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Exploring performance of the integrated project delivery process on complex building projects

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Abstract

Many building projects do not meet owners' performance expectations. Integrated project delivery (IPD) has emerged as a new delivery system with the potential to provide better performance through more supply chain integration. However, there is a knowledge gap surrounding how project delivery systems, IPD in particular, affect supply chain relationships and potential project performance. To fill this gap, we applied a simulation method, General Performance Model (GPM), to assess the interactions between numerous project delivery variables and compare potential performance between delivery systems. This study presents a GPM analysis of a complex hospital project and based upon cross-impact assessments by owners, architects, constructors, and specialty contractors from the building industry. The results found the most influential drivers of project delivery performance to be communication, alignment of interest and objectives, team working, trust, and gain/pain sharing. The performance of the supply chain was found to drive the project delivery performance.

Keywords: Project delivery; Integrated project delivery; Supply chain relationships

1. Introduction

The design and construction industry is changing in its approach to the integration of construction teams in the design process. Vertical building construction currently uses three primary project delivery systems: design–bid–build (DBB), construction management at risk (CMR), and design–build (DB). Owners choose these delivery systems, in part, to meet their goals for time, cost, and quality performance. Despite this range of options, many building projects do not meet the owner's performance expectations (Lichtig, 2006). Researchers often cite the lack of integration in these delivery systems as the reason for this poor performance. Authors suggest that the building design and construction industry needs to move towards a better coordination of participants and more collaborative approaches to overcome these problems (Egan, 1998; Latham, 1994; Mitropoulos and Tatum, 2000; Kim and Dossick, 2011). In recent years, the United States (U.S.) construction industry has started to use integrated project delivery (IPD) in attempt to achieve more collaboration and, hopefully, better performance.

The relevant literature analyzes the impact of the three primary U.S. project delivery systems on cost, time, and quality (Konchar and Sanvido, 1998; Hale et al., 2009; Thomas et al., 2002; Ibbs et al., 2003). While the IPD system proposes to be a response to poor performance in the design and construction industry, there is a knowledge gap surrounding how project delivery systems, IPD in particular, affect the project environment, supply chain relationships and potential project

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performance. Due to the number of required variables to analyze and the limited number of completed IPD projects, an empirical study of project performance is impractical. This research helps to fill the gap of knowledge by modeling IPD performance through a methodology of decision making and simulation called the General Performance Model (GPM) (Alarcón and Ashley, 1996, 1998). The GPM conceptual model was applied to a complex hospital project and cross-impact assessments were made by owners, architects, constructors, and specialty contractors from the building industry. While this paper presents an analysis of only one project application, the model can be applied more widely. The GPM analysis approach provides insights into how project delivery systems impact project performance at the supply chain level. The GPM model structure provides a contribution that researchers can use to explore project delivery performance with a multitude of project delivery, contracting, and procurement options.

This study addresses the following research question: How do the organizational strategy, contractual relationship, and supply chain relationships affect project delivery performance? In other words, we want to explore what factors drive project delivery performance and how the project delivery system creates an environment for people and processes to be successful. This research will add to the body of knowledge and delivery system research and help owners to choose appropriate systems for their projects.

The paper is organized in six sections. In the first section, we explain our research methodology. We then explain the GPM conceptual model and define main concepts such as the project delivery system and the supply chain. In the third section, we explain the data collection and the procedure for our consensus-building workshop. Next, we explain the GPM mathematical model assessment. In the fifth section, we present the analysis of simulation results along with the model sensitivity analysis and a discussion of project delivery performance. We conclude with a summary of the contributions to the body of knowledge, discuss the study limitations, and make suggestions for future research.

2. Methodology

Few studies have explored how the project delivery system is related to the project environment, supply chain relationships and potential project performance. The most often cited studies on project delivery system performance have applied statistical analyses of data from completed DBB, DB, and CMR projects to show which delivery system enables better project performance. The most common metrics relate to cost, time, and quality (Konchar and Sanvido, 1998; Hale et al., 2009; Thomas et al., 2002; Ibbs et al., 2003). However, a statistical study of IPD projects is impractical due to the low number of completed projects (El Asmar et al., 2013). Statistical methods also provide a limited understanding of the relationships between the project delivery factors that we wish to explore. Simulation modeling provides an alternative approach to exploring project delivery performance. Simulation modeling can take advantage of professional experience where aggregate project data are not available. It can also provide a richer understanding of the variables that drive performance.

Due to the nature of this research and the number of variables that require consideration, we chose cross-impact analysis (CIA) as an appropriate methodology of analysis. CIA allows for capturing uncertainty propagation and the interaction among variables inherent in a decision-making process (Tran et al., 2015). Researches have applied CIA in different areas in the construction industry. Calhoun and Hallowell (2010) conducted a pairwise cross-impact analysis to quantify the interaction among safety program elements. Tran et al. (2015) developed a hybrid CIA approach to project delivery decisions in highway design and construction. However, no previous study attempted to explore the relationship between project performance, delivery systems, and supply chain relationships through CIA.

In this research, we use an advanced form of CIA that was developed for strategic decisions in the design and construction industry, called General Performance Model (GPM) (Alarcón and Ashley, 1992, 1996). The GPM approach has been implemented in different areas in the construction industry. Venegas and Alarcón (1997) developed a model for the selection of long-term strategic planning approaches for construction firms. Alarcón and Mourgues (2002) developed a model for the selection of a contractor based on a set of performance criteria. Given the lack of project data for IPD projects, but the wealth of practitioner knowledge about project delivery processes, the GPM method is appropriate to measure potential IPD project performance in comparison to other available delivery systems. Additionally, the GPM approach has the ability to evaluate the simultaneous effect of multiple strategies and provide a sensitivity analysis of project outcomes on various factors (Alarcón and Ashley, 1996, 1998). Given the fact that these type of analysis is essential to answer the research questions, the GPM method is appropriate for this study.

