A Project Performance Rating Model for Water and Wastewater Treatment Plant Public Projects

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ABSTRACT

Water and Wastewater construction capital projects are distinctive, highly complex, and do not currently have well-established overall performance rating models to assess their projects' success. Project performance used for gauging the overall success of project delivery is a complex concept that cannot be measured by one factor. It involves several criteria with many factors that need to be accounted for. Data from forty three water and wastewater projects delivered using the traditional Design-Bid-Build (DBB) delivery method is collected to form a dataset that is utilized to build a Project Performance Rating (PPR) model. The developed PPR model combines the key performance factors of a project into one performance index. The PPR model is tested on a controlled case study project delivered by infusing certain Integrated Project Delivery (IPD) principles into the DBB delivery method. The PPR Model showed the implementation of the IPD principles to improve the performance of the case study project by a factor of 1.3. The developed model is a tool that helps utility owners compare the performance of various projects while getting a detailed insight into critical problem areas that are likely to impact performance rating.

Keywords: Project Performance, Performance Factors, Water Treatment, Wastewater Treatment, Public Projects, Design-Bid-Build, Integrated Project Delivery (IPD).

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INTRODUCTION

Assessing the level of success of completed projects is essential to owners and contractors alike. Although researchers have studied this concept, no agreement has been reached on how to measure the level of project success. The fact that the concept of project success remains loosely defined has left owners and contractors allocating resources in an ad hoc approach to meet various, and sometimes contradicting, project goals.

Project success is a complex concept that cannot be measured by one performance factor. It involves several success criteria and corresponding performance factors that need to be accounted for. Many early studies have identified critical success criteria in construction projects, such as Sanvido et al. (1992), Chua et al. (1999), Chan et al. (2001 and 2002), Odeh and Battaineh (2002), Mohamed (2003), Chan et al. (2004), and Rashvand and Abd Majid (2014). Time, cost, and quality are identified in almost all studies as the critical success criteria of a project (Chan and Chan, 2004). In addition to these basic criteria, other—so called "soft"—criteria have also been identified such as interpersonal relations between the project participants (Pinto and Pinto, 1991) and absence of legal claims (Pocock et al., 1996). However, these studies compared different projects based on one or more of these individual success criteria and fell short of combining them into a comprehensive model that can quantify the overall project success.

More important to this study is later research that attempted to develop models and frameworks to quantify project success. Such models use the measurement of a series of identified key performance indicators (KPIs) of projects to quantify their success. Some of these models, such as those developed by Alarcon and Ashley (1996), Lam et al. (2007), and Liu et al. (2014) use subjective evaluation of KPIs based on construction experts' knowledge and experience, thus limiting their validity. Other models, such as the one developed by Cha and Kim (2011), use simple linear summation of selected KPIs values, along with the relative importance of each KPI, in order to obtain the performance score of the project. More recently, Hanna et al. (2014) and El Asmar and Hanna (2016) used the rating method of the quarterback position on American football teams, which combines key sports metrics to compare quarterbacks' performances, as an approach to assess the performance of construction projects. Their rating model used a complex algorithm that combined seven performance areas, namely: customer relations, safety, schedule, cost, quality, profit, and communication into one comparable score for each project. Most recently, Leon et al. (2018) used system dynamics to forecast the performance of unit price construction projects by integrating eight performance measures: cost, schedule, quality, profitability, safety, environment, team satisfaction, and client satisfaction. The lack of raw data from a large number of actual projects being incorporated in these models limits their functionality as tools for benchmarking a project's performance with respect to others. Other project-based performance models that used raw data from actual projects to develop a baseline of performance metrics, such as the one developed by Francom et al. (2016), compared only a limited array of success indicators like cost and schedule.

