Incentivizing Effort in Highly Collaborative Construction and Design Teams

by

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ABSTRACT

The commercial construction industry has been experiencing a transition to project types that promote increased collaboration between designers and contractors, such as integrated project delivery and design-build. The project performance of these highly collaborative projects appears to be greater than that of traditional project types, such as design-bid-build. Collaboration can be challenging though, as the contracted collaborators can provide varying levels of needed effort. Thus, promoting and monitoring the collaborative effort of project participants is of value to the project owner and project participant alike.

However, there is a lack of guidance regarding how to promote efficient and effective effort from project team members. Traditional construction and design projects (Lump Sum/Hard Bid, for example) utilize procurement and contracting methods that incentivize individual profit maximization over project success. Rational contracted parties are forced to balance collaboration with the need to maximize profits. If collaboration comes at a cost, and profit realization is not guaranteed, the rational party must act in self-interest over that of the project. These self-interested actions may or may not degrade project outcomes.

This focus on self-interest contrasts with highly collaborative projects where the contractual intent is to incentivize "collaborative effort" of the project team. Unfortunately, there is little guidance regarding what “collaborative effort” means or how to measure it. The following research examines the measurement of collaborative effort, the contractual implications, and incentives structures of “collaborative effort”, and the association “collaborative effort” to project outcomes.

The form and content of this abstract are approved. I recommend its publication.

Approved: Caroline M. Clevenger

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CHAPTER I

PREFACE/INTRODUCTION

1.1 Introduction

Collaboration is not easy.

The construction industry is transitioning to procurement and contracting methods that incentivize collaboration amongst project participants. These highly collaborative and integrated construction projects (commonly referred to at Integrated Project Delivery, or IPD) have shown reduced cost and project delays (El Asmar & Hanna, 2012). Though IPD projects have shown to be somewhat more successful for certain project types, collaboration alone is not a guarantee for project success.

My own personal and professional observation is that project outcomes vary seemingly independently of team qualifications but can be highly influenced by a contract and procurement methods. Previous research findings, along with my person observations, motivated this research. Specifically, I was interested in the latent element commonly observed between successful IPD projects, thought to be higher effort provided by project participants.

I refined my research objective to seek to understand how effort is affected by a chosen contracting method. The construction industry's move to more collaborative contract agreements has resulted in a need to monitor team performance differently. The decision to collaborate can be due in part to self-gain, enhance credibility, or even to appear to form a community (Maienschein, 1993).

Collaboration is a dynamic action where collaborators can decide when and how much they intend to collaborate. Collaborators of an agreement can become defectors based on rational self-interest (Skyrms, 2004). Defectors can also swing back to collaborators when the opportunity, social dynamic, or incentive structures change. Thus, choosing and monitoring the collaborative effort of project participants is of value to the project owner and project participant alike.

The choice to collaborate comes with the intent to draw on the diversity of differences in pursuit of a common goal, while leveraging the multitude of human and material resources that collaboration affords (Schindler-Rainman, 1981). However, there is a risk with collaboration that effort will degrade into self-interest, which can dissuade many from providing the additional effort needed to collaborate (Nidumolu, 2014; Terman et al., 2020).

This problem was originally documented by the author in two conference papers (see Appendix) published in the 2018 ASCE Construction Research Congress Proceedings (Mulholland & Clevenger, 2018) and the 2019 Associated Schools of Construction Conference Proceedings (Mulholland & Clevenger, 2019a). This preliminary research compared two collaborative healthcare construction projects with different contractual agreements and reviewed how the contract type and subsequent language affected team member's perception of productivity, trust, and impact to profit. In addition to these papers, a third conference paper (Mulholland & Clevenger, 2019b) in the ASCE/CSCE 2019 Construction Research Congress Proceedings (see Appendix) reviewed how the construction and design industry's definition and measure of effort can be informed by other disciplines. Collectively, these conference papers confirmed a gap exists in current academic literature, as well as highlight an opportunity to define, measure and analysis effort on collaborative projects. Specifically, the gap surrounding the relationship of effort to construction project outcomes provided motivation to explore the issues of effort in the design and construction process as my dissertation topic. Monitoring collaborative effort can be challenging due to its seemingly subjective nature. The following dissertation is my attempt to objectively define, measure and analyze collaborative effort in the face of such challenges.

1.2 Problem Statement

Based on experience and literature, there is a lack of guidance to promote efficient and effective effort from project team members to affect and promote desired project outcomes. This is not unique to highly collaborative project teams, but rather is a problem seen throughout all construction and design teams. Traditional construction and design projects (Lump Sum/Hard Bid, for example) utilize procurement and contracting methods that incentivize individual profit maximization over project success. Rational contracted parties are forced to balance collaboration with the need to maximize profits. If collaboration comes at a cost, and profit realization is not guaranteed, the rational party must act in their own self-interest over that of the project. These self-interested actions may or may not degrade project outcomes.

The difference for collaborative project teams is that the contractual format incentivizes a framework that dissolves the silos and barriers commonly seen in traditional contracting and procurement methods. The contractual intent is to incentivize a “collaborative effort” of the project team. Unfortunately, there is little guidance of what “collaborative effort” means or how to measure it. This led me to develop a problem statement specific to the level of collaborative effort of project teams relative to project outcomes.

Research Statement:

> Collaborative effort by construction and design teams is measurable and influences individual effort, and, thus, is associated with positive project outcomes.

To test and explore this research statement, I posed the following research questions.

Research Questions:

Q1. How does contracting language relate to collaborative effort?

Q2. How does the contractual relationship of collaborative contract participants effect the amount of effort that is rationally provided?

Q3. How is collaborative effort defined and measured?

1.3 Research Objectives

Research objectives established to address each of these three questions are summarized in Figure 1. The first objective seeks to characterize and determine how and to what extent the language and content of standard form contracts emphasizes or promotes effort. The second objective seeks to quantify the effects of contract language and type on effort and project outcomes based on game theory and real-world project participant feedback. The third objective seeks is to generate a reliable definition and measures of effort by synthesizing literature review and real-world project participant feedback. Figure 1 outlines these objectives as well as the supporting propositions used to achieve these objectives.

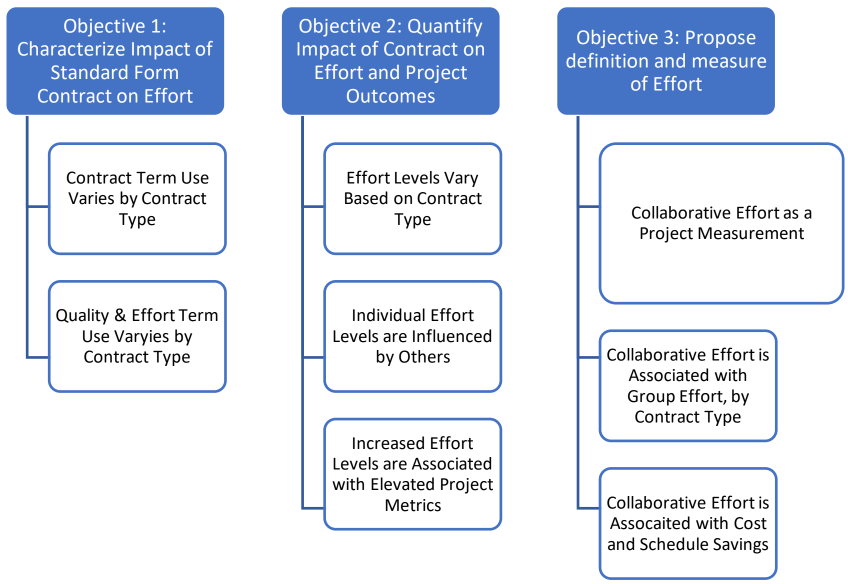

Figure 1 - Research Objectives

- Research Objective 1: This objective is addressed in Chapter 2. The first research proposition will quantify the term use by contract type, while the second objective evaluates how each contract type addresses quality and effort related term use by contact type.
- Research Objective 2: This objective is addressed in Chapter 3. The research propositions seek to validate assumptions of the contract models by validating how contracting methods and other contracted parties can affect effort, and its possible impact to project metrics.

- Research Objective 3: This objective is addressed in Chapter 4. The synthesized definition of effort is evaluated by the research propositions and evaluated based on the project related data.

1.4 Research Framework and Methods

The format for this dissertation follows a three-paper format with a total of five chapters. The following chapters are presented sequentially but are interrelated as they address the three research objectives. Furthermore, chapters two through four are written in the format of standalone, self-contained research documents, ready for journal submission. A summary of each chapter is listed below:

- Chapter 2 – This chapter uses an analytical/quantitative research method to quantify differences in the language and content across various contract types common to building practice, with emphasis on content specific to effort relative to project participants.
- Chapter 3 – This chapter uses mixed methods research approach to explore how effort changes based on contract type. Aspects of game theory inform the research. In addition, cost and schedule data from a qualitative survey of project participants are used to further explore and to validate the game theory results.

- Chapter 4 – This chapter builds upon the preceding chapters to develop a definition specific to collaborative effort relative to a collaboration environment in the construction and design community. A mixed methods approach was used for this research, using both project cost and scheduling data in conjunction with qualitative survey data of project participants

- Chapter 5 – The final chapter speaks to the contribution of the research to the body of knowledge to the Architecture, Engineering and Construction (AEC) community, limitations of research, and research application.

CHAPTER II

CONTRACTING FRAMEWORK CONTENT ANALYSIS

2.1 Introduction

Construction contracts define a mutual agreement between entities which include conditions for project delivery and project requirements, and can influence the behaviors of the parties involved (Cheung, Yiu, & Chim, 2006; Franz et al., 2017; Mulholland & Clevenger, 2018). These contracts delineate elements of project participants, project scope, project cost, schedule and duration of project, project requirements (bonding, insurance, specifications, etc.), and legal preferences (mutual waivers, mediation, arbitration, jurisdiction clause, etc.) to name a few ("AIA C195," 2008). In addition to contract requirements and the referenced documents (contract drawings and specifications for example), contracts provide a framework for project expectations (Anderson & Oyetunji, 2003; Yee et al., 2017).

Success of a project can depend on multiple factors but is largely measured against contractual stipulations. The construction industry has historically defined success by traditional key performance indicators (KPI's) such as cost (above or below budget), schedule (ahead or behind schedule), and quality/safety (project met or exceeded specifications and standard of care) (Bennett, Pothecary, & Robinson, 1996; Cox, Issa, & Ahrens, 2003; Toor & Ogunlana, 2010). As the construction industry has moved to more collaborative agreements, it is reasonable to assume that contractual language in these agreements has also changed to reflect the promoted values and joint effort of project participants (Su, Hastak, Deng, & Khallaf, 2021; Teng, Li, Wu, & Wang, 2019). This paper seeks to analyze the content of standard form contract (SFC) templates and fully executed contracts typical of commercial construction within the healthcare industry to assess their alignment to the previously noted KPI's as well as collaborative effort needed to meet the intent of more collaborative project types.

In these project types, there is a risk of an imbalance of engagement, participation, and contribution between project members that can affect success in achievement of project goals. For this research, collaborative effort is assumed to be the amount of decisive intensification of mental of physical activity or involvement required to meet the project goals by the construction and design teams. For contracts promoting collaborative effort of a project team, it is assumed that language specific to collaborative effort would increase compared to the content in less collaborative contract types.