The GPM methodology consists of conceptual and mathematical model structures. The conceptual model is a simplified model of the variables and interactions that influence project performance. The mathematical model uses cross-impact analysis and probabilistic inference to capture the uncertainties and interactions between project variables. A generic GPM conceptual model has the following variables: strategies, drivers, process, outcomes, and project agents (Alarcón and Ashley, 1996, 1998; Venegas and Alarcón, 1997).

According to the GPM variables and their logical sequence of impact, the authors defined a conceptual framework that describes the building project delivery process (Fig. 1). A literature review on project delivery systems and supply chain relationships identified and defined the key variables for inclusion in the GPM conceptual model. Upon completing the GPM model, the authors conducted a validation and assessment process through a series of workshops. At these workshops, a group of experienced professionals with different roles in the building construction industry (i.e., owner, contractor, subcontractor, and designer as explained later) assessed the impact among the variables. This assessment comprised the evaluation

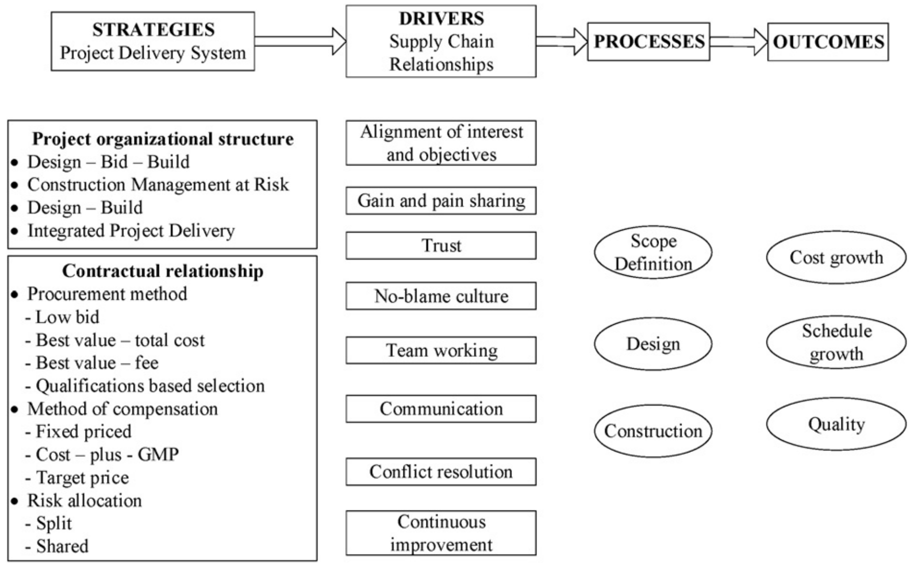

Fig. 1. Conceptual model of GPM.

of the effect of project delivery systems on supply chain relationships, the effect of supply chain variables between themselves and on project processes, and the effect of project process between themselves and on project outcomes.

3. GPM conceptual model

The interactions of project delivery systems, supply chain relationships, project processes, and project outcomes define the GPM conceptual model (Fig. 1).

The sequence of events in the GPM model represents an owner's strategic decision-making process and the impact of these decisions on the supply chain relationships, project processes, and performance outcomes. Based on past studies, project delivery performance begins with the owner's selection of strategies that define a project delivery system. For the purpose of this research, a project delivery system *defines the roles and relationships between the participants*; *the timing and sequence of events and practices and techniques of management*; *and the contractual responsibilities for defining*, *designing, and constructing a project* (Dorsey, 1997; Kenig, 2011; ASCE, 2000; AIA, 2007; Ireland, 1984). Project delivery systems have distinguishing characteristics. The fundamental variants between project delivery systems include the *organizational structure* that defines the manner in which participants communicate with and report to each other and the *contractual relationship* that defines the contractual responsibilities, risk allocation, the form of compensation and the procurement methods for selecting participants (Alarcón et al., 2011; Thomsen et al., 2009).

The owner's strategy decisions impact the management of the supply chain relationships. The manner in which the owner defines the project organization and contractual relationships impacts the configuration of the supply chain relationship of the construction project. For the purpose of this research, a supply chain is defined as *a network of organizations involved through upstream and downstream linkages in the different processes that deliver value in the form of products and services to end users* (Christopher, 1992). This supply chain relationships are characterized in the literature by the following drivers: alignment of interest and objectives, gain and pain sharing, trust, no-blame culture, team working, communication, conflict resolution, and continuous improvement (Chan et al., 2004; Cheng et al., 2000; Das and Teng, 1998; Meng et al., 2011; Meng, 2012; Xue et al., 2010).

The project processes are a result of the strategy decisions and the supply chain management. The processes are simply defined as scope definition, design, and construction. The strategies, drivers, and processes ultimately impact the project outcomes. In this GPM approach, the project outcomes are defined by cost growth, schedule growth, and quality.

In summary, the GPM model considers four basic variables: strategies, drivers, processes, and outcomes. The following sections explain in detail each of these four basic variables.

3.1. Strategies

The strategies are the factors that define a project delivery system. One of the most important decisions at the beginning of a project is the project delivery system selection. Therefore, the owner has to define the type of organization structure and contractual relationships for the development of the project. The conceptual model captures each of these decisions.