A review of literature to date shows no studies that have quantified project success into a performance index that is obtained from a model incorporating all success factors and using raw data for baseline comparison with past projects. Furthermore, water and wastewater construction capital projects do not currently have a well-established performance rating model. This paper bridges this gap and offers two major contributions to the construction engineering and management body of knowledge: (1) it presents the development and implementation of the first project performance rating (PPR) model for water and wastewater construction projects through a single comprehensive index using raw data; and (2) it demonstrates the positive impact that IPD has on the project performance of traditional DBB projects. The PPR is developed using various key performance factors in an algorithm that yields an overall project performance index. The aim is to have a model that allows owners and contractors to compare the success level of past projects and determine critical problem areas, as well as identifying practices that can be infused into the project delivery in order to improve certain key performance indicators.

The success criteria and the corresponding success factors adopted in this study for performance measurement are first described, followed by an illustration of the KPIs used to quantify these success factors. The PPR model framework and the raw data used to develop the model and benchmark projects' performance are then presented. The mathematical formulations for the performance factors scores are then defined and the PPR algorithm is expressed mathematically. To demonstrate the application of the model, a case study project is used and assessed using the proposed model. Finally, results are presented, analyzed and discussed.

SUCCESS FACTORS AND KPIs

Before discussing the project success criteria and performance factors adopted in this study, it is important to draw the distinction between the two. Success criteria are the dimensions of a project by which the project success or failure will be judged. Success factors or performance factors are those measures which contribute to achieving success in each criterion. Based on existing literature, five project dimensions were identified as the basic criteria for measuring success of water and wastewater construction capital projects. The first three criteria are those comprising the iron triangle of project success: cost, time, and quality. The fourth and fifth success criteria adopted in this study are customer satisfaction and early involvement. Nine performance factors were selected through a review of existing literature and the opinion of a focus group comprising owners, engineers, and contractors of DBB water and wastewater construction projects. The performance factors were used for measuring the project success in the various success criteria: (1) cost overrun, (2) change orders (CO) cost, (3) time overrun, (4) request for information (RFI), (5) errors and omissions cost, (6) claims, (7) RFI response time, (8) field rework, and (9) owner-requested changes. The performance factors for each of the five success criteria are shown in Figure 1.

Figure 1

In order to quantify project performance, a set of KPIs, denoted by x_j, were used to measure each of the nine performance factors. Those KPIs are functions of a vector $\vec{d}$ composed of a number of well-defined parameters of a project, as shown in Equation 1. In order to eliminate any bias resulting from the project size, KPIs were normalized by the total project cost.

$$x_j = f(\vec{\boldsymbol{d}}) \quad (1)$$

$$where\ j = 1,2,3,\dots,9 \qquad and\ \vec{\boldsymbol{d}} = \begin{bmatrix} \boldsymbol{d_1} \\ \boldsymbol{d_2} \\ \boldsymbol{d_3} \\ \vdots \\ \boldsymbol{d_i} \end{bmatrix}$$

(1) Project Cost: this includes the ability to control and adjust the project contract costs and cost reductions through value engineering. The main consideration when evaluating project cost is the measurement of the contractor's performance against the bid cost of the contract. Construction cost performance is relatively easy to track because project teams keep useful records of several cost items for different project phases. Two KPIs were used to quantify the cost performance of a project: *cost overrun as a percentage of the total project award price*, and *change order cost as a percentage of total project cost*. The values for these KPIs are obtained from the expressions shown in Equations 2 and 3, respectively.

$$x_1 = Cost\ Overrun\ \% = \frac{Actual\ Project\ Cost - Award\ Price}{Award\ Price} \times 100 \quad (2)$$

$$x_2 = Change\ Order\ Cost\ \% = \frac{\sum Cost\ of\ Change\ Orders}{Actual\ Total\ Project\ Cost} x100 \quad (3)$$

A change order cost covers the work that is added to or deleted from the original scope of work of a contract. Common causes for change orders are: 1) Design Errors and/or Omissions, 2) Unforeseen Conditions that are realized on site during construction, and 3) Owner's request substitutions or changes.

(2) Project Schedule: this performance factor reflects the timely and efficient preparation, implementation and closeout of tasks, meeting key program milestones and contractual delivery dates, recovery from delays, and appropriateness of response to changes. A single KPI was used to quantify the schedule performance of a project: *time overrun as a percentage of the original project schedule*. The value for this KPI is obtained from the expression shown in Equation 4.

$$x_3 = Time\ Overrun\ \% = \frac{Actual\ Project\ Duration}{Scheduled\ Project\ Duration} x100 \quad (4)$$

where Actual Project Duration is calculated as the time span between the *Notice to Proceed* date and the date when all work has been completed.

