog of ready-work; Last Planner process; root cause analysis; Just-In-Time; autonomation (Jidoka); production leveling (Heijunka); standardization; continuous improvement (Kaisen); and visual management tools. In one of the recent studies, Sacks et al. (2010) investigated the interaction between lean and BIM and found that utilizing these paradigms simultaneously can improve construction processes. They also stated that companies implementing any of these paradigms should consider the application of the other one to corroborate their performance. Among all delivery methods, it is believed that the IPD can facilitate the use of BIM and lean concept more than the others.

6. Conclusions

By considering that "construction project success is repeatable" (Ashley et al. 1987, p. 69), there is value in investigating completed projects and identifying variables that influence project success. This desire led several researchers to construct empirical databases of construction projects to find meaningful relationships between these project variables and project outcomes. However, many of these studies are losing their relevancy due to introduction of new concepts such as IPD, the importance of knowledge transfer, and adopting new process and technologies such as BIM. Therefore, there is an emergent need to develop a new project delivery database. The cornerstone of establishing a reliable database is the development of a comprehensive survey data collection instrument to capture the required information about the project.

To address these recent changes in industry, this study was conducted to determine the essential elements of a comprehensive project delivery questionnaire. An in-depth literature review was conducted to identify the critical variables that should be captured in the database. In addition, an advisory board was formed from industry experts across multiple disciplines to review the selected topic areas and provide insight into potential survey questions in a two-day workshop. There were two main obstacles in developing a comprehensive survey instrument tool: the survey should be concise to assure large number of responses while important variables are collected; and the collected variables should be reliable and objective. To overcome these obstacles, the advisory board rated the importance and availability of variables and the highly rated variables were selected for inclusion in the final survey instrument. The academic contribution of the study is to develop a survey instrument based on the importance and availability of data that should be gathered. The study contributes to practice by assisting practitioners in creating an empirical project delivery database. The final results of the study will empower owners to make informed decisions regarding the project delivery selection to drive successful levels of integration on their projects.

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