In general, contracts reflect the promoted values of the contractual intent, be it cost, schedule, quality, and/or the effort expectations of the project team. These promoted values would be reflected in the content/term use of the contract. Based on this assumption, the null and alternative hypotheses regarding the comparison of content (contractual terms) across contract forms, therefor can be summarized by:

> $H_{o:}$ Contractual term use will not vary based on the intention of the SFC.
>
> $H_{a:}$ Contractual term use will vary based on the intent of the SFC, specifically, collaborative SFC's will show an increase in terms associated with quality and effort when compared to less collaborative SFC's.

2.2 Literature Review

Word-frequency and co-word frequency analysis (also referred to as "text analysis", "text mining", "keyword analysis", "key word in context (KWIC)", "content analysis", and "word frequency analysis") relies on the premise that (i) wording and key terms are purposely chosen by the author(s), (ii) variations in term use throughout a document reflect the specific intention of the author(s), and (iii) similarly used term(s) between different documents and authors may be reasonably assumed to have some significance (Whittaker et al, 1989). It is reasonable therefore to rely on word(s) frequency to account for the concepts embodied in an article or in this case, construction contracts (Whittaker et al., 1989). Further, as this research is specific to construction contracts, it is reasonable to assume that keyword use is generally similar between drafters of contracts, and that variations in keyword use is specific to the overall intention of the contract.

Similar methods have been used in previous research. Alves and Shah used a keyword count methodology in analyzing collaborative keyword frequency in construction contracts (2018). Using keyword frequency and other text mining techniques, Liu et al. develop a statute retrieval method to assist the general public in legal research (Liu, Chen, & Ho, 2015). Pons-Porrata et al. applied an established keyword structure and created a primary/secondary hierarchical code system based on text analysis to develop a topic discovered a system of news feeds (2007).

Marzouk and Enaba utilized text analysis to analyze project contracts and correspondence of project participants to monitor project performance, and found the method useful in presenting patterns in project correspondence (2019). Harper and Molenaar (2014) employed content analysis to quantify the presence of behavior norms common to relational contract theory in SFC. Document data mining was used to assist in an automated pattern identification process for construction-defect litigation cases, but the results had shortcoming specific to construction defect identification (Jallan et al., 2019). Jobidon et al. performed an extensive analysis of relational contract law of completed projects in the Quebec region using a software package to mine contractual terms of existing contracts (2019). In a previous study, an analysis of 826 publications using keyword and co-occurrences of terms was used to understand the direction of project management research in Kazakhstan (Narbaev, 2015). In a further study, Azam and Yao theorized that based on experimental observation, term frequency was superior compared to document frequency in smaller data sets (2012). Gosling and Naim utilized keyword analysis for a literature review of engineer-to-order supply chain management in various scholarly databases (2009).

2.3 Research Methods

For this research, content analysis and specifically word frequency was used to review SFC templates and executed contracts to form a basis of understanding for the contractual concepts emphasized by the selected contract types. As noted, frequency analysis of key terms is based on the premise that the more frequently a term or "keyword" occurs in a document, the more relevant the term is to the subject of the document (Marzouk & Enaba, 2019). Neuendorf noted limitations to keyword counts alone, compared to analysis of the keywords in context, since frequency analysis may produce errors relating to overall use of the keywords between differing documents, authors, originating bodies, etc. (2017). While the authors acknowledge such limitations, this research focuses on similar construction SFCs in which the authors assume a high level of similarity for text and grammatical constructs within the narrow focus of construction contracts. Therefore, although the formatting of the SFC may differ amongst the different templates, the content of the contract is assumed to be similar irrespective of the document originating body (Rameezdeen & Rajapakse, 2007).

The analysis of construction contracts is based on a multi-step process adopted from previous noted research. The steps include: (i) document selection, (ii) keyword coding query (known as "coding queries" and "level of analysis"), (iii) document sampling, and (iv) tabulation and analysis ("Content Analysis Guide," 2020; Neuendorf, 2017) . Contract documents were chosen from three separate organizations common to the commercial/healthcare industry: American Institute of Architects (AIA), Design-Build Institute of America (DBIA), and ConsensusDocs. The specific contracts from each organization were selected on the bases of use in collaborative and non-collaborative agreements common to the healthcare construction industry and can be seen in Table 1. Executed contracts were selected based on similarities between geographic location (western United States), industry (healthcare construction), and dates of completion (between 2014 and 2020).

Table 1 – Contract Type and Originating Organization

Contract Type and Originating Organization		
Organization	**Contract(s)**	**Contract Description**
American Institute of Architects (AIA)	A101/201 (2017)	Standard Form of Agreement Between Owner and Contractor
American Institute of Architects (AIA)	A133/201 (2009)	Owner-Construction Manager as Constructor Agreement
American Institute of Architects (AIA)	C191 (2009)	Multi-Party Agreement - IPD
Design-Build Institute of America (DBIA)	D530/535	Standard Form of Agreement Between Owner and Design-Builder
ConsensusDocs	CD300/305/397	Multi-Party Integrated Project Delivery Agreement

In addition to the chosen collaborative contracts, the AIA-A101/201 Lump Sum contract was selected for a baseline comparison. The following provides a brief description of the contract types and selection criteria. The AIA-A101/201 is a standard Lump Sum contract and provides a theoretical benchmark of contract terms for traditional contract language. The AIA-A133/201 is a Construction Manager as Constructor (CMGC) contract that utilizes a Guaranteed Maximum Price and Cost-plus Fee (GMP) fee structure. Depending on the contractual terms, this SFC template can be viewed as either strictly a GMP type contract, or an IPD-like contract, as influenced by the presence of specific contractual terms noting the level of collaboration, shared incentives, and level of early involvement. (Alves & Shah, 2018; Hanna, 2016; Kulkarni, Rybkowski, & Smith, 2012a). This, too, allows for a comparison of a more collaborative agreement to that of a traditional agreement.

The DBIA-D530 & D535 is a design-build contract, and depending on the incentive structure utilized, can be viewed as either an IPD or IPD-like contract (Hanna, 2016). The AIA-191 contract establishes the basic framework for a multi-party agreement for integrated project delivery (*Document Commentary*, 2009), with exhibits that list items such as: target cost breakdown, project definition, project goals, integrated scope of services, project schedule, digital data protocol, etc. The last contract reviewed for this research was the ConsensusDocs CD300/305/396, which is used for Integrated Project Deliver (IPD) projects and comprises a multi-party agreement (CD 300), Lean construction addendum (CD 305), and a joining agreement for integrated project delivery (CD 396).

Both Standard Form Contracts (SFC) templates and executed contracts were reviewed. Based on the SFC templates chosen for sampling, fully executed contracts using these templates were obtained (either in a MS Word or PDF format) to analyze variations in keyword use from that of the SFC template. Review of both the SFC template and executed contracts were chosen for this research to ensure that concepts specific to this research were not omitted by reviewing the SFC template alone. In each case, review of the contracts was inclusive of all exhibits and amendments referenced in the contract by the execution date. This included reference documents (BIM standards, facility standards, organizational contractor access requirements, etc.) that may not be typical of the actual SFC template but were referenced by the executed contract. It is assumed that these reference documents may contain information that would have otherwise been directly written into the document if not for the separately drafted reference document and therefore pertinent to the body of this research.

For the content analysis, documents were reviewed with two separate software programs used for text analysis: NVIVO and Voyant (www.voyant-tools.org). NVIVO is a downloadable software offering text analysis in a variety of media's, and Voyant is a free web-based software with a more limited analysis capability. Both software programs allow for multiple analysis of documents, including word searches and text queries, and were jointly used to verify results.

2.4 Analysis

Part I – Document Selection

SFCs were chosen from three separate organizations common to the commercial/healthcare industry: American Institute of Architects (AIA), Design-Build Institute of America (DBIA), and ConsensusDocs (see Table 1). The contracts from each organization were selected as representative of each organization's collaborative contract. In total, five industry standard form contracts (SFC) templates and eight fully executed contracts were reviewed. As noted, the templates and executed contracts were selected based on being representative of healthcare construction along the western United States.

Part II – Keyword Coding Query/ Establishment of Search Criteria:

Since this research focuses on contractual language related to traditional key performance indicators of "cost", "schedule", "quality", in addition to the previously noted collaborative effort (simply referred to as "effort"), these keywords were utilized as the primary level of coding Structuring coding query is an iterative process and a secondary level structure was established by a literature review to ascertain a reliable search criterion for the content analysis (Neuendorf, 2017).

To establish an expanded keyword code structure, a primary-secondary relationship was established based on input from an extensive literature review similar to Neuendorf (2017). Primary keywords, or primary nodes, (“budget” for example) and co-words (“change order” for example) were selected based on a primary/secondary node relationship, as can be seen in Table 2. Keywords were chosen based on contextual similarity and industry connotations of the primary nodes as done by (Harper & Molenaar, 2014; Marzouk & Enaba, 2019). For example, Arditi and Pattanakitchamroon (2006) used the terms “delay”, “time”, “extension”, and “float” in direct analysis and review of project schedules and was therefore assumed to be reliable secondary tier keywords for the primary keyword “schedule”. This method is often used to tap a broad concept, and it is common in content analysis to have multiple indicators to meet the requirements of content validity of a term or concept (Neuendorf, 2017). This process was used for each primary node to establish a reliable search criterion. Results of the secondary tier keyword literature review can be seen in Table 3, Table 4, and Table 5.

To establish a reliable second tier node, a minimum threshold of three references was selected as a reliable indicator of the primary/secondary relationship. For the primary node “cost” (Table 3), all terms met this criterion except for the term “labor” and was thus omitted from the text analysis (step 3). This was also the methodology used for the primary node “quality” (Table 4), whereas the terms “inspection” and “standard of care” did not meet the referenced threshold. Terms associated with effort (Table 5) met the minimum criteria and were all used in the text analysis.

Table 2 - Primary/Secondary Keyword Relationship

Primary Node	Secondary Node
Cost	budget, target (cost), cost, change order, price, labor
Schedule	schedule, delay, time, extension, float
Quality	quality, inspection, specification, defect, workmanship, safety, standard of care, rework
Effort	effort, waste (process), collaboration, incentives, communication, decision making, behavior, trust, engagement.