(3) Quality: a good design typically includes detailed approach in design concepts, analysis, and detailed execution procedures, thoroughness and accuracy. Such a design is also based on meeting technical requirements for design, performance and processing, reliability, and adequate design reviews. Two KPIs were used to quantify the quality performance of a project: *number of RFIs per unit price*, and *errors and omissions cost as a percentage of total cost of change orders*. The values for these KPIs are obtained from the expressions shown in Equations 5 and 6.

$$x_4 = RFIs\ per\ Unit\ Price = \frac{Total\ Number\ of\ RFIs}{Actual\ Total\ Project\ Cost} \quad (5)$$

$$x_5 = Errors\ and\ Omissions\ Cost\ \% = \frac{\sum Cost\ of\ Errors\ and\ Omissions\ CO}{\sum Cost\ of\ Change\ Orders} x100 \quad (6)$$

(4) Customer Satisfaction: a successfully managed and delivered project is one which results in customer satisfaction and repeat business. A project's performance with respect to owner satisfaction can be measured by the amount of claims resulting from that particular project. Construction claims can typically arise from many root causes related to schedule and cost overruns. Disputes often arise between contractors and owners based on project performance of involved parties, scope discrepancies, and quality of work performed and materials delivered. Therefore, the number and cost of construction claims is a KPI that provides insight into the team's relationships and their ability to resolve disputes before they escalate to claims. Claims are thus a critical performance factor for customer satisfaction since an owner is unlikely to hire a contractor in the future if the current project resulted in high number of claims. The KPI used to quantify the customer satisfaction performance of a project: *total claims cost as a percentage of the total project cost*, as shown in Equation 7.

$$x_6 = Total\ Claims\ Cost\ \% = \frac{\sum Direct\ Cost\ of\ Claims}{Actual\ Total\ Project\ Cost} x100 \quad (7)$$

where the *Direct Cost of Claims* is the amount of money paid by the owner, contractor, or design professional as resolution of disputes as ruled by mediation, litigation, or arbitration.

(5) Early Involvement: effective communication and collaboration among project participants are signs of a well-developed relationship among project participants, and are essential at all levels where decisions can be made and results achieved. Frequent and honest communication improves project efficiency through reduced RFI response time, improved labor relations, reduced owner-requested changes, and field rework through improved planning, organizing, and managing of all program elements. Management actions are needed to achieve and sustain a high level of communication and collaboration, thus resulting in recognizing critical problem areas

and ensuring integrated operational efficiency. Three KPIs were used to quantify the performance of a project as it relates to early involvement: *RFI response time per project cost, cost of field rework as a percentage of total project cost, and owner requested changes as a percentage of total cost of COs*. The values of these three KPIs can be obtained from the expressions shown in Equations 8 through 10.

$$x_7 = RFI\ Response\ Time\ per\ Unit\ Price = \frac{Average\ RFI\ Response\ Time}{Actual\ Total\ Project\ Cost} \quad (8)$$

$$x_8 = Total\ Cost\ of\ Field\ Rework\ \% = \frac{Total\ Direct\ Cost\ of\ Field\ Rework}{Actual\ Total\ Project\ Cost} x100 \quad (9)$$

$$x_9 = Owner's\ CO\ Cost\ \% = \frac{Total\ Cost\ of\ Owner's\ CO}{\sum Cost\ of\ Change\ Orders} x100 \quad (10)$$

Field Rework is typically caused by poor communication among the project participants. *Owner's CO Costs* are generated based on lack of pre-construction coordination with the owner and lack of owner's involvement during design to express their needs and preferences.