3.1.1. Project organization structure

The first strategy refers to the level of participation of the owner, the designer, and the constructor through the phases of definition, design, and construction; the communication protocols; and the authorities. This GPM model evaluates four principal design and construction project organization structures: DBB, CMR, DB and IPD.

In the DBB organizational structure, the owner has separate contracts with the designer and the constructor. Contractual lines typically define the communication protocols. The owner's control derives from monitoring the designer's and constructor's results or outcomes.

The CMR organizational structure provides the owner with separate contracts with the designer and the constructor. The constructor provides essential preconstruction services. The owner's control primarily derives from monitoring the designer's and constructor's behavior or the means used to achieve the design and the construction of the project.

In the DB organizational structure, the owner only has a contract with a design–builder, who is a single entity that performs both the design and the construction. The owner's control primarily derives from monitoring the design–builder's behavior or the means used to achieve the design and the construction of the project.

In this final organizational structure, IPD, the owner, designer, and constructor sign one contract. There is a direct communication among the owner, the designer, and the constructor. The owner's control primarily derives from building a common organizational culture that encourages team control.

3.1.2. Contractual relationships

The second strategy defines the procurement of the project team, the form of compensation, and risk allocation. The procurement method is the manner in which the owner makes the final selection of the primary members of the project team. Depending on the organizational structure, the selection may extend to the design professionals, the constructor, the DB team, or, in the case of IPD team, all the signatories to the multiparty contract. We define each of the procurement method in the context of this study in the following paragraphs (Kenig, 2011).

Low bid is a competitive procurement process that uses price as the only factor in the final selection criteria. The price is the total construction cost or design and construction cost if it is DB.

Best-value total cost is a procurement process that uses price and non-price factors in the final selection. The price is the lump sum total construction cost (or design and construction cost if it is DB). Award algorithms to perform the tradeoff between price and non-price factors can vary, but the price component represents the contracted cost.

Best-value fee is a second variant of best-value procurement. In best-value fee, a competitive procurement process uses price and non-price factors in the final selection. The price is the fees, and the fees are not the total construction cost.

Qualification-based selection is a procurement process in which price is a not a factor in the final selection criteria. Final selection criteria equals 100% of non-price factors.

The form of compensation defines the reimbursement contract amount. This basis also often relates to the sharing and/or access of information between owner and contractor ("open or closed book") (Kenig, 2011). Fixed price is a set price in exchange for a set scope of work. In cost-plus with a guaranteed maximum price (GMP), the owner agrees to pay for the cost of the work up to a prescribed ceiling amount, the GMP. In the target pricing strategy, the owner, the designer, and the constructor collaboratively establish a price for the project and then work together to maximize the value that the owner receives for that amount. The team achieves the owner's value proposition for a cost no greater than the target price.

Risk allocation is a process by which the owner, designer, and constructor identify risks arising from the project and define how they will be allocated (Gilbreath, 1992). We employ two strategies for risk allocation for this model: split and shared. In the split strategy, the owner, the designer, and the constructor individually manage risks. The owner transfers risks to the designer and the constructor through the contract. In the shared strategy, the owner, the designer, and the constructor collectively manage and appropriately share risks, frequently through a shared contingency pool.

3.2. Drivers—Supply chain relationships

The selection of the type of project organizational structure and contractual relationship defines the configuration of the supply chain relationships. The management of the supply chain will determine the propagation of effects of the project delivery system. Existing studies have investigated the critical success factors for the construction supply chain relationship, particularly in the application of alliancing, partnering, and relational contracting in construction (Black et al., 2000; Chan et al., 2004; Cheng et al., 2000; Larson, 1997; Meng, 2012; Rahman et al., 2007; Rahman and Kumaraswamy, 2008; Rowlinson and Cheung, 2005; Tang et al., 2006). Based on the analysis of common factors identified in these studies, eight key factors were selected to describe the construction supply chain relationship. We define each of this factors in the context of this study in the following statements (Chan et al., 2004; Cheng et al., 2000; Das and Teng, 1998; Meng et al., 2011; Meng, 2012; Xue et al., 2010).

- Alignment of interest and objectives refers to the level of alignment of interest and objectives among the owner, the designer, and the constructor.
- Gain and pain sharing defines the level of sharing of profits or cost savings as well as losses or cost increases among the owner, the designer, and the constructor.
- Trust refers to the expectations of the owner, the designer, and the constructor regarding one another in a risky situation.
- No-blame culture refers to the relationship between the owner, the designer, and the constructor focusing on identifying and resolving problems, instead of judging or allocating blame.
- Team working defines the level of collaboration among the owner, the designer, and the constructor that allows them better coordination and decision making.
- Communication refers to the level of exchange of information, knowledge, and skills openly, timely, and adequately among the owner, the designer, and the constructor.
- Conflict resolution refers to the use of early warning mechanisms among the owner, the designer, and the constructor to allow for anticipation of potential problems and resolving them at the lowest level of management in a timely manner.

- Continuous improvement defines the use of common performance indicators and joint efforts among the owner, the designer, and the constructor to promote the project team in constantly improving and adding value to the project.

3.3. Project processes

Project processes correspond to three stages: definition, design, and construction. In the definition stage, the appropriate team member(s) determines what it may take to meet the client requirements and develops a plan for that purpose. During this stage, several broad plans are studied in sufficient detail to establish the feasibility of the project. The project is organized, objectives are set, and decisions with major cost, scope, and schedule impact are made. In the design stage, the appropriate team member(s) refines the alternatives chosen from conceptual to detailed engineering design. Drawings, specifications, and estimates are prepared during this process. In the construction stage, the appropriate team member(s) carries out the physical realization of the designs. This process involves contract administration, and the management and control of the construction operations. This process continues until the facility is constructed through pre-startup inspection (Alarcón and Ashley, 1992, 1998).