Table 3 – "Cost" and "Schedule" Secondary Tier Keyword

	Cost						Schedule				
	budget	target (cost)	cost	change orde	labor	price	schedule	delay	time	extension	float
Mesa, A. et al		x									
Baiden, B & Price, A.											
Dziadosz, A & Rejment, M											
Pinto, J. et al											
Chan, D. et al	x	x	x			x					
Das, T.K. & Teng B.											
Bajari, P. & Tadelis, S.									x		
Harper, C. et al											
Gransberg, D. & et al			x				x	x	x		
Lahdenpera, P.	x	x	x			x					
Xue, X. et al											
Gonzalez, P. et al											
Franz, B. et al											
Hamilton, M.R. & Gibson, G.E.											
Aibinu, A.A,, et al											
Yeo, G., & Neal, A											
Collinge, W											
Chinyio E., & Akintoye, A.											
Collinge, W. & Harty, C.											
Maier, E. & Branzei, O	x		x				x	x	x		
Davis, K., et al			x								
Ibbs, W. & Ashley, D.			x	x			x				
Al-Momani, A.				x			x	x	x	x	
Meng, X.	x		x	x				x	x		
Arditi, D. & Pattanakitchamroon, T.			x				x	x	x	x	x
Williams, T.				x			x	x	x	x	x
Eriksson, E. & Westerberg, M.			x			x					
Mitkus, S. & Mitkus, T.				x				x			
Jaffar, N. et al			x				x	x	x	x	
Atkinson, A. & Westall, R.											
Wanberg, J. et al					x						
Abdul-Rahman, H.			x		x				x		
Lopez, R. et al	x		x						x		
Selviardidis, K. & Wynstra, F.	x		x								
Sakka, Z. & El-Sayegh, S.			x				x	x	x		x
Harper, C. & Molenaar, K.											
Jobidon, G. et al											

Table 4 - "Quality" Secondary Tier Keyword

	Quality							
	Quality	Inspection	Specs	Defects	Workmanship	safety	standard of	Rework
Mesa, A. et al								
Baiden, B & Price, A.								
Dziadosz, A & Rejment, M								
Pinto, J. et al								
Chan, D. et al	x							
Das, T.K. & Teng B.								
Bajari, P. & Tadelis, S.	x		x					
Harper, C. et al	x							
Gransberg, D. & et al								
Lahdenpera, P.								
Xue, X. et al								
Gonzalez, P. et al								
Franz, B. et al								
Hamilton, M.R. & Gibson, G.E.	x							
Aibinu, A.A,, et al								
Yeo, G., & Neal, A								
Collinge, W								
Chinyio E., & Akintoye, A.								
Collinge, W. & Harty, C.								
Maier, E. & Branzei, O								
Davis, K., et al	x		x		x			x
Ibbs, W. & Ashley, D.	x		x	x	x			x
Al-Momani, A.								
Meng, X.	x			x				
Arditi, D. & Pattanakitchamroon, T.								
Williams, T.								
Eriksson, E. & Westerberg, M.	x		x					
Mitkus, S. & Mitkus, T.	x				x			
Jaffar, N. et al	x		x	x				
Atkinson, A. & Westall, R.						x		
Wanberg, J. et al	x			x		x		x
Abdul-Rahman, H.	x	x	x	x	x			
Lopez, R. et al	x			x		x	x	x
Selviardidis, K. & Wynstra, F.	x		x					
Sakka, Z. & El-Sayegh, S.								
Harper, C. & Molenaar, K.							x	
Jobidon, G. et al								

Table 5 - "Effort" Secondary Tier Keyword

	Effort										
	Effort	risk mngmt	waste (process)	collaboration	incentives	communicat	productivity	Decision-ma	behavior	trust	engagement
Mesa, A. et al				x	x					x	
Baiden, B & Price, A.	x		x	x		x	x	x			
Dziadosz, A & Rejment, M		x						x			
Pinto, J. et al									x	x	
Chan, D. et al		x					x				
Das, T.K. & Teng B.											
Bajari, P. & Tadelis, S.	x				x						
Harper, C. et al	x										
Gransberg, D. & et al											
Lahdenpera, P.	x	x		x	x	x		x		x	
Xue, X. et al				x	x	x			x	x	
Gonzalez, P. et al											
Franz, B. et al											
Hamilton, M.R. & Gibson, G.E.	x	x		x		x		x	x	x	
Aibinu, A.A,, et al	x		x	x		x			x		
Yeo, G., & Neal, A	x			x		x	x	x			
Collinge, W		x						x	x	x	x
Chinyio E., & Akintoye, A.			x		x	x					x
Collinge, W. & Harty, C.	x					x					x
Maier, E. & Branzei, O											
Davis, K., et al	x										
Ibbs, W. & Ashley, D.					x	x					
Al-Momani, A.											
Meng, X.	x	x		x	x	x				x	
Arditi, D. & Pattanakitchamroon, T.	x										
Williams, T.							x				
Eriksson, E. & Westerberg, M.				x	x						
Mitkus, S. & Mitkus, T.						x					
Jaffar, N. et al		x		x		x			x	x	x
Atkinson, A. & Westall, R.						x					
Wanberg, J. et al											
Abdul-Rahman, H.											
Lopez, R. et al						x			x		
Selviardidis, K. & Wynstra, F.	x	x			x						
Sakka, Z. & El-Sayegh, S.		x									
Harper, C. & Molenaar, K.	x			x							
Jobidon, G. et al		x								x	

A minimum value was set at five primary/secondary keywords for each primary category, with a maximum value being no more than twice that of the minimum primary/secondary nodes selected. No guidance was given in literature as to a minimum/maximum number of keywords used in proportion between primary keyword categories, and the value selected here was assumed to be conservative. As part of the iteration process, the keyword count is reviewed based on the number of primary/secondary keywords used to ensure that the total number of keywords used does not skew the results.

Part iii – Document Sampling

Keyword sampling of documents were completed using both software programs previously noted. Sampling was completed with the inclusion of "stemmed words" (variations of the same word, for example talk, talking, talked, etc) and “stop words” (prepositions and non-pertinent phrases captured in headers and footers; copyright, AIA, etc). The results are generated in part iv.

Part iv - tabulation and analysis

Results of the analysis were compiled and reviewed by an author and a research assistant to validate the keyword use and counts of each document. The results were then downloaded to Microsoft Excel for further analysis and comparison of results between the two-separate human-coders. The results reviewed further in the next section, were summarized at the primary node level. The use percentage (UP) of an individual primary keyword (subscript “ipk”) compared to that of the sum of all the primary keywords (subscript “spk”): $UP = \Sigma_{ipk}/\Sigma_{spk}$.

2.5 Results

Apart from the AIA 101/201, the primary keywords surrounding “costs” had the highest frequency count (see Table 6 and Figure 1). The primary node with the highest frequency count in the AIA 101/201 was “schedule”, followed by “cost”. For the majority of the SFC reviewed, this is not surprising as construction is complex, and the implicit difficulty in establishing fair and equitable cost targets requires expanded clarifications (Bajari & Tadelis, 2001). Figure 2 presents the same data from Table 6 to assist in the visualization of the differences between data sets. From Table 6 it can be seen the relative similarity in term use between the differing SFC’s.

Table 6 - Keyword Use by Primary Node

Average Keyword Count by Primary Node of Total Keyword Count				
	Avg Total Cost	Avg Total Schedule	Avg Total Quality	Avg Total Effort
A101/201	28.37%	38.38%	22.12%	11.13%
A133/201	43.39%	31.26%	14.62%	10.73%
C191	48.24%	24.14%	13.44%	14.18%
DBIA 530/535	44.97%	30.50%	15.60%	8.93%
ConsensusDocs	40.76%	20.38%	14.72%	24.13%
Average	41.15%	28.93%	16.10%	13.82%
Standard Deviation	6.83%	6.22%	3.09%	5.43%

The relative standard deviation from the mean between term uses were similar between "cost" and "schedule" primary nodes. Term frequency use for "quality" had the smallest standard deviation from the mean and was consistently in the bottom half of the rank order (Table 7). The standard deviation for the primary node "effort" fell between the other primary nodes, and depending on the SFC used, had between the 2nd highest and the lowest rank order.

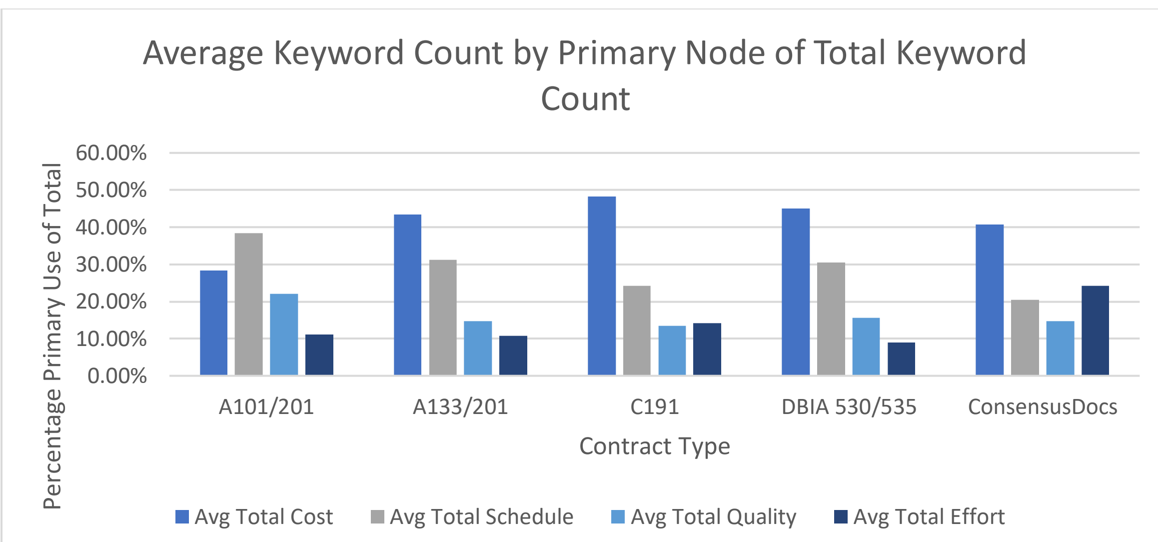

Figure 2 – Primary node use, as percentage of

Table 7 - Node Use Rank Order

	Highest Rank Order	2nd Highest Rank Order	3rd Highest Rank Order	Lowest Rank Order
A101/201	Schedule Node	Cost Node	Quality Node	Effort Node
A133/201	Cost Node	Schedule Node	Quality Node	Effort Node
C191	Cost Node	Schedule Node	Effort Node	Quality Node
DBIA 530/535	Cost Node	Schedule Node	Quality Node	Effort Node
ConsensusDocs	Cost Node	Effort Node	Schedule Node	Quality Node