RAW DATA COLLECTION

When evaluating the performance of a project, it is essential to first develop a baseline for project performance comparison using raw data from actual similar projects. Project performance data for water and wastewater construction projects delivered using the most traditionally-used method of design-bid-build (DBB) was collected from water utilities in South Florida. Such project data was obtained from in-house documents and intranet databases of the water utilities owners. First, all water utilities in South Florida were contacted in order to identify the population of water and wastewater projects completed since the year 2000. The population was found to be 60 projects of varying sizes. Second, the performance data of these projects was examined to determine whether sufficient information was available for them to be included in the statistical analysis. Some projects had insufficient records with missing data with regards to one or more performance factor, and thus had to be excluded from the analysis. The remaining 43 projects formed the dataset for this study.

When categorized by their total base contract value, the raw dataset encompassed projects of varying, but somewhat uniformly distributed sizes, thus making up a highly representative and unbiased sample of the population. Figure 2 shows the project size categories and the total number and percentage of projects falling in each category. The somewhat normal distribution of project sizes makes the dataset a good representative of the entire water and wastewater construction market. Figure 3 shows the number of projects per award year and their average contract value.

Figure 2

Figure 3

Using the collected raw data, the KPI values of the nine performance factors were calculated for each of the 43 projects. The means and standard deviations of the dataset were then computed for each of the nine KPIs, as summarized in Table 1.

Table 1

PPR MODEL FRAMEWORK

The PPR model was designed to have an algorithm consisting of a three-level series of computations leading to an overall performance index for a project. The first level (Level I) in calculating the performance index of a project consists of evaluating its KPIs for each of the nine identified performance factors. Level II involves combining—for each of the five success criteria—the values of the relevant performance factors to yield a numerical score for each success criterion.

The third and final level (Level III) consists of combining the scores of the five success criteria into a single performance index that allows the user to quantitatively assess the overall project success.

Mathematical Formulation

Level I

Since the KPIs used in this study have non-homogeneous units, values for different performance factors cannot be simply added together, and standardization is necessary. A standardization method is used that can transform any set of numbers to their equivalent values on the standard normal distribution by subtracting the mean and dividing by the standard deviation, as expressed is Equation 11.

$$Z_j = \frac{x_j - \mu_j}{\sigma_j} \qquad (11)$$

where Z_j is the standardized value of a KPI, x_j is the value of the KPI as calculated from Equations 2 through 10, and where μ_j and σ_j are, respectively, the mean and standard deviation of the KPI as calculated from the dataset of past projects (from Table 1).

The measurement units of the standardized value Z_j of a particular KPI are therefore the number of standard deviations (N) above or below the mean of the dataset for that KPI (μ_j). Equation 12 was then developed and used to calculate the score for each performance factor, designated by a_j, using the standardized value Z_j of its corresponding KPI.

$$Performance\ Factor\ Score = a_j = 10 \times \left(\frac{-Z_j + N}{2N}\right) \quad \text{where } -N \leq Z_j \leq N \qquad (12)$$

Equation 12 is designed in such a way so as to yield a performance factor score that is based on a variable scale between 0 and 10; zero being the lowest performance score and 10 being the highest.

N is a user-specified value which represents the number of standard deviations from the mean that designate the boundaries of the performance measurement scale. For example, and as shown in Figure 4, an owner choosing a value of N = 2, is basically choosing to have a project whose Z_j value of a particular performance factor is above $2\sigma_j$, to have a performance score of zero. Similarly, by choosing a value of N = 2, a project whose Z_j value of a particular performance factor is below $-2\sigma_j$ will have a performance score of 10. It is important to point out that due to the nature of the KPIs which measure indicators such as cost and schedule overruns, cost of change orders and claims, negative values of Z_j indicate above average performance while positive values indicate below average performance, while zero indicates the average project performance with respect to a specific performance factor. Hence, the performance factor score values are obtained by multiplying Z_j in Equation 12 by -1. Table 2 summarizes the use of Equation 12.

Table 2

Figure 4

A higher N value increases the score of a performance factor for a positive value of Z and decreases the score of a performance factor for a negative value of Z. Choosing a value for N is thus subjective and should be determined by the owner depending on the project. For example, an owner might choose a value of N=2 for projects exceeding $10 million and N=3 for projects equal to or less than $10 million. Other owners might choose the value of N based on the level of complexity of the project.