3.4. Project outcomes

Cost growth, schedule growth, and quality most frequently define project performance. We define each of the project performance indicators in the context of this study in the following paragraphs. Cost growth provides a measurement of the percent change in project cost contract award, GMP, or target price to project completion. Cost growth could be positive or negative (Konchar and Sanvido, 1998). Schedule growth provides a measurement of the percentage change in project duration from contract award, GMP, or target schedule to project completion. Schedule growth could be positive or negative (Konchar and Sanvido, 1998). Quality defines the degree to which the facility meets the requirements at the time that it is turned over to the owner (Konchar and Sanvido, 1998).

4. Data collection

Theoretically, owners can select to use IPD on any type of building project. However, the use of a multiparty contract and the high levels of collaboration found in the IPD system do not lend the delivery system to smaller, non-complex projects. Current industry practice demonstrates that owners most frequently apply IPD to complex building projects that require a high level of contractor integration (AIA, 2010). For the purpose of this analysis, the authors defined a healthcare project as prototype of a complex project in order to frame the data collection and organization of knowledge for the CIA analysis. The healthcare project is located in Denver, Colorado. The building size is 430,000 sf. with a cost of $160 million. The project schedule is 24 months, and the specified project quality is 5 (scale index 1–10). The assessment of the GPM model will vary with each specific project, but this healthcare example is illustrative of a project that could be completed with all four project delivery systems.

The analytical processes for the GPM method require data for a cross-impact analysis. Researchers most frequently collect these data through a consensus-building workshop with experienced professionals (Alarcón and Ashley, 1996). To select workshop participants, this research qualified professionals through the following criteria, which were adapted from (Hallowell and Gambatese, 2010). For this research, it was determined that all professionals must have

(1) at least 10 years of professional experience in the building industry;
(2) direct involvement in the management of building construction projects;
(3) experience in DBB, CMR, DB, and IPD; and
(4) an advanced degree in the field of civil engineering, architecture, or other related field (minimum of a bachelor of science).

The authors created a questionnaire to select the experienced professionals. The questionnaire was sent to two regional design and construction associations, the Design–Build Institute of America Rocky Mountain Region and the Construction Management Association of America Colorado. These associations were chosen due to the skill sets of their members and the location for facilitating an in-person workshop. Using the previously mentioned criteria, nine professionals were selected for the consensus-building workshop. The workshop participants consist of two private owners, one public owner, one architect, two general contractors, two consulting engineers, and one mechanical engineer. All workshop participants worked in the building (i.e., vertical) construction sector and they all had experience with the four primary delivery systems. The average experience of the group was 25 years.

The goal of the data collection workshops was to assess the cross-impact relationships in the model. The professionals participated in a series of three workshops spanning more than 8 hours. The workshops were organized in three sessions that consisted of the assessments of the strategies on drivers, the drivers on drivers, and the processes on each other and the project outcomes. Participants were physically in the same location, but they assessed the cross-impact relationships virtually, through an anonymous electronic voting system. The anonymous voting approach minimized potential bias and allowed each individual to participate equally. The workshop facilitator asked a question, the participants provided their anonymous answers, and after all votes were received, the facilitator showed the group's results. Consensus was defined as seven of nine participants having the same answer. If consensus was achieved on the first round, the facilitator moved on to the next question. If consensus was not achieved, the facilitator led a discussion about the answers giving participants an opportunity to justify a response. After all participants had a chance to speak, the group voted a second time. This process was repeated for each question up to three times if necessary.

5. GPM mathematical model

According to GPM theory (Alarcón and Ashley, 1996), the mathematical model comprises the assessment of the interactions among all variables defined in the GPM conceptual model. By definition, strategies impact only drivers. Drivers impact one another and also processes. Finally, processes impact one another and project outcomes. The first set of assessments relates to the impact of strategies on drivers. According to the previous discussion, the strategies are project organizational structure and contractual relationship. To explain this process, this paper presents the input data for the organizational structure strategy. The same process was applied to the others strategies.

The organizational structure strategy, noted as scenarios in Fig. 2, considers the following design and construction project organizational structures: DBB, CMR, DB, and IPD. The impact of these strategies on the drivers is gathered in the matrix showed in Fig. 2 using a scale five ratings to cover the range of possible outcomes: high positive (PP), positive (P), no effect (O), negative (N), and high negative (NN) (Alarcón and Ashley, 1996). The general question to assess the matrix shown in Fig. 2 is: *If the scenario m is applied*, *what is the impact on driver n*? In our example, one question would be: *If DBB structure is applied*, *what is the impact on the alignment of interest and objectives between the owner*, *the designer, and the constructor*? The results from the data collection workshop are shown in Fig. 2.

The second set of assessments corresponds to the evaluation of the cross-impact matrix. This matrix defines the interactions among drivers, processes, and project outcomes (Fig. 3). The first part assesses the impact of the drivers on each other and on the processes directly. The last part assesses the impact of the project processes on themselves and on the project outcomes. The scale in Fig. 3 is used to assess the cross-impact matrix. This scale considers the direction of the impact (positive or negative) and the strength of the impact (significant, moderate and slight). To produce the assessments indicated in Fig. 3, workshop participants were asked the question: *If the performance of the variable m occurs* (*column*), *what is the impact on the performance of the variable n* (*row*)? For example, the assessment indicates that communication has a significant effect on the design process in the same direction (+). “In the same direction” means the better communication, the better the design process (Alarcón and Ashley, 1992, 1996).