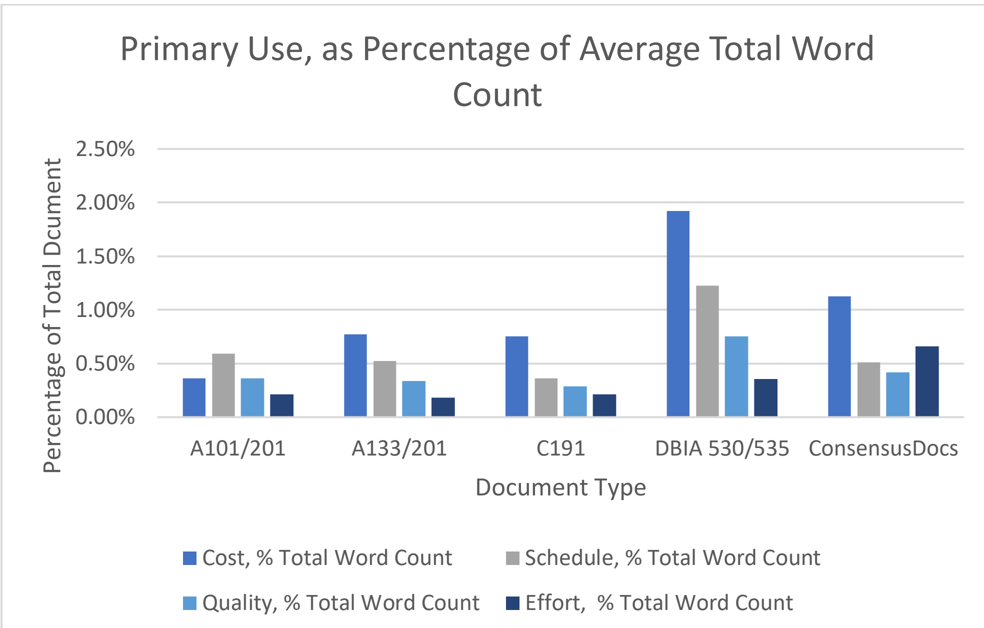

Figure 3 -Primary node use, by use percentage

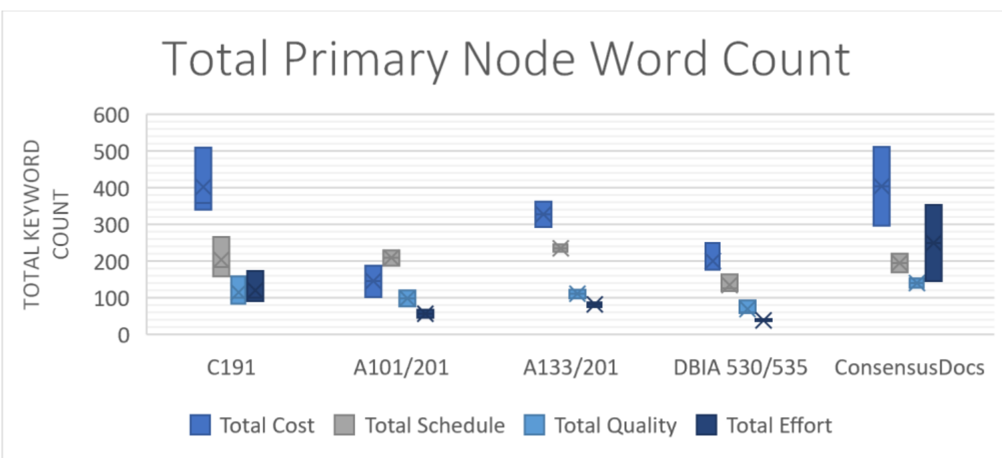

Figure 4 – Primary node us, by total word count

The rank order based on frequency percentage of total primary node use throughout the documents is summarized in Table 7. The rank order of primary node use was consistent whether analyzed as a percentage (as in *Figure 1*), or when presented as a percentage of primary node use to that of the entire document (Figure 2). Figure 2 highlights the differences between more collaborative contract's primary node use, compared to the overall word count in each document. This too showed littler variation in primary node rank order. Figure 3 shows the range in primary node use based on total word count. The ranges can vary, specifically with the ConsensusDocs where the variation that can be seen were primarily from the influence of contractual attachments over that of the SF template alone. Based upon the findings noted in the Figure 6 and Figure 7 and Figure 2, Figure 3, and Figure 4, the data suggest that the application of contractual content changes little between differing SFC type, based upon the relative use of the primary/secondary keyword nodes.

This is an interesting finding, in that the application of terms use influences the contractual content, regardless on the contractual intent. One would expect a closer alignment between content and intent regarding collaborative agreements, since the contractual framework and content assists in identifying the desired processes and behaviors outside of traditional contracting concepts (Ashcraft, 2011). Based on this expectation, those drafting or negotiating a collaborative agreement should question whether their contractual content matches the intent of their agreement to avoid future differences in project satisfaction and/or disputes in project outcomes.

2.6 Discussion

The keyword variance between assumed contractual intent and contractual content may or may not convey the importance of the primary keyword topics to the contracted parties, but appears to validate similar research which has demonstrated the extent of the party's obligations to one another via the terms (and thus content) of the contract (Korobkint, 2003). Depending on the contracting parties, project costs may be the singular most important issue. The expanded clarification defines the obligations between the contracted parties, to include the allocation of risk, in order to ensure that the contracted parties act in accordance with each other's expectations and interest (Zhang et al., 2016).

Standard form contracts provide a starting point for negotiations and clarifications and are a crucial instrument in the establishment and maintenance of the contractual relationships (Scott, 2006). Negotiating contractually agreeable terms is necessary to find the common interest between parties and use of SFC assist in facilitating this communication (Ashcraft, 2011). Based on the legal framework provided in a standard form contract, a certain number of modifications to the content of the SFC are necessary to communicate the requirements and expectations for project completion. (Rameezdeen & Rajapakse, 2007). The results do represent the challenge in moving towards more collaborative agreements where efforts of the project team are incentivized, but contractual terms may not be reflective of what this encompasses.

Challenges in more collaborate agreements have been seen to indicate that issues surrounding the primary key words of "quality" and "effort" are not given an expanded contractual definition that is needed to meet the intent of these agreements (Ebrahimi & Dowlatabadi, 2019; Franz et al., 2017). Correlating the increased use of these primary key words and project success is beyond the scope of this paper, but it does provide an opportunity for not only future research but also the practical application of project participants to integrate and document many of the topics covered by the primary key words of "quality" and "effort".

2.7 Conclusion

This research presented an evaluation method of contracts language to quantify the content of standard construction KPI expectations and the differences in contract language between delivery methods. It analyzed five industry standard form contracts (SFC) and eight fully executed contracts to quantify and compare the content of the contract terms for alignment to industry standard performance indicators of cost, schedule, quality, and effort. Apart from the AIA-A101/201 contract, keywords associated with the primary node “costs” had the highest frequency amongst the other contracts reviewed. This was true for both the SFC templates and for the fully executed contracts. The AIA-A133/201, and the DBIA 530/535 contracts all had similar frequencies rankings of the primary keyword node of “cost”, followed by “schedule”, “quality”, and “effort”. The AIA-A101/201 had a keyword node frequency ranking of “schedule, “cost”, “quality”, and “effort”. The frequency rankings of the AIA-C191 was “cost”, “schedule”, “effort”, and “quality”. The analysis of the ConsensusDocs 300/305/396 resulted in keyword node frequency ranking of “cost”, “effort”, “schedule”, and “quality”.

These findings suggest that the null hypothesis offers the more accurate assessment of contract language, but results were mixed overall. As noted above, there is little difference with the primary node keyword rank order, except for the ConcensusDocs contracts. Though the primary node “effort”, had a higher rank order with the ConsensusDocs and AIA-C191 SFCs, the other primary nodes had similar rank order profiles. It is worth noting that as shown in Figure 3 both “quality” and “effort” primary nodes had higher use percentage when compared to the entire document. Though this still doesn’t disprove the null hypothesis, it does show a progression of these promoted values in these more collaborative contract types. As the commercial design and construction industry continues to adopt more collaborative methodologies, the contractual language used will need to also shift to stipulating the expectations of collaborative efforts beyond concentrating on construction at completion alone.

2.8 Limitations of Research

Based on the total number of SFCs and executed contracts reviewed, generalization of the applications described may be limited. The widespread use of the selected SFC's within the commercial construction healthcare industry though does allow for the transferability of the concepts described here within. Changes from the SFC template to the executed contract indicating an elevated level of importance of the contractual subject by the contract executing teams is beyond the scope of this paper.

2.9 Recommendation for Future Research

It is recommended that future researchers review modifications to SFCs to further explore how the construction and design industry adapts to market pressures, risk mitigation, cost and schedule concerns, and project team objectives/incentives to name a few. Additionally, future research should evaluate the possible correlation between the content of the executed contracts to that of the success of the projects (cost, schedule, quality, effort).

CHAPTER III

INCENTIVES AND EFFORT ELICITATION IN CONSTRUCTION CONTRACTING

3.1 Introduction

Dr. Daniel Kahneman noted in an interview that,"….there's natural stresses in collaboration. The world is not kind to collaboration" (Vedantam & Kahneman, 2018). To the extent that this is applicable to construction and design is noteworthy due to current industrial trends. The construction and design industry has experienced a shift from a "master – builder" concept prevalent in the early 1900's, to the separation of design from construction common for most of the second half of the 20th century, to the current shift of incentivizing collaborations between designers and builders. Though the intent of this collaboration is for greater project outcomes, collaboration has potential cost and risk implications to the project owner.

Research has shown that project types utilizing alternative contracting methods such as design-build and integrated project delivery (IPD) have generally resulted in better project outcomes. However, variation of project elements (location, design/project type, experience and sophistication of companies and people) makes evaluation of specific inputs, such as contract type and incentives, challenging to isolate and generalize in terms of specific project outcomes. Furthermore, due to the many variations in construction and design, it can be difficult for a project owner to choose which procurement and contracting method to utilize.

Peldschus noted that the application of game theory research related to multi-criteria decisions assists in understanding technical complexities and influencing factors that cannot be solved using traditional engineering knowledge (2006). This research uses elements of game theory to provide conceptual models of typical contract structures common to the commercial construction industry, as well as project outcomes based on specific contract scenarios, and the commiserate effort of the contracted participants. The goal is to use these conceptual models of contract structures and effort to inform and illuminate the influence of the interplay between contracted parties. Specifically, this research uses a framework based on game theory models of strategic interactions between principals and agents to illustrate collaborative and non-collaborative relationships imbedded in standard-form construction contracts that influence the behaviors of project participants and thus project outcomes.

3.2 Research Objectives

This research seeks to develop and study generalizable incentive structures and their impact on collaborative behaviours. Specifically, this research seeks to demonstrate how effort levels of agents are altered or influenced by the observable and/or projected effort level of the other agents based on contract type.

This research objective will be met by first developing and analysing agent behaviour and contract type using established game theory models. Second, this objective will be further illustrated and tested using three discrete propositions. Specifically, survey data from real-world project participants will be analysed to establish:

> **Proposition$_1$**: Effort levels, both self-reported and observed, of contracted agents vary between contract types.
>
> **Proposition$_2$**: Individual effort levels are influenced by the perceived level of effort of the alternate agent

Proposition$_3$: Increased effort levels (group/individual) are associated with increased schedule and cost savings

3.3 Literature Review

Findings regarding contract and delivery methods' impact on project outcomes have been mixed. Prior research has indicated positive impacts of collaborative project delivery methods compared to traditional delivery methods (Asmar, Hanna, & Loh, 2016; 2013; Kahvandi et al., 2017; Kulkarni, Rybkowski, & Smith, 2012), while other research has indicated less successful outcomes in terms of total cost savings (Bilbo et al., 2015a; Rojas & Kell, 2008). The authors of this paper chose to use elements of game theory to evaluate common contracting methods in conjunction with known project risks, expected behaviours of contracted parties, and their strategies. Past research has primarily used game theory to evaluate contracts in the context of risk, decision management, and resource allocation for fields such as logistics, transportation, labour negotiation, international affairs, and engineering to name a few. This research builds upon a well-established body of literature documenting the utilization of contact and game theory in engineering and construction disciplines. Such research is summarized in the following section.

Studies in Economics

The field of economics informs this research by providing insights into contract theory, incentive structures, and their resulting impacts on behaviors. This research utilizes models presented in prior research for alignment to contracting structures common to the commercial construction industry.