Level II

Once the standardized Z_j value is calculated for each KPI using Equation 11, and the corresponding performance factors scores (a_j) are computed using Equation 12, the overall score for each of the five success criteria can be obtained. This is done by simply adding the scores of the performance factors contributing to each success criterion, after multiplying them by user-assigned weights, as expressed in Equation 13. The user-assigned weights allow the owner to customize the model by increasing the importance of one performance factor over the other, depending on his specific needs and preferences.

$$S_k = \sum_{j=m}^{n} \omega_j a_j \qquad k = 1,2,\ldots,5 \qquad 1 \le [m,n] \le 9 \tag{13}$$

where ω_j are the user-assigned weights for each performance factor a_j, and are chosen such that:

$$0 \le \omega_j \le 1 \;;\; and \;\; \sum_{j=m}^{n} \omega_j = 1$$

Equation 14 demonstrates how the score (S_1) of the success criterion related to *project cost* is obtained. It can be seen that the standardized value Z_j for each of the two KPIs and the corresponding performance factor score are formulated separately in the expression of Equation 14.

$$S_1 = \sum_{j=1}^{2} \omega_j a_j$$

$$Project\ Cost\ Score = \left\{\omega_1 \times 10 \times \left[\frac{-\left(\frac{Cost\ Overrun\ \Delta\% - 7.38}{6.59}\right) + N}{2N}\right]\right\} + \left\{\omega_2 \times 10 \times \left[\frac{-\left(\frac{Change\ Order\ Cost\ \% - 5.83}{5.40}\right) + N}{2N}\right]\right\} \tag{14}$$

Similarly, the scores of the remaining four success criteria are determined by applying Equation 13 separately to each one of the success criteria.

Level III

The third and final level of the PPR algorithm involves the determination of the overall performance index of the project. The performance index is expressed as the linear weighted sum of the five success criteria scores, as expressed in Equation 15. Users of this model can adjust the weights of the success criteria based on specific needs and perceived importance of individual performance criteria for their project. A score (S_k) will be computed for each of the five success criteria, and subsequently plugged into Equation 17 to obtain an overall performance index for a project.

$$PI = \sum_{k=1}^{5} \gamma_k S_k \quad (15)$$

Where γ_k is the user-assigned weight for each success criterion S_k, and are chosen such that:

$$0 \leq \gamma_k \leq 1 \ ; \ and \ \ \sum_{k=1}^{5} \gamma_k = 1$$

These user-assigned weights allow users to customize the model in a way so as to relate directly to the various project goals and objectives that the user sets out to achieve at the beginning of the project. For example, one owner might value high quality of the project as a more important indicator of success than within-budget completion. Also, the same owner might in one expedited project value on-time delivery of the project as a more important indicator of success than cost. These user-assigned weights can thus allow the user to tweak the model to meet the special conditions of each project without the need to modify the algorithm.

CASE STUDY

A wastewater construction project was used as a case study for demonstrating the use of the model and verifying its output. The case study project is Final Site Work at Miami Dade Water and Sewer Department, which started in the first quarter of 2013 and was completed in middle of 2014. The case study project was delivered using the traditional DBB delivery method, but with some selective infused IPD principles. The project team consisted of owners, engineers, construction managers, contractors, and accountants. The first author of this paper served as the construction manager on this project, thus allowing the research team access to collect critical data related to the project parameters $\overrightarrow{d_\iota}$, while at the same time having the ability to fully plan, implement, and administer IPD principles into the delivery of the project.

A number of constraints limited which IPD principles could be integrated into the case study project. The first constraint is the public nature of the case study project—the regulations and limitations of which preclude the implementation of certain IPD principles. The second constraint is related to the contract documents language and requirements of the case study project which limited the implementation of certain IPD principles. Accordingly, the selected IPD principles and practices that were integrated with the case study project by the research team are described below.