6. Analysis of simulation results

The GPM conceptual model assumes a directionality in the propagation of effects from strategies to project outcomes (Alarcón and Ashley, 1992, 1996). Strategies constitute initial conditions and modify the probability in the occurrence of drivers. Fig. 4 provides an example of the propagation of effects from the IPD organizational strategy to cost growth. This is one of 360 potential GPM simulation paths. First, the workshop participants stated that the IPD strategy positively affects communication; that is, it equates to the probability of realizing the driver's maximum potential in at least three out of five opportunities. Second, communication affects scope definition performance significantly in the same direction; that is, if communication is at a high positive level, the probability of scope definition performance reaching a high positive level will significantly increase. Finally, scope definition affects cost growth slightly in the same direction. In the GPM simulation, this procedure repeats for each interaction among strategies, drivers, project processes, and project outcomes. The mathematical model uses a Monte Carlo simulation approach to carry out the cross-impact analysis and to perform probabilistic inference (Venegas and Alarcón, 1997). In this case, the simulation converged after 15,000 simulations. More detailed information of the mathematical model is described by Alarcón and Ashley (1998) and Alarcón and Bastías (2000).

Using the data collected in the consensus-building workshop, simulations were made with the computer software GPM 2.0, a later version of the system described in Alarcón and Bastías (2000). The following sections present first the sensitivity analysis of project performance to drivers, and second, the discussion of the performance of project delivery systems. The model structure and sensitivity analysis provide insights into the factors that drive the project delivery performance. The

PROJECT ORGANIZATIONAL STRUCTURE	SUPPLY CHAIN RELATIONSHIP FACTORS							
	Alignment of interest and objectives	Gain and pain sharing	Trust	No-blame culture	Team working	Communication	Conflict resolution	Continuous improvement
Design-Bid-Build	N	NN	NN	N	N	NN	NN	O
Construction Management at Risk	O	NN	O	N	O	O	N	O
Design-Build	O	O	O	N	O	O	N	O
Integrated Project Delivery	P	PP	P	P	P	P	P	P

Fig. 2. Matrix of the impact of project organizational structure on SCR's factors.

		First Part								Second Part		
		DRIVERS								PROCESSES		
		Alignment of interest and	Gain and pain sharing	Trust	No-blame culture	Team working	Communication	Conflict resolution	Continuous improvement	Definition	Design	Construction
DRIVERS	Alignment of interest and objectives		MOD+	MOD+	MOD+	MOD+	SLI+	SLI+	SLI+			
	Gain and pain sharing	SLI+		MOD+	MOD+	MOD+	SLI+	SLI+	SLI+			
	Trust	SLI+	NO		MOD+	MOD+	MOD+	SLI+	SLI+			
	No-blame culture	NO	NO	MOD+		MOD+	MOD+	SLI+	NO			
	Team working	MOD+	MOD+	MOD+	MOD+		MOD+	SLI+	SLI+			
	Communication	SLI+	SLI+	SLI+	MOD+	MOD+		SLI+	SLI+			
	Conflict resolution	MOD+	MOD+	SLI+	MOD+	SLI+	MOD+		NO			
	Continuous improvement	SLI+	SLI+	SLI+	SLI+	MOD+	MOD+	SLI+				
PROCESSES	Definition	MOD+	SLI+	MOD+	SLI+	MOD+	SIG+	NO	SLI+		NO	NO
	Design	MOD+	MOD+	SLI+	SLI+	MOD+	SIG+	SLI+	MOD+	MOD+		NO
	Construction	MOD+	MOD+	MOD+	SIG+	MOD+	MOD+	MOD+	NO	MOD+	MOD+	
PROJECT OUTCOMES	Cost growth									SLI+	SLI+	MOD+
	Schedule growth									MOD+	SLI+	MOD+
	Quality									MOD+	MOD+	MOD+

Scale of the impact of the cross – impact matrix	
Interpretation	**Symbol**
Significant impact in the same direction	SIG+
Moderate impact in the same direction	MOD+
Slight impact in the same direction	LIG+
No impact	NO
Slight impact in the opposite direction	LIG-
Moderate impact in the opposite direction	MOD-
Significant impact in the opposite direction	SIG-

Fig. 3. Cross-impact matrix.

GPM results summarize the potential project outcomes from each project delivery system.

6.1. Sensitivity analysis of project outcomes to drivers

The GPM structure and sequence of events represent the sequence of actual project events. This model structure allows us to study how the propagation effects occur from the selection of the project delivery system to project outcomes. The performance of the supply chain relationship is key in this propagation. Table 1 presents a sensitivity analysis of project outcomes to drivers' performance that define the supply chain relationship. These results are important to discuss before examining the project delivery systems individually. The percentage values represent the relative impact of drivers on each project outcomes. The higher the relative impact, the

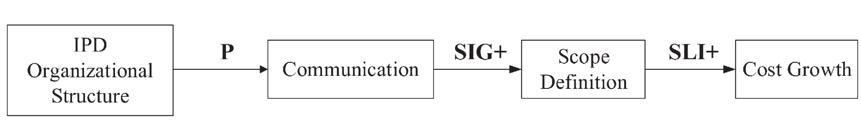

Fig. 4. Propagation of effects from IPD organizational structure to cost growth.