In terms of contract design for this research, the principal-agent model is a fundamental concept to the conceptual narrative of the relationship between an owner (principal) and an individual person(s) or entity producing a good or service (agent) on behalf of the owner. The Principal-Agent model refers to a condition where a party (the principal) hires/contracts another party (the agent) to work on their behalf. The principal is only able to verify the outcome of the project and not the agent's actual effort (Watson, 2013). The general framework of the principal-agent model, also known as the "Theory of Agency," has been in publication since the middle of the 20th century, with Stephen Ross and Barry Mitnick each independently publishing their own theory of agency in the 1970's (Mitnick, 2006). Further research explored the principal's relationship with the agent in terms of monitoring costs and the incentives required to ensure the agent would not take actions to harm the interest of the principal when completing the contracted work (Jensen et al., 1976). Since then, the field of economics has produced a wide range of publications and laboratory experiments validating the model and proving its applicability to contracted relationships.

Conceptually, the principal delegates a task to an agent, and the agent may choose actions that affect the value of the project or that of the agent's performance. This presents a conflict between the principal and the agent, as the agent(s) have agency over their actions that may be in conflict to the belief and desires of the principal. Such conflicting actions have been coined as a moral hazard (Laffont & Martimort, 2002). In studying contracts, McAfee and McMillan concluded that the optimal principal-agent contract should reduce the moral hazard with the opportunity of sharing risk with other agents and the principal (1986). The blind spot in the principal's oversight that created the moral hazard can be mitigated, as Bortolotti et al. note, by the role of trust and social capital that can assist in the completion of tasks (2016). Macleod cautions against the use of this strategy, however, stating that if the agent(s) disagree with the principal's evaluation and/or beliefs that the evaluation is based on, the principal is more likely to see higher costs and lower levels of performance by the agent(s) (2003).

In collaborative scenarios with multiple agents, as studied by Itoh, teamwork is optimal for a principal-agent model even with the possibility that an agent's preference may be to exhibit less effort when compared to other agents (also called free-riding) (1991). Exploring the issues of free-riding at Continental Airlines, Knez & Simister found that mutual monitoring can force employees to internalize and evaluate the impacts of their action, or lack thereof, on their co-workers when incentives are obtainable (2001). Sappington agreed when writing about incentives and free-riding, noting that relative performance of agents, when compared to the individual performance of other agents, can provide motivation to avoid free-riding without imposing excessive risk to the agents (1991). Kandel and Lazear found that in the absence of peer pressure, larger partnerships have greater free-rider problems. By improving incentives, however, the peer group responsible for profit can apply the needed pressure to minimize a free-rider problem (1992). In summary, the principal-agent model illustrates opportunities within the contact structure to incentivize varying levels of effort and avoid adverse outcomes.

Incentives are a defining factor in a principal-agent model, by encouraging actions by an agent while preserving their overall agency. In prior research, Poblete and Spulber surmised that the optimal contract between the principal and agent(s) incentivizes the level of effort required to maximize the principal's and agent's expected benefit (2012). Grossman and Hart studied the optimal incentive scheme for a principal-agent model by analyzing an agent's action at different times during a contracted period and found that it is never optimal to have a negative payoff scheme between the principal and agent(s) (1983). Radner discussed how an agent's effort will change based on the agent's knowledge of future contract iterations with the principal, and in parallel, to other agents (1985). Itoh came to similar conclusions in multi-agent situations and noted that teamwork is optimal if an agent increases their effort in conjunction with an increase of effort by other agents (1991). Effort by the agent(s) was also explored in multi-task environments by Holmstrom and Milgrom; they noted that greater success occurred with the use of goal driven incentives and easily measured performance indicators than with the use of menial incentives and vaguely worded performance measures (1991). These are important finding in that effort of the agents are explored independently and in-conjunction with other agents.

Research regarding the effectiveness of incentive strategies differs. Rayo studied the outcomes of agreements where certain agents received varying incentives. He found that by targeting incentives to key agents, an increase of effort by the remaining agents occurred due to the targeted incentives, creating a local principal that could more easily encourage increased effort by the entire team (2007). By contrast, McCabe studied a team's effort when constructing electrical utility plants. The inconsistent expectations put forward by a principal limited a firm's ability to improve on previous project metrics. This led to a higher probability of diminished incentives received and/or the necessity to provide additional effort which resulted in decreased efficiency (1996). Forno and Merlone (2010) had similar findings, with their data indicating that individual incentives may not elicit sufficient discretionary effort from agents to overcome project obstacles. Dugar and Shahriar also noted that when the principal's payoff is made more important than that of the agent's own, the efficiency-enhancing choices made by the agent will diminish (2012). These research findings indicate that incentives alone are no guarantee of increased effort by the agents, but that the type of incentive and who is being incentivized do have impact.

The goal of incentivizing effort is to increase behaviors that maximize benefit to the principal and agents. Behaviors that enhance cooperation needed for contracted relationships were reviewed in the laboratory by Devetag and Ortmann (2007). They found the following behaviors enhance efficiency: pre-play communication, quality, and the strength of common knowledge amongst participants, and observing actions after implied intent of the actions, among others. Pre-play communication with its associated cost have been further reviewed in a laboratory setting, and findings include that communication, even with an associated cost, increase efficient coordination towards the pay-off strategy (Büyükboyacı & Küçükşenel, 2017). In another laboratory setting researchers concluded that players have sensitivity to historical choices of other players, and that coordination behavior converges more quickly between players when the optimal pay-off strategy has a larger premium associated with it (Battalio, Samuelson, Huyck, & Huyck1, 2001).

Notably, Zagare used 2-by-2 games, including the Stag-Hunt model, to demonstrate that game theory provides a comparative analysis to real world issues (1984). Using a Stag-Hunt simulation with artificial intelligence, researchers concluded that trusting individuals can influence a population or team based on learning from the previous actions of others (Fang et al., 2002). Dubois et al. confirmed this in another laboratory experiment and found that players' behaviors become more sensitive to risk when past outcomes of players are revealed (2012). Bosworth used the Stag-Hunt game in yet another laboratory experiment to demonstrate the importance of beliefs for successful coordination among players (2017). In another study, a player's attitude toward risk affected the level of coordination in another Stag-Hunt laboratory experiment, and researchers concluded that communicating a player's risk tolerance prior to choosing an action led to better coordination (Büyükboyacı, 2014). Collectively such findings suggest that the effort levels of agents are influenced by the behaviors and risk tolerance of the other agents.

Studies in Engineering and Construction Management

In the field of engineering, contract structure and associated behaviors have been studied relative to decision support, conflict management and other contract issues. Madani and Lund explored multi-criteria decision making with non-cooperative game strategies to model outcomes of water resource management conflicts that arise from competing interest between different stakeholders (2011). Madani also used game theory to highlight the influence that those in authority have to change the behavior of players from a non-cooperative strategy to a Pareto-optimal one (2010). Páez-Pérez & Sánchez-Silva showed that with regard to infrastructure procurement, the Principal-Agent model can work as a starting point to develop a framework to evaluate a player's strategies and their effect on an infrastructure system (2016).

Within construction management and construction engineering, researchers have studied game theory as a tool to analyze coordination and decision analysis. Asgari et al. researched the gains associated with partnering amongst sub-contractors using the Nash-Harsanyi bargaining solution with the results showing that game theory methods help design fair and efficient schemes for sharing the benefits of cooperation (2014). Sacks and Harel used game theory to model the conflict between general contractor and sub-contractor regarding resource allocation. Their research confirmed the adversarial relationships common to many traditional contracting methods had lesser project outcomes when compared to contracting methods that promoted collaboration and communication (2006). A game theory model was shown to be of use when evaluating and negotiating contract terms or other issues of conflict between contracted parties (Ramón & Cristóbal, 2015). Jung et al. used a game theory model similar to the Prisoners Dilemma and Stag Hunt to demonstrate the applicability of game theory to collaborative behaviors in construction and design (2012). A traditional Prisoners' Dilemma style game is one in which the individually rational choice leads to a Pareto inferior outcome. While the agents interacting in the game would prefer to cooperate, they face a conflict between group and self-interests. For more on this see Poundstone (1992) .

Muller and Turner studied the impact of communication within a principal-agent relationship and found that different construction contracting methods can have an impact on the cost of communication between principal and agents (2005; 2003). Wu et al. used game theory applications to highlight the benefit of cooperation in sustainable construction projects and noted a positive association between the amount of collaboration, project outcomes, and the effort by the principal and agents (2017). Chang reviewed the incentives used in the principal-agent model, specifically the incentives needed to buffer against possible breakup costs. Findings indicated that the incentives are a useful tool to promote efficiency enhancing behaviors and reducing risks associated with breakup cost. In sum, prior research findings demonstrate that the principal-agent framework provides a useful method to explore how effort affects project outcomes. Specifically, such research demonstrates that game theory is applicable to the construction industry where decisions and behaviors by individual agents can impact project outcomes.

3.4 Preliminary Application of Game Theory to Common Contracting Methods

For this research three contract and procurement methods are studied: Design-Bid-Build (Lump Sum contact type), Construction Manager at Risk (Guaranteed Maximum Price, “GMP”), and Integrated Project Delivery (Multi-Party agreement, “IPD”). For each, it is important to understand the relevant relationship of agents as well as the associated incentive structure.

Models of Relationships and Incentive Structure

Design-Bid-Build/Stipulated Sum Contract

When a building owner (the principal) utilizes a design-bid-build (DBB) process, the owner seeks to leverage a competitive bid environment to a qualified prime contractor (also known as a General Contractor, or GC) to benefit from the lowest submitted price (Hale et al., 2009). The bidding process by which the principal selects a contractor is not within the scope of this paper. For a review of the literature on auction design and bidding see (Bogus, Shane, and Molenaar, 2010).Typically, the prime designer (also known as the architect) has nearly completed their scope of services, which would include drawings, projects specifications, and due diligence to meet the standard of care at the time of bidding. Depending on the terms of the agreement between the principal and prime designer, the prime designer may provide oversight during the construction process (Hallowell & Toole, 2009). In this delivery model the prime designer has been paid a stipulated sum as either a cost-plus fee or lump sum contract for the completed construction documents.

During the design process the prime designer, explicitly or implicitly, decides the level of effort that they are willing to provide to complete the design documents. This decision can be attributed to various causes, such as staff ability, staff availability, and comprehension of project requirements to meet the minimum standard of care. The prime designer benefits from creating higher quality designs because this will require fewer modifications, revisions, and additions later during construction, which will have positive implications to the design team's construction administration obligations (Yean, Ling, & Ang, 2013). The owner benefits from higher quality designs due to the reduction in Spearin Doctrine or defect issues (Prentice, 2004). It is generally assumed that when agents (i.e., the prime contractor or designer) provide high effort there will be a positive correlation to project outcomes, via the quality of design and built environment (Grossman & Hart, 1983).

Importantly, the contractor also benefits from a higher effort design plan since it facilitates better construction (Yean et al., 2013). That said, the prime designer has little monetary incentive to apply a level of design effort beyond the contracted terms and industry standard of care. Based on the contract, any additional design effort is typically not compensated. In addition to the direct cost of the additional effort by the design team, there exists a non-trivial opportunity cost in additional time and resources on project documents that have already met the standard of care. The conflict demonstrated by opposing incentives of the owner and the designer is at the heart of the Principal-Agent Dilemma. Specifically, success of the project is contingent on high effort from both prime designer and contractor, but the designer and the contractor are, in fact, incentivized to not provide a higher level of effort.