1- Open Communication within the Project Team and Ability to Address Issues

Essential team meetings and collaboration among project participants help in opening venues for more communication. The research team (construction manager) held weekly progress meetings with the contractor, consultant, owner and other stakeholders who have the ability to address issues. The weekly meeting agenda was set to discuss the progress of each element of current work, schedule revisions, milestone dates and updated contract cost and time. Within three days after each meeting, copies of the meeting minutes, including a brief summary of the progress of the work were distributed to all project participants.

In addition to weekly meetings, the research team held informal daily meetings between the construction manager and the general contractor, regardless of the presence of any issues to help stay updated with the progress and to be prepared for any upcoming conflict. Open communication through phone conversations between the engineer and the general contractor were kept frequent as well. For example, the contractor would call to notify the engineer of any engineering documents requested by the Miami Dade Building Department officials. The engineer would also call the contractor requesting clarifications or supplemental information during shop drawing review process to expedite its approval. This helped with addressing issues faster and conveying messages right on the spot. Phone calls to different parties disseminated resolved problems and addressed issues expeditiously.

2- Integrated and Collaborative Teams

The project team was led by the construction manager in a collaborative manner, by having the project participants working as team members not as adversaries. This was accomplished by maintaining integrity among project participants. The contractor's project manager, consultant's construction manager, and the owner's representatives have performed several previous projects which helped in establishing good working relationships. The past experience on previous construction projects assisted in promoting a collaborative team environment with chemistry among the key project participants on the case study project.

The study also prompted integration and collaboration by introducing social activities outside the workplace. These activities included Halloween pumpkin carving, breakfast fundraising for breast cancer awareness, Thanksgiving lunches, Christmas lunches, Easter egg decorating contest, and other activities. All parties participated in these activities and helped in organizing the events. These activities are essential in bringing people together and promoting friendship.

3- Lean Principles

During the design phase, and before the research team joined the project, lean principles were integrated in the design process and were focused on maximizing value and eliminating waste. During the execution phase, the efficiency of lean principles was increased by adhering to the construction project schedule through monthly construction schedule updates that were required to be submitted for review and approval by the engineer. The research team also required detailed two-week "look ahead" schedules to be prepared and thoroughly reviewed during the weekly progress meetings. The process of eliminating waste, meeting or exceeding all project requirements, focusing on the entire value stream, and pursuing perfection in the execution of the project was continuous and was monitored closely by the research team throughout the project execution with corrective actions taken immediately.

4- Co-location of Team

Co-location increases opportunities for collaboration and innovation, and helps in meeting project goals and commitments. On the case study project, this was done after the project was awarded to the contractor. The owner provided for approximately one (1) acre of contiguous physical space on site for project participants. This space included a 700 m^2 pre-engineered metal building for the owner, engineers, and construction manager (research team), 2,880 m^2 of field office parking, and a 2,323 m^2 of trailer city for contractors and subcontractors. In addition to the engineers and contractors, the onsite team included schedulers, accountants, inspectors, state inspectors general, document control staff, safety officers, and auditors.

5- Performance Evaluations

Evaluations are useful in determining defects in a program and in providing information necessary to improve current performance. On the case study project, the owner was asked by the research team to fill monthly performance evaluations for both the contractor and the consultant. In addition, the research team required the consultants to evaluate their personnel yearly including engineers and construction managers. Those performance evaluations helped improve the project's effectiveness and the overall program.

6- Mutual Respect and Trust

For a successful IPD implementation, a level of trust needs to be developed among the project participants so that they will not be taken advantage of during the project. Ghassemi and Becerik-Gerber (2011) demonstrated through case studies that trust comes in two ways: preexisting trust and forced trust. Where preexisting trust does not exist, a set of tools and activities will need to be implemented to allow the project team members to acquire trust forcefully. In the case study project, preexisting trust was present among the owner, consultant, and contractors due to having had repetitive work and good long lasting work relationships from the previous projects. In addition, forced trust among the project participants was promoted through transparency, open conversations, and collaboration from the inception of the project. This tremendously assisted in promoting a mutual respect and trust environment among the key participants in the case study project.