Table 1
Sensitivity analysis of project outcomes to driver's performance.

Driver	Cost	Schedule	Quality
Communication	16%	17%	16%
Alignment of interest and objectives	15%	14%	15%
Team working	14%	14%	14%
Trust	13%	13%	13%
Gain/pain sharing	13%	13%	13%
No-blame culture	12%	12%	12%
Continuous improvement	9%	10%	10%
Conflict resolution	7%	7%	7%

higher the sensitivity of the project outcome to the associated driver.

According to sensitivity analysis, the most influential variable is communication, followed in descending order by alignment of interest and objectives, team working, trust, gain/pain sharing, no-blame culture, continuous improvement, and conflict resolution. The recommendation that comes from these results in that owners should use a project delivery system that encourages a positive performance of the supply chain regarding communication, alignment of interest and objectives, team working, trust, and gain/pain sharing. These most sensitive drivers can affect, either positively or negatively, the project outcomes. For example, if there is very positive communication, the expected cost is $140 million. But if there is very negative communication, the expected cost is $240 million. With this sensitivity analysis in mind, we will discuss the performance of the project delivery methods.

6.2. Discussion of project delivery performance

This section presents the prediction of potential project performance resulting of the propagation of effects from the four project delivery system strategies (Table 2). As shown in Table 2, the project delivery system strategies (column 1) are structured in terms of the type of project organizational structure (column 2) and contractual relationships (columns 3–5). Columns 6–8 show the prediction of expected project performance.

In the DBB strategy simulation, the expected project cost was $200 million with a duration of 30 months and a project quality index of five. The DBB system serves as the baseline delivery method and we will compare each method to the DBB system in ascending order of performance. The CMR strategy had a better performance. The expected project cost and schedule decreased by 13% over the DBB strategy and the expected project quality increased from five to six. The DB strategy outperformed the DBB and CMR strategies. The expected project cost and schedule decreased by 17% and the expected project quality index increased from five to seven. Finally, the IPD strategy significantly outperformed the DBB system and the others. The expected project cost decreased by 26% and the expected project schedule decreased by 27%. The expected project quality index increased from five to eight.

The results in Table 2 yield insights into how the project delivery system affects the supply chain and how the supply chain in turn affects project performance. More simply, the results stem from the impact of the organizational structure and contractual relationships on the eight supply chain drivers. We will explain each delivery strategies' performance in terms of their organizational structure and contractual relationship. We will focus our discussion on the most sensitive drivers found through the simulation: communication, alignment of interest and objectives, team working, trust, and gain/pain sharing. We will support the discussion using the simulation results, comments from the consensus-building workshop, and results of previous research from the literature.

6.2.1. Design–bid–build delivery system strategy

In the DBB system, the owner has separate contracts with the designer and the constructor. The owner makes the final selection of the primary members of the project team through low bid. The basis of reimbursement is a set price in exchange for a set scope of work. The owner, the designer, and the constructor individually manage risks.

As shown in Table 2, the DBB delivery system has the highest cost, the longest schedule, and the lowest quality index. We found that these results are due to the negative effects that the DBB strategy has on the supply chain relationships. During the assessment workshops, participants rated the DBB organizational structure as having a high negative (NN) impact on the communication driver (see Fig. 2). One professional stated, "*DBB is the worst strategy for communication*, *everything requires formal written Requests for Information.*" The negative impacts of poor communication are widely cited by researchers. Xue et al. (2005) stated that poor communication is one of the important factors causing performance-related problems, such as low productivity, cost and time overrun, conflicts and disputes.

Table 2
Predicted results for project delivery strategies.

Project delivery system strategy	Project delivery systems				Project cost (millions)	Project schedule (months)	Project quality (index 1–10)
	Type of Organizat. structure	Contractual Relationship					
		Procurement method	Compensation method	Risk allocation			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DBB	DBB	Low bid	Fixed price	Split	200	30	5
CMR	CMR	Qualification-based selection	Guaranteed maximum price	Split	175	26	6
DB	DB	Qualification-based selection	Guaranteed maximum price	Split	167	25	7
IPD	IPD	Qualification-based selection	Target price	Shared	149	22	8

The DBB organizational structure also had a negative (N) effect on the alignment of interest and objectives among the owner, the designer, and the constructor. The literature supports the participants' assessment. Multiple researchers state the impact of aligning the key project parties for project success. Alignment on mutual objectives helps to ensure overall project success (Bennett and Jayes, 1995) and this alignment generates win–win scenarios, which in turn avoids opportunism (Meng et al., 2011).

The DBB organizational structure also had a negative (N) effect on team working among the owner, the designer, and the constructor. The literature reports that the separation of design and construction, lack of coordination and integration are critical factors that affect the project success (Xue et al., 2005).

Workshop participants assessed the DBB organizational structure as having a high negative (NN) impact on trust among the owner, the designer, and the constructor. One of the designers stated, "*Trust is one of the worst parts of DBB. This form of delivery is very confrontational.*" Previous studies have identified trust as the most important behavioral factor in managing a relationship. Trust within a project team would certainly improve the project outcome (Wong et al., 2008; Egan, 1998).

The DBB organizational structure prohibits the use of pain/gain sharing and can even promote opportunism. One professional noted, "*In DBB, there is really no sharing of gain and pain.*" The high negative (NN) assessment of the impact of gain and pain sharing among the owner, the designer, and the constructor results in a higher simulated cost than the other four methods.