To formalize this scenario, the authors use a solution concept in game theory known as backwards induction. Backwards induction is the process by which sequentially rational and forward-looking agents determine their best set of choices by considering what other agents will choose following their own action. Backwards induction related to construction requires the assumption that both the prime designer and contractor are 1) profit maximizing and 2) forward looking. Backwards induction involves looking at the last decision-maker first. In this contract scenario, the prime contractor makes the final decision. When deciding on what level of effort to provide, the prime contractor will not only look at their own cost of providing additional effort, but also at the quality of design, and implicitly the level of effort, of the designer. A rational prime contractor, however, will not take into consideration the perceived effort level of the designer, because the prime contractor understands the contractual terms mean that additional effort comes at an uncompensated cost. Therefore, additional designer effort will only decrease the designer's expected profit in a stipulated sum environment, and as such, the contractor can only assume that their own additional effort is not rational either. The contractor will thus choose to provide an effort level commiserate with the standard of care. The result of this interaction closely follows the outcome predicted by the canonical model of the Prisoners' Dilemma, but, the dynamic nature of the game means the model of a DBB contract scenario is best represented by a *sequential* Prisoner's Dilemma.

To model DBB within a game theory framework, consider that both the prime designer and prime contractor's stipulated sum contract payoffs are described by the simple expression

$$Profit\ (P) = Stipulated\ Sum\ Contract\ Value\ (W) - Labor\ and\ Material\ Effort\ Cost\ (E)$$

Equation 1 - Base Profit Expression

When considering self-interest alone and knowing that low effort is less costly than high effort, the prime designer and the contractor will maximize profits by choosing less effort under a stipulated sum contract.

$$W - E_{low} > W - E_{high}$$

Low effort, here, is defined as the minimal effort required to meet the standard of care. That said, the prime designer and contractor do not make their effort decisions in a vacuum. Profit will depend on their own level of effort *and* the effort of the other party. For example, the prime contractor costs will be reduced if they choose low effort—but will be further reduced if the prime designer provides them with high quality (i.e., high effort) construction/design plans. Conversely, prime designer costs will be reduced if they choose low effort—but it will be even lower if the contractor puts in high effort during construction- arguably, making up for deficiencies in the design plans or avoiding the need to make modifications.

In such a model, the choice of "low effort" ($E_{C,low}$) is always better when seeking to maximize the profit of the prime contractor (noted by subscript C), conditional on the effort decision of the prime designer (E_D).

$$(W_C - E_{C,low} | E_{D,high}) > (W_C - E_{C,high} | E_{D,high})$$

$$(W_C - E_{C,low} | E_{D,low}) > (W_C - E_{C,high} | E_{D,low})$$

Relating these two conditions, the payoffs of the prime contractor and prime designer can be ranked. The best payoff for the contractor is one in which they provide low effort, but the designer provides high effort. Conversely, the worst payoff for the prime contractor is one in which the prime contractor provides high effort while the designer provides low effort (the other two outcomes fall between these two scenarios).

$$(W_C - E_{C,low} | E_{D,high}) > (W_C - E_{C,high} | E_{D,low})$$

To the owner, high quality plans and construction (resulting from high effort by both parties) provides the best quality project while the combination of low-quality plans and low-quality construction results in the worse quality project. Given the basic incentive structure outlined in the DBB process, therefore, the owner is effectively enabling an undesirable outcome.

DBB Game Structure

The following figure describes the flow of the decision-making process given the prime designer (A_D) and contractor (A_C) can choose "high" or "low" effort. Restricting the agents' action to a binary choice is a simplification that does not impact the overall implications of the model. After the principal determines the pay structure (in this case, DBB), the game is initiated by the prime designer who chooses an effort level (low effort assumes completion of work just at the allowable standard of care). Following this decision, the prime contractor chooses an effort level with full knowledge of the prime designer's choice of effort. Figure 5 is the decision tree representative of the scenarios established in DBB construction contracts.

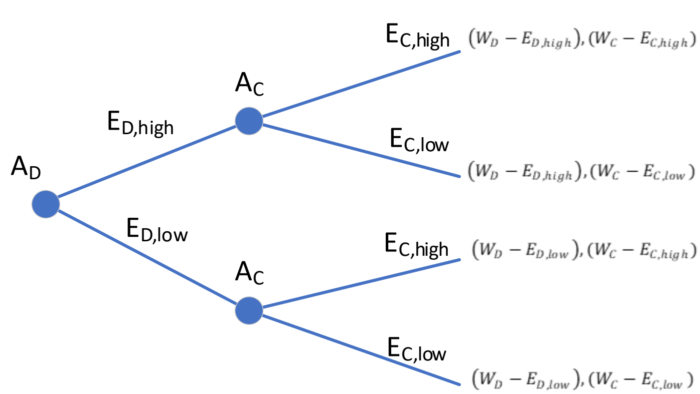

Figure 5 - DBB Extensive Form Game Tree

<u>Note</u>: The prime designer, A_D, and the prime contractor, A_C, have a binary "high" or "low" effort choice at their decision node. The designer begins by making a decision to provide high or low effort. The contractor

observes the designer's effort level and makes a decision contingent on their location in the game tree. The unique sequence of actions results in payoffs specified in Table 8.

The payoffs resulting from the decisions by the prime designer and contractor are summarized in the 2-by-2 matrix below.[1] Each cell lists one of four outcomes with the payoffs in the left part of each cell corresponding to the prime contractor and the payoffs in the right part of each cell corresponding to the prime designer. Note that while the owner receives a payoff (i.e., the item being built) which depends on the actions of the prime designer and contractor, they do not participate in the game. Instead, the owner's decision relates to the nature of the contract and is outside of the interaction between the designer and contractor.

$$\left(W_D - E_{D,low}\right), \left(W_C - E_{C,low}\right)$$

Table 8 – DBB Extensive For Game Payoffs

		Prime Contractor	
		High effort $E_{C,high}$	Low effort $E_{C,low}$
Prime Designer	High effort $E_{D,high}$	$\left(W_D - E_{D,high}\right), \left(W_C - E_{C,high}\right)$	$\left(W_D - E_{D,high}\right), \left(W_C - E_{C,low}\right)$
	Low effort $E_{D,low}$	$\left(W_D - E_{D,low}\right), \left(W_C - E_{C,high}\right)$	$\left(W_D - E_{D,low}\right), \left(W_C - E_{C,low}\right)$

Note: The payoffs of the designer are in the left side of each cell, while payoffs for the contractor are in the right side. Each cell represents the payoffs resulting from the combination of both agents' action, and are also shown as outcomes in Figure 5.

The prime designer and the prime contractor each have a decision to make concerning whether or not to provide additional effort on the construction project. Using backwards induction, the prime contractor will choose low effort in both scenarios. The low effort choice is

[1] The payoff matrix does not display all of the possible strategy profiles of the prime designer and contractor—instead it is a summary of the possible payoff outcomes. In the formal game, the strategies for the prime designer are $\{H, L\}$ effort and the strategies for the prime contractor are $\{hh', hl', lh', ll'\}$ effort to account for the possible branches of the game tree. This payoff matrix is, however, qualitatively the same.

a dominant strategy—it always results in a higher payoff regardless of what the other agent chooses because, $E_{C,low} < E_{C,high}$ in the two possible scenarios. Thus, the contractor will rationally choose to only meet the minimum standard of care necessary to fulfil the duties of their contract. This outcome is represented by the lowest branch in the game tree in Figure 5.

With the knowledge the contractor is profit maximizing, the prime designer rationally assumes that the contractor will not provide additional effort during the construction process and will instead provide the lowest effort level to meet the industry standard of care. Given a low effort choice of the prime contractor, the prime designer chooses between high effort and low effort, ultimately deciding on low effort.[2] As noted, it is assumed that less effort will result in lower quality and/or a less desirable outcome for the principal. When modelling DBB relationships using game theory, it becomes evident that neither party is incentivized to escape the trap of low effort. Both party's decision rests on choosing less effort to maximize their own profit regardless of a common belief or ability to trust the other.

As an aside, and a topic for future research, a potential solution to escape the Prisoner's Dilemma is for the principal to modify the standard stipulated sum contract by offering bonuses for completion of a higher quality project. Bonus structures in DBB contracts are not unique, with schedule incentives being most straightforward (Abu-Hijleh & Ibbs; 1989). This strategy of providing incentives is in line with previous research from Mesa et al. (2016), Asmar et al. (2013), and Chan et al. (2003), among others that highlight increased quality metrics and reduced

[2] As in the canonical Prisoner's Dilemma, the strategy profile in which both choose low effort is the Nash Equilibrium.

claims as construction projects move away from DBB to more collaborate contract types such as CMR and IPD.

Specifically, after including a bonus to incentivize higher effort, the profit maximizing conditions for the prime contractor are now

$$(W_C - E_{C,low} | E_{D,high}) < (W_C - E_{C,high} + B | E_{D,high})$$

$$(W_C - E_{C,low} | E_{D,low}) > (W_C - E_{C,high} | E_{D,low})$$

Where B is just *slightly* greater than the difference in effort costs, but no more than is necessary.

$$B > E_{C,high} - E_{C,low}$$

By pushing the prime contractor to choose higher effort in this scenario, the backwards induction outcome of the game changes. The pathways for low effort remain unchanged. However, looking ahead and knowing that the prime contractor will choose the high level of effort if the designer chooses high effort, it is now in the best interest of the prime designer to put forth the additional effort necessary to produce high quality plans.[3] This seems counter-intuitive, given in the typical Prisoner's Dilemma the maximizing response would be for the designer to free-ride on the contractor's high effort by choosing low effort. Unlike a standard simultaneous Prisoner's Dilemma, the sequential nature of the game means if the designer chooses low effort in an attempt to free-ride, the contractor observes this, triggering low effort on their part as well. However, if the designer chooses high effort, they will trigger high effort from the contractor and, possibly, a higher payoff with the inclusion of a bonus structure. As long as both agents choose high effort, it is pareto superior than both choosing low effort, and thus the prime

[3] Professional recognition or concern for reputation also impact the designer's motivations. The framework explored in this paper can be extended to incorporate these concerns through game repetition but is not done here.

designer and the contractor escape the Prisoner’s Dilemma—much to the benefit of the building owner.[4]

Interestingly, the principal does not need to explicitly incentivize the *designer* with a bonus since they will rationally choose a higher level of effort knowing the payoff from both choosing high effort is larger than the payoff for both choosing low effort. The key empirical issues are being able to estimate the effort cost differential and assessing whether a bonus makes financial sense to the owner.

Cost Plus a Guaranteed Maximum Price Contract

A project owner may choose an alternate contracting method if a construction project is too complex, or project documents cannot be sufficiently designed without the assistance of the prime contractor. In this scenario the owner may utilize a procurement method where the prime contractor is awarded the construction project before the construction plans are completed. The owner’s intent is for the prime contractor to provide pricing and schedule guidance to the prime designer before the construction documents are completed. The ultimate intention of the owner is that collaboration will improve the value of the finished project. This procurement method typically involves the prime contractor submitting a proposal with a guaranteed maximum price (GMP).[5]

[4] For the prime designer, the payoffs must be $\left(W_D - E_{D,high} \middle| E_{C,high}\right) > (W_D - E_{D,low} | E_{C,low})$.