7. Jointly Developed Project Target Criteria

Carefully defining project performance criteria early in the design phase with the input, support, and acceptance of project participants ensures that maximum attention to be paid to the project. For the case study project, Jointly Developed Project Criteria was planned and agreed upon with the project participants during the design phase and during preconstruction phase. During the execution phase, the construction manager held monthly meetings with the contractor, consultant, owner and other stakeholder to monitor and update the jointly developed project target criteria. For example, the case study project was among other projects that were required to be in compliance with a Consent Order with the Florida Department of Environmental Protection (FDEP). One of the main project target criteria was to meet the milestone dates and satisfy all other Consent Order requirements. Structured jointly developed project criteria meetings were key in meeting those requirements.

8. Collaborative Decision Making

On the case study project, the construction manager formed a leadership team including the contractor, consultant, owner and other stakeholder for decision making purposes. The team held monthly meetings and provided recommendations on decision making priorities and activities and communication tools towards enhancing system efficiencies for the project. The team also assigned specific tasking to develop options for potential opportunities that could be beneficial for the project.

PPR Implementation

The PPR model is implemented on the case study project to demonstrate its use. In order to do so, critical project parameters $\overrightarrow{d_\iota}$ were collected by the research team for the case study project, as summarized in Table 3. The KPIs, x_j, were then computed, followed by the standardized value, Z_j, for each KPI, and the performance factors scores, a_j based on a value of N=2, as summarized in Table 4.

Table 3

Table 4

The performance index (PI) of the case study project was subsequently calculated to be 6.98, using a series of user-defined weighing factors, ω_j and γ_k, that were chosen by the project owner.

Four additional simulations using randomly-selected weighing factors, ω_j and γ_k, were conducted to examine the sensitivity of the project PI to the choice of weighing factors—the results of which are summarized in Table 5.

Table 5

Figure 5 shows the PI of the case study project for each of the five simulation runs and the corresponding performance improvement over the average of the dataset. The PI of the case study is on average 36.2% higher than the average PI of the dataset (dataset PI = 5.00), and in one instance is as much as 43.8% higher. This implies that the case study project performed noticeably better than average, despite the major limitations that prevented the implementation, during the design and construction phases, of the full array of commonly agreed-upon IPD principles.

Figure 5

In order to better understand the effect of implementing IPD principles on the overall success of public wastewater projects delivered using traditional DBB, the percentage improvement is calculated separately for each performance factor of the case study project. Table 6 summarizes the percentage change (Δa_j) in the performance factors scores for the case study project.

Table 6

The results indicate improved scores for most performance factors of the case study due to the implemented IPD principles. While project performance related to *field rework* shows the highest sensitivity to the benefits of IPD, performance related to *owner requested changes* shows the lowest sensitivity to IPD. This can be attributed to the fact that implemented IPD principles do not limit the owner from issuing change orders due to a change in preferences during construction. The project performance related to *change order cost* has shown a 21.48 % decline in the case study. This was due to changes in the scope that were related to unforeseen conditions and design deficiencies that were beyond the stakeholder's control during the construction phase. Implementing IPD principles during the design phase of a DBB project could have prevented such a below average score.

CONCLUSIONS AND LIMITATIONS

This paper provides owners and contractors of water and wastewater capital construction project with a simple-to-use model for accessing the success of a project relative to database of past projects delivered using the traditional DBB delivery method. Through a review of relevant literature, success criteria for a project along with the corresponding success factors were identified. A number of KPIs were developed to quantify those success factors based on a vector of critical project performance data. Using a dataset comprised of 43 actual water and wastewater projects delivered using DBB, an algorithm was developed and presented for computing a single-number performance index for a project. The algorithm leaves room for users to customize the model in a way so as to satisfy their specific preferences with regards to the relative importance of each success factor and success criteria. A case study project—managed by the research team and delivered by infusing a number of IPD principles into the traditional DBB delivery method—was used to demonstrate the use of the PPR model.