The professionals' assessments generally found that the contractual relationships of the DBB system had a high negative (NN) impact on the majority of variables that define the supply chain relationships. One professional stated, "*Once you get a low bid, I do not know how you can effectively align interests and objectives.*" Other professionals stated, "*There is not shared gain/pain in this system; it is each entity for themselves.*" "*DBB often results in zero trust.*" "*Communication is difficult in the low bid fixed price approach because it tends to be written, formal communications and not open discussions.*"

6.2.2. Construction management at risk delivery system strategy

Similar to the DBB delivery system, the CMR delivery system has separate contracts with the designer and the constructor. However, the constructor joins the team before the design is complete and provides preconstruction services. The owner makes the final selection of primary members of the project team through qualification-based selection. The basis of reimbursement is a guaranteed maximum price (GMP), in which the owner agrees to pay for the cost of the work up to a predetermined amount. The risk allocation strategy is similar to the DBB delivery system. The owner, the designer, and the constructor individually manage risk, but they can more openly discuss risk in the preconstruction phase.

As seen in Table 2, the CMR delivery system improves the potential cost, schedule, and quality performance. These results are due to enhancing communication, alignment of interest and objectives, team working, and trust. According to the professionals' assessment, the CMR organizational structure did not have the negative effects (O) on communication seen in the DBB organizational structure (see Fig. 2). One professional stated, "*CMR is better than DBB because contractor is there early; decisions I make as designer have input from contractor.*" The positive impacts of early involvement and information sharing early are widely cited by researchers. The Construction Users Round Table (2004) stated, "*owners driving full collaboration through information sharing early in the project process are most likely to achieve the desired outcomes. Such collaboration shifts the bulk of analysis, design, and decision-making earlier in the design process, giving the collaborators maximum opportunity for good decisions.*"

The CMR organization structure also had no negative effects (O) on the alignment of interest and objectives among the owner, the designer, and the constructor. This assessment is more positive than the DBB organization structure. However, there was much debate between the participants on this assessment. Some questioned if the early involvement of the constructor truly negated the separate contracts between the designer and contractor.

The CMR organization allows more team working (O) among the owner, the designer, and the constructor than the DBB organization structure (N). Jackson (2011) stated, "*The primary reasons for choosing CMR have to do with the benefits realized by a more collaborative process.*"

The application of the CMR organization structure provides more trust (O) among the owner, the designer, and the constructor than the DBB organization structure (NN) (see Fig. 2). One professional stated, "*In CMR, when you have someone involved early on, it gives opportunity to build trust.*" Trust reflects the willingness of one party to leave oneself vulnerable to the actions of the trusted partners (Das and Teng, 1998). When trust is developed, other elements that improve performance are likely to be present (Construction Industry Institute, 1991; Bennett and Jayes, 1998).

Interestingly, the participants also assessed the CMR organization structure with a high negative (NN) effect on gain and pain sharing. One professional stated, "*In CMR, I look at it the same as DBB; as owner, we are no sharing anything. Maybe communication is better, but not sharing pain and gain. We continuously use independent estimators to assess costs.*" Another professional noted, "*Under separate contracts the parties would tend towards positional bargaining and not pain and gain sharing.*"

According to the consensus assessments, in general, the type of contractual relationship of the CMR delivery system neutral (O) or negative (N) affects all variables that define the supply chain relationships. One professional stated, "*Qualification-based selection will allow a proposer to put its best foot forward and it allows an owner to determine what is most important to them. The GMP pricing structure lessens the risk that a proposer bares, but owner still has maximum price.*"

Another professional noted, "*Because you selected someone on qualifications and negotiated a price, there is at least some trust involved, but, in the end, the GMP and split risk work against that.*"

6.2.3. Design–build delivery system strategy

In the DB delivery system, the owner has one contract with a design–builder, who is a single entity that performs both the design and the construction. Owners can use a variety of procurement and compensation methods with the DB project delivery system. In this study, we analyzed DB with a qualification-based selection and a GMP compensation method. The owner and the design–builder individually manage risks, which is typical in DB delivery. As seen in Table 2, the DB delivery system improved project cost, schedule, and quality performance. These results are due to the impacts of the design–construction team integration. This change is most notable in the improvement in pain/gain sharing that occurs between the designer and constructor.

The DB organizational structure had a neutral (O) effect on communication, which is similar to the improvement of CMR over the DBB organizational structure. The literature shows that excellent and effective communication is essential for successful relationship building (Chan et al., 2010). The DB organizational structure was also assessed to have the same impact on the alignment of interests as the CMR organizational structure (neutral "O"). Likewise, the DB organizational structure was assessed to have the same impact as CMR on trust and team working. DB integrates the designer and the constructor as team under a single contract. This process implies, or has the intention, that the designer and the constructor work as a team in a more collaborative process (Jackson, 2011).

The primary reason for DB performance improvement was that the organizational structure did not have the negative effect on gain and pain sharing seen in the CMR and DBB organizational structures. The literature shows that gain/pain sharing provides incentives to achieve project goals (Bayliss et al., 2004; Walker and Hampson, 2003). One professional stated, "*DB is better for potential sharing pain and gain due to the single contract between the designer and constructor. However, DB is still contractually similar to CMR because of the split in risk.*" In essence, the designer and the builder are both responsible for design errors and omissions (the "pain"), but they can also both profit from more efficient designs (the "gain"). However, there is no substantial improvement in pain/gain sharing between the owner and the design–builder due to the use of a GMP compensation structure and the split risk allocation.