[5] Cost plus a guaranteed maximum price contracts are also known as design-assist or construction manager at risk contracts. Contracts would be similar to the AIA A133,

The contractor’s payment under a GMP type contract depends on whether the prime contractor finishes the project below, at, or above a stipulated GMP amount, calculated by adding the cost of the direct cost of work plus the prime contractor’s overhead and profit. If the prime contractor finishes the project below the GMP amount, the owner may elect (predetermined via the contract) to provide a bonus for all, or part of the savings realized. The prime contractor is solely responsible for any costs exceeding the GMP.

The intent of the owner is to incentivize the prime contractor to assist keeping the entire project on schedule and budget, while simultaneously meeting the quality expectations of the owner. Typically, at the time of award to the prime contractor, the prime designer has made substantial design progress, but has not completed their entire scope of services subject to the terms of their agreement with the owner. In this delivery model, the prime designer is still paid a stipulated sum for the completed construction documents. Therefore, providing additional design effort for construction documents above the standard of care would result in no additional payments. From the perspective of the designer, the coordination with the prime contractor can be viewed as additional effort compared to DBB, but coordination also results in less re-work (either during design and/or during construction) and a better understanding of the acceptable design minimum– which by itself would result in less overall effort. This can be seen in the relative comparison of claims by contract type, with previously research noting a reduction in claims with the use of more collaborative contract types (El Asmar et al., 2013; Lopez and Love, 2012; Love et al., 2012).

While cooperation with the prime contractor may save costs later in the construction process and may reduce the risk of design related legal claims, the prime designer is still paid according to a stipulated sum. Consequently, there is little incentive to provide additional effort in the collaborative process and produce higher quality plans.

GMP Game Structure

During the design process in a GMP contract, the prime designer decides the level of effort that they are willing to provide to complete the design documents, knowing that there is an expectation to collaborate with the prime contractor to minimize the amount of design rework. The prime contractor is incentivized to deliver the project within budget and schedule expectations set by the owner, in part through collaboration with the prime designer, and thus earn a bonus for themselves. Though the structure of the design process is slightly different from the DBB contract, the sequence of decision-making outlined in *Figure 5* stays the same.

Specifically, the prime designer is first to make an effort choice, similar to DBB. This choice is observed by the prime contractor, who subsequently makes an effort decision influenced by the choice of the designer. A difference exists, however, in the payoffs. For the prime designer and prime contractor, the payoffs are expressed by the following equations:

$$Profit\ (P_D) = Stipulated\ Sum\ Contract\ (W_D) - Labor\ and\ Material\ Effort\ (E_D)$$

Equation 2 - GMP Prime Designer Profit

$$Profit(P_C) = GMP_C - Labor\ and\ Material\ Effort(E_C) + Bonus(B_C)$$

Equation 3 - GMP Prime Contractor Profit

Unlike in the DBB contract, the prime contractor does not face the same payoff relationship as the prime designer. Their payoff will depend on the construction costs relative to the GMP, where the GMP is the estimated cost of work plus overhead and profit. In the scenario outlined, the profit for the prime contractor can be positive, negative, or zero. If the construction costs are over the GMP, the bonus is 0, the contractor is paid the GMP, and any additional costs is borne by the contractor thereby reducing their profit. If the construction costs are less than the GMP, the difference between the GMP and the actual cost may be split between the owner and the contractor in the form of a predetermined bonus. If the construction costs are exactly the GMP, the bonus is 0 and the contractor is paid the GMP. The bonus structure is explicitly specified below where π represents the share of the surplus designated to the contractor [0,1].

$$B_C = \begin{cases} \pi(GMP_C - E_C) & if \;\; GMP_C > E_C \\ 0 & if \;\; GMP_C \leq E_C \end{cases}$$

Based on the three possible outcomes, this paper defines and explores a stylized scenario to model GMP contracts. Assume that for a project to be under the GMP the contractor must provide high effort and the prime designers must also provide costly high effort (or at least higher effort when compared to the DBB scenario) during the cooperative design process. If both prime designer and contractor provide low effort, construction costs are over the GMP. If the prime designer or contractor provide low effort while the other provides high effort, the construction costs are exactly the GMP. Importantly, note that any excess costs and project savings are captured solely by the prime contractor and not the prime designer under this delivery method.

As before, higher effort by the designer in the form of higher-quality plans is costly. One conceptual difference from DBB contracts is that high effort can also characterize the effort spent on cooperation with the prime contractor. The prime designer provides higher effort in the form of flexible and an intensive design collaboration with the prime contractor, and though the total effort may not necessarily be more than in a DBB project, timing and focus of this effort could be. For example, the prime contractor may direct the prime designer to provide additional design input into a specific building component, instead of the prime designer providing this same effort preparing bid documents for a DBB project. The prime designer would be motivated to provide this effort during the design phase, instead of providing additional effort during the construction phase, due to the inefficiencies of changing/altering designs during construction activities by the prime contractor.

The payoffs of the GMP model are summarized in Table 9, showing the adjustments due to the introduction of the incentive to the prime contractor in the form of a bonus when both agents provide high effort. While the contractor's incentive to provide high effort is augmented by the introduction of a bonus, the payoffs for the prime designer have not changed. Table 6 is the decision tree representative of the scenarios established in GMP construction contracts.

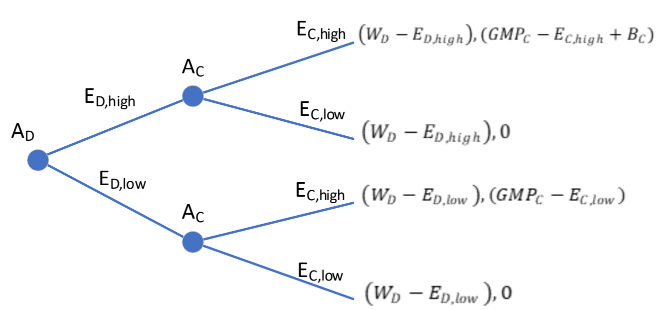

Figure 6- GMP Extensive Form Game Tree

Table 9 - GMP Extensive Form Game Payoffs

		Prime Contractor	
		High effort $E_{C,high}$	Low effort $E_{C,low}$
Prime Designer	High effort $E_{D,high}$	$(W_D - E_{D,high}), (GMP_C - E_{C,high} + B_C)$	$(W_D - E_{D,high}), 0$
	Low effort $E_{D,low}$	$(W_D - E_{D,low}), 0$	$(W_D - E_{D,low}), (GMP_C - E_{C,low})$

Note: The payoffs of the designer are in the left side of each cell, while payoffs for the contractor are in the right side. Each cell represents the payoffs resulting from the combination of both agents' action.

The prime designer is rational and will not choose to reduce their profit for the benefit of the contractor alone.[6] However, unlike the DBB contract, this game is not a Prisoner's Dilemma. To understand this, first consider the case when the prime designer provides high effort. The prime contractor *voluntarily* chooses high effort, making it possible that the project to be completed under the GMP. This decision holds as long the payoff for high effort with the bonus is greater than the alternative of 0.

$$\left(GMP_C - E_{C,high} + B_C \middle| E_{D,high}\right) > 0$$

Second, when the prime designer provides low collaborative effort, the prime contractor still *voluntarily* chooses high effort to avoid exceeding the GMP and taking a loss.

$$\left(GMP_C - E_{C,high} \middle| E_{D,low}\right) > \left(GMP_C - E_{C,low} \middle| E_{D,low}\right)$$

$$0 > \left(GMP_C - E_{C,low} \middle| E_{D,low}\right)$$

Thus, choosing high effort is a dominant strategy for the contractor. This game setup is a version of the classic game sometimes referred to as "pigs" or the "subordinate and dominant pig game"

[6] Repeat business with the owner or contractor, and/or reputational concerns may be reasons for the prime designer to provide additional effort at the cost of net profit, but both of those are not included in this simplified example.

experimentally tested by Baldwin and Meese (1979) and applied to cartel agreements in McMillan (2018). Adding a sequential component to this game does not alter the game's primary conclusion—the designer, knowing high effort is a dominant strategy for the contractor, has leverage over the contractor in that they can influence whether the contractor receives a positive or zero payoff.

The prime designer will choose low effort if they are sequentially rational since their payoff is simply the stipulated sum minus their labour and materials costs. Similar to the DBB contract, low designer effort is the backwards induction dominant strategy. The equilibrium outcome is the prime designer chooses low effort and the prime contractor chooses high effort—negating the opportunity for the contractor to earn a bonus.

Key to this game structure is the designer's and contractor's common knowledge of outcomes. Understanding the game, the prime contractor knows high design effort can only be ensured when the cost of additional designer collaborative effort is appropriately compensated. This is achieved through an alternate compensation scenario, for example, the prime contractor *shares* their bonus with the prime designer.[7] The additional compensation is a transfer from contractor to designer and is just enough such that the designer is better-off providing high effort.

$$\left(W_D - E_{D,high} + B_D | E_{C,high}\right) > \left(W_D - E_{D,low} | E_{C,high}\right)$$

$$B_D > E_{D,high} - E_{D,low}$$

[7] Alternatively, we could assume cooperation with the contractor reduces the cost of effort as the designer "transfers" some of the effort cost to the contractor. This would include reduction efforts of bid documents, anticipated construction changes, and greater construction administration demands. Reputation and/or repeat business with the principal and/or prime contractor can also be a form of a bonus. The reduction in cost is equivalent to receiving a bonus on net.

Ultimately, GMP differs from DBB because the designer has the bargaining power. In the GMP framework, the designer can extract the bonus payment from the contractor by making a "credible threat". The threat of low effort is credible because low effort is their dominant strategy and could result in reduced compensation to the contractor. The bargaining power shifts to the designer, and this shift is reflected in the setup of the bonus and transfer payments. In the incentive structure outlined in the GMP process, the owner is effectively incentivizing a more desirable outcome by leveraging the prime contractor to assist in extraction of a successful project.

Tri-Party or Multi-Party Agreements/Integrated Project Delivery (IPD)

To better align the strategy and interests of both the prime designer and prime contractor, construction contracting methods have progressed to encourage broader integration, involvement, and responsibility by project team members (Bilbo et al., 2015). Typical characteristics of these agreements are early involvement of key stakeholders (e.g., the owner, prime contractor, and prime designer), and key stakeholders are signatory to one multi-party agreement (El Asmar et al., 2013). To owners, IPD has become attractive because of its enhanced collaboration, shared risk/incentives approach among the project team, and early participation of contractors and vendors (Franz and Leicht, 2012). This method differs from the other delivery models because of the unique contractual arrangements that can be implemented between project members that bind their success to that of overall project's success. This arrangement comes with the expectation that this delivery method will enhance team performance, and thus the project as well (Garcia et al., 2015).