The application of the PPR model on the case study project demonstrated the ease of use of the model and the insight it can give the user about the various performance areas of the project being evaluated. The case study showed an improvement in the overall performance index of the project by a factor of 1.36 over the dataset. The implementation of IPD principles in the delivery of the project resulted in performance improvement in all success factors, with the exception *change order cost* which had a decline in its performance score. While the performance index varied with the choice of different user-assigned weights, all five simulation runs of the PPR model showed the implemented IPD principles to have a positive effect on the project performance regardless of the randomly-chosen values of ω_j and γ_k. While the model was developed based on a dataset limited to a specific geographical region, the uniformity in project size distribution and large number of selected projects included in the dataset renders the PPR model applicable to water and wastewater construction projects at large.

Despite benchmarking using single-value indices being a significant tool for measuring the level of success or failure of a project and for identifying methods for performance improvements, a single-number performance index is not without limitations. Since the performance index is specific to certain projects, it offers very little indication as to the performance of the industry or the organization from a business point of view. It also lacks the ability to incorporate the entire set of factors that can affect the performance of a project. Such factors as the project manager's competency, efficacy, and leadership are probably the most significant factors affecting project success as it is the people they manage who deliver the projects.

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Fig. 1. Project Performance Model

Fig. 2. Number and Percentage of Projects for Specified Range of Contract Value

Fig. 3. Number of Projects and Contract Average Value per Award Year

Fig. 4. Comparison of Performance Score to *Z*

Fig. 5. PI for Each Simulation Run

Table 1: Normalized KPI Mean and Standard Deviation of the Dataset

KPI	Mean (μ)	Standard Deviation (σ)
Cost Overrun %	7.38	6.59
Change Order Cost %	5.83	5.40
Time Overrun %	23.25	34.51
RFIs per Million Dollars Award Price	16.40	33.88
Errors and Omissions Cost %	27.68	25.23
Total Claims Cost %	4.85	14.21
RFI Response Time per Million Dollars Award Price	6.13	14.85
Total Cost of Field Rework %	0.93	0.058
Owner's CO Cost %	55.08	35.29

Table 2: Metric Standardization

KPI Standardized *Z*-Score (Z_j)	Performance Factor Score
$Z_j \geq N$	0
$Z_j \leq -N$	10
$-N < Z_j < N$	$10 \times \left(\frac{-Z_j + N}{2N}\right)$

Table 3: Case Study Project Parameters Summary

i	Project Parameter	$\vec{d_i}$
1	Project Award Price	$3,017,000
2	Project Total Actual Cost	$3,119,826
3	Total Cost of Change Orders	$ 254,115.27
4	Number of RFIs	10
5	Notice to Proceed Date	3/15/2013
6	Actual Completion Date	4/17/2014
7	Project Scheduled Duration	399 days
8	Cost of Errors and Omissions	$ 18,107.91
9	Total Cost of Claims	$0.00
10	Cost of Owner Requested Changes	$ 135,210.77
11	Cost of Field Rework	$0.00
12	Average RFI Response Time	3 days

Table 4: Case Study KPIs and Performance Factors Scores

j	Performance Factor	x_j	Z_j	a_j*
1	Cost Overrun	3.41 %	-0.60	6.51
2	Change Order Cost	8.15 %	0.43	3.93
3	Time Overrun	0.00 %	-0.67	6.68
4	RFIs	3.21	-0.39	5.97
5	Errors and Omissions Cost	7.13 %	-0.81	7.04
6	Claims	0.00 %	-0.34	5.85
7	RFI Response Time	0.96	-0.35	5.87
8	Field Rework	0.00 %	-16.03	10.00
9	Owner Requested Changes	53.21 %	-0.05	5.13

*Based on a value of N=2

Table 5: PPR Simulation Output Summary

PPR Model Simulation Trial Number	PI of Case Study
1	6.98
2	6.46
3	6.59
4	7.19
5	6.83
Average PI	6.81

Table 6: Case Study Performance Factors Improvement

Performance Factor	Δa_j
Cost Overrun	30.12 %
Change Order Cost	-21.48 %
Time Overrun	33.69 %
RFIs	19.47 %
Errors and Omissions Cost	40.73 %
Claims	17.07 %
RFI Response Time	17.40 %
Field Rework	100.00 %
Owner Requested Changes	2.65 %