6.2.4. Integrated project delivery system

In the IPD delivery system, the owner, the designer, and the constructor sign one contract. The owner makes the final selection of primary members of the project team through qualification-based selection. The basis of reimbursement is a target price in which the owner, the designer, and the constructor collaboratively establish a price for the project and then work together to maximize the value that the owner receives for that amount. The owner, the designer, and the constructor collectively manage and appropriately share risks, frequently through a shared contingency pool. As seen in Table 2, the IPD delivery strategy significantly improved project cost, schedule, and quality performance over the DBB strategy. These results are due to the positive impact that the IPD delivery system has on the supply chain relationships in comparison to the other strategies.

The IPD organizational structure positively (P) affects communication as noted in Fig. 2. The positive impacts of effective communication are widely cited by researchers. Improving communications means that it is less likely to encounter schedule delays and additional costs, which often lead to disputes and litigation that can compound schedule delays and cost increases (Brown, 1994; Chan et al., 2010; Li et al., 2001; Moore and Dainty, 2000; Sanders and Moore, 1992). The workshop participants similarly assessed the IPD organizational structure to have a positive (P) effect on the alignment of interest and objectives. The literature shows that commonly developed goals, such as achieving value engineering savings, delivering a project on time or early, and maintaining desired quality, are more frequently achieved through the development of shared goals (Hellard, 1996; Construction Industry Institute Australia, 1996).

The IPD organizational structure positively (P) affects team working. One professional stated, "*theoretically it should be very positive, but there's always people who haven't done it, they are learning it.*"

The IPD organizational structure also positively (P) affects trust. One professional stated, "*Singing a shared contract should encourage trust to be very positive.*" Previous studies have shown that a collaborative climate based on trust and commitment better facilitates project performance in terms of decreased cost overruns, time performance, quality, and customer satisfaction (Chan et al., 2003; Cole, 2000; Eriksson and Westerberg, 2011; Iyer and Jha, 2005; Phua and Rowlinson, 2004; Shen and Tam, 2002).

The IPD organizational structure was assessed to have a highly positive (PP) effect on gain and pain sharing. Target pricing includes the use of pain and gain sharing for the entire team (Darrington and Lichtig, 2010; Love et al., 2011; Zimina et al., 2012). One professional stated, "*In terms of pain and gain sharing, there is nothing more positive; if this is not very positive, nothing is.*"

According to the experience professionals' assessments, in general, the contractual relationship of the IPD delivery system most positively affects all variables that define the supply chain relationships. One professional stated, "*I think there can be no better alignment for these three things* (*communication, joint goal setting, and pain and gain sharing*; *how much more aligned can you get*?" Other professionals stated, "*The whole idea of a target price is to align objectives.*" "*This process helps team members to work together for the common good.*" Darrington and Lichtig (2010) stated that traditional contracting structures have many collateral or hidden costs because they come with greater risks of increased contingencies, more change orders, higher transaction costs in contract and claim management, and more frequent and severe disputes. The IPD structure helps to alleviate these hidden costs as seen through the GPM simulation predictions.

7. Conclusions

This study provides a model for exploring the performance of project delivery systems. This model allows for a better understanding of how DBB, CMR, DB, and IPD systems operate in terms of their organizational structure and contractual relationships. It provides predictions of how the project delivery systems perform and the factors that drive their performance based on consensus input from experienced industry professionals.

The model's novelty is that it simulates how the behavior of the supply chain relationships drives the project delivery system performance. In essence, the owner's decisions about the project delivery system directly affect, or even define, supply chain relationships. The supply chain relationships propagate this effect within the system thus directly affecting the project process and, ultimately, the project performance. According to this statement, the factors that define the supply chain relationships, such as communication, trust, conflict resolution, etc., drive the project delivery performance.

The complex healthcare project under analysis demands an exceptional level of integration between key project participants. The sensitivity analysis showed that project outcomes were very sensitive to communication, alignment of interest and objectives, team working, trust and gain/pain sharing. This suggests that this type of complex project should be developed using a project delivery system that influences positively the supply chain relationships in terms of communication, alignment of interest and objectives, trust, etc. This observation is connected with the GPM results.

For the complex healthcare project, the GPM results showed that the IPD system outperformed DBB, CMR, and DB because the IPD organization and contractual strategy positively impacted the drivers that define the supply chain relationships.

This research has limitations. The GPM results are based on the assessments of experienced professionals for a single complex healthcare project. Therefore, the results should not be interpreted as universal across all types of building construction projects. For example, smaller, non-complex healthcare projects would likely yield different results because these projects generally require lower levels of integration and can benefit from competitive bidding. However, the GPM model is applicable to other types of complex building projects. We would only need to collect different assessments to analyze another building type. The authors will continue to refine and apply this GPM model to derive conclusions that are more generalizable.

Another research limitation is the fact that the GPM model focuses on the building sector. IPD is applicable to other sectors, such as industrial construction or infrastructure. In future research, it would be advisable to study the application of the IPD system in other areas of construction.

Limitations also exist due to the absence of other conceptual model variables that could affect performance. This structure contains the primary variables in the project delivery decision. Future research should consider other such as the use of incentive plans and lean construction methods that might affect construction operations.

Project team integration holds the potential to mend construction industry fragmentation, which often results in poor performance. This research demonstrates that the IPD project delivery system can remove team fragmentation. This research found that integration, as seen through the improvement of communication, alignment of interest and objectives, trust and gain/pain sharing, improved the potential for better project performance. As more IPD projects are completed, researchers will be able to provide a more empirically based exploration of performance. At present, the GPM model in this research provides insights into how IPD projects impact potential performance on complex building projects.

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