Unique to this contracting method, the prime designer and prime contractor are jointly incentivized to achieve the project budget and schedule expectations set by the owner. In turn, the prime designer and prime contractor also place their profit at risk for costs that are greater than the budget. For example, the project team can agree to a target cost that is 95% of the estimated project value. Being under or over the target cost is a result of the combined efforts of the design and contracting teams. Costs in excess of the target costs are proportionally subtracted from the prime designer's and prime contractor's profit at risk. If the project cost exceeds the sum of the target cost and profit at risk of the prime designer and prime contractor, the owner is financially liable for the remaining cost of the project.[8] This creates a unique situation for the companies of the principal designer and principal contractor in allocating the needed effort to a project experiencing cost overruns. If a project has lost the opportunity to obtain a bonus and the profit at risk has been reduced to zero, there will be no incentive to allocate the additional effort to complete the project when there may be an opportunity to work on a more profitable project. Figure 3 is the decision tree representative of the scenarios established in IPD construction contracts.

[8] Direct cost includes the actual cost of labor (including actual cost of benefits), material, equipment, etc. with no markup or general overhead expenses.

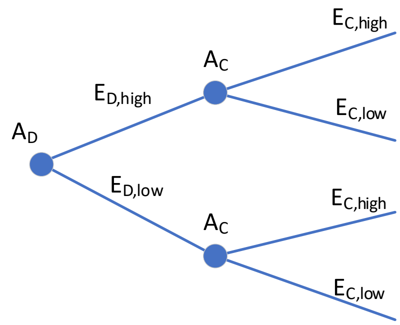

Figure 7 - IPD Extensive Form Game Tree

The structure of the design and construction process for IPD is different from that of the DBB and GMP contract types, in that for an IPD type project the game is played iteratively throughout the duration of a project. Payoffs noted in Figure 5 and Figure 6 are conceptually from a sequentially played game. Whereas for IPD type projects, interactions between agents are continual, and thus effort choices noted in Figure 7 are made continually. This alteration in the contract and incentive structure allows both parties to escape the scenario previously compared to the Prisoner's Dilemma game. In order to escape a Prisoner's Dilemma, collaboration is necessary, and thus similar to The Stag Hunt. In the Stag Hunt, ". . . what is rational for one player to choose depends on his beliefs about what the other will choose", compared to Prisoner's Dilemma situation where "If two people cooperate in prisoner's dilemma, each is choosing less rather than more. . . there is a conflict between individual rationality and mutual benefit" (Skryms, 2004).

IPD Game Structure

For the prime designer and prime contractor, the payoffs are expressed by the following equations:

$$Profit\ (P_D) = Target\ Cost_D - Labor\ and\ Material\ Effort(E_D) + Bonus(B_D)$$

Equation 4 - IPD Prime Designer Profit

$$Profit\ (P_C) = Target\ Cost_C - Labor\ and\ Material\ Effort(E_C) + Bonus(B_C)$$

Equation 5 - IPD Prime Contractor Fee

$$B_C = \begin{cases} \pi(TC_C - E_C) & if\ \ TC_C > E_C \\ 0 & if\ \ TC_C \leq E_C \end{cases}$$

In typical IPD type contracts the profit of the prime contractor and prime designer are at risk and established during contract negotiations. Like the GMP scenario, there are three possible outcomes. Assume that for a project to be under the Target Cost the contractor and designer must provide high effort. If both prime designer and contractor provide low effort, design and construction costs will exceed the Target Cost resulting in loss of profit and bonus[9] - but effort would be reserved for other opportunities by the designer and constructor. If the prime designer or contractor provide low effort while the other provides high effort, the construction costs are exactly the Target Cost which results in loss of bonus but profit at risk is retained by the low effort agent while the high effort agent would experience an opportunity cost. Any excess costs and project savings are shared by the prime contractor and the prime designer under this delivery method. The IPD scenario is unique compared to the other two models in that cost overruns are shared by the prime contractor and prime designer, based on the direct effort costs (DEC).

[9] For typical IPD contracts, the owner is at risk for direct cost of work above the target cost, but only after the profit at risk of the contractor(s) and designer(s) have been utilized to cover cost overruns

The payoffs are summarized in Table 10 showing the adjustments due to the introduction of incentive to the prime contractor and prime designer in the form of a bonus when both agents provide high effort. It is assumed for this research that both agents are aware that the bonus incentives are based on jointly providing high effort to achieve the necessary project goals. It is assumed that when one agent provides high effort, while the other provides low effort, a reduction in profit is realized by the high effort agent that is not fully shared by the low effort agent. It is important to note that part of this game is played by the agents outside of Table 10. Trust and goodwill by the agents and principal are important to their success in this contractual arrangement. The payoffs, however, suggest a game in which high effort in incentivized, but low effort is still compensated by the principal.

Table 10 - IPD Extensive For Game Payoffs

		Prime Contractor	
		High effort $E_{C,high}$	Low effort $E_{C,low}$
Prime Designer	High effort $E_{D,high}$	$(DEC_{D,high} + P_D + B_D), (DEC_{C,high} + P_C + B_C)$	$(DEC_{D,high} + \pi P_D), (DEC_{C,low} + \pi P_C)$
	Low effort $E_{D,low}$	$(DEC_{D,low} + + \pi P_D), (DEC_{C,\text{high}} + \pi P_C)$	$(DEC_{D,low}), (DEC_{C,low})$

Note: The payoffs of the designer are in the left side of each cell, while payoffs for the contractor are in the right side. Each cell represents the payoffs resulting from the combination of both agents' action.

In this contracting method, risk is now shared across both agents and the principal by arrangement of the DEC being compensated by the principal no matter the final cost of the work. Though the profit and bonus of the agents are at risk, the low effort/low effort payoff of the agents could provide a low enough bar to dissuade high effort. It is assumed though, that the prime designer and prime contractor are both rational, and because of the introduction of the joint incentive, both are expected to choose high effort.

$$\left(TC_C - E_{C,high} + B_C \middle| E_{D,high} + P_C\right) > \left(TC_C - E_{C,high} \middle| E_{D,low} + P_C\right)$$

Similar to the GMP contract type, when the prime designer (or prime contractor) provides low collaborative effort, the prime contractor (or prime designer) still *voluntarily* chooses high effort to avoid exceeding the Target Cost, which results in a loss of the bonus and reduction of their profit. A key difference for this scenario is not only the unlikelihood of one of the agents voluntarily providing low effort, since this would result in the loss of their bonus and reduction in profit, but that there is a risk for either party providing low effort that would directly affect the others expected bonus and profit. This possible reduction of profit would be identical to each agent (as a percentage), and is noted as π in Table 10, but the high effort agent would be at a greater loss due to the additional expenditure of additional effort.

$$\left(TC_{C/D} - E_{C,high} \middle| E_{D,low} - opportunity\ cost\right) \leq \left(TC_C - E_{C,low} \middle| E_{D,low}\right)$$

Thus, choosing high effort is the Pareto optima strategy for both the contractor and designer. As is the case for scenarios typical of the Stag Hunt, the prime designer and prime contractor have two equilibria to choose between: high effort/high effort, and low effort/low effort. Key to this game structure is the designer’s and contractor’s common knowledge of the potential outcomes. Understanding the game, the prime contractor and prime designer would know high effort can only be ensured when the cost of additional collaborative effort is appropriately compensated via the bonus and profit at risk structure.

3.5 Testing Game Theory Models using Real-world Data

The previous models illustrate how different contract and procurement methods incentivize or disincentivize effort. Mulholland & Clevenger in an upcoming publication point out that effort from project participants is assumed to be beneficial and take the form of productive mental and physical engagement or exertion (Mulholland & Clevenger, 2021). The three models as presented highlight the impact one agent's behaviour can have on the other's behaviour. Specifically, the models demonstrate that agents weigh the risk associated with providing varying levels of effort, based on the knowledge of the implication to their profit. However, such relationships are largely dependent on the contract type, and the principal chooses the contract structure that provides a framework to incentivize effort. Furthermore, the models imply an association between effort and project outcomes. Specifically, the rational agent will provide an effort level that provides optimal conditions for expected or increased profit. The conditions for profit, with or without incentives, is detailed within the contract itself.

Unfortunately, alignment of the theoretical models to actual project data is limited due to the variations in construction projects and the nonreproducible nature of construction itself. Typical commercial construction projects are unique in not only their application of a design, but also by the variations in project participants, material availability, local building codes, project schedules, to name a few. In the following section, the authors use survey data regarding the perceptions of project participants on real-world projects to test the findings of the game theory models. Specifically, the authors provide three propositions to test whether real-world data aligns with the models' findings regarding contract type and agent behaviour.

> **Proposition$_1$**: Effort levels, both self-reported and observed, of contracted agents vary between different contract types.

Proposition$_1$ is important to establish that i) effort varies between agents, ii) effort changes by contact type, and iii) effort increases with more collaborative contact types. Assuming additional effort by agents makes for a higher quality project, the models presented illustrates that increased effort can result in increased or decreased profit based on the effort by the alternate agent. For this proposition to be true, design and construction agents will provide dissimilar levels of effort depending on the contract type. Specifically, both the self-reported level of effort, and the observed level of effort of the alternate agent will differ based on contract type and should increase for collaborative contracts (IPD).

> **Proposition$_2$**: Individual effort levels are influenced by both the perceived level of effort of the alternate agent and by contract type.

The second proposition relates to proving or disproving the influential link between an agent's effort and the effort of the other agent. Game theory models demonstrate that an agent is influenced by the perception and/or actual effort of others. In short, the perceived level of effort of the other agent, is a factor in an agent's risk assessment and decision regarding whether or not to provide low or high effort. For this proposition to be true, data from real-world projects participants should show an association between an agent's willingness to provide a level of effort and the effort of the alternate agent. In addition, this relationship will exist for, but vary by each contract type.

Proposition$_3$: Increased effort levels (group/individual) are associated with increased schedule and cost savings

Propostion$_3$ is important in establishing the association that if effort is contractually incentivized, and benefit to both the agents and principal. It was already noted that increased effort by agents will result in a better product to the principal. Increasing effort, however, may or may not positively affect the agent's profit, depending on the contract type and the reciprocated effort by the other agents. For this proposition to be true, data from real-world projects should show an association between contractual incentive structures to that of project outcomes.

Data and Demographics

To test these propositions, the authors developed and administered a survey to individuals who recently complete projects delivered under either Lump Sum, GMP or IPD project delivery methods. The project retrospective survey in Qualtrics was emailed to a convenience sample of designers and contractors who worked on 21 different commercial construction projects located in the western United States. As summarized in Table 11, 63 respondents self-identified as either an architect or general contractor. The average years of experiences of the survey respondents was 21.07 years for architects and 20.69 years for general contractors. Results were reviewed for statistical significance.

Table 11 - Proposition 1 Survey Demographics

Proposition1 Demographics				
(n=63)		Gender Identification		
		Male	Female	Average Experience (yrs)
Contractor		31	5	20.69
Designer		21	6	21.07

To test the first and second proposition, the survey asked respondents to use a 5-point Likert scale to self-assess their level of effort and assess the level of effort of the alternate agent. Using a Likert scale to measure effort has been used in previous research to quantify the level of effort (Brown & Leigh, 1996; Inzlicht et al., 2018; Yeo & Neal, 2004). The specific questions used in the survey to test this proposition were as follows:

a) *Compared to other projects, my level of effort exerted on this project was (none at all (1) – a great deal (5))*

b) *In retrospect, the observed level of effort by the _______ (architect or general contractor) was: (Far below average (1) – Far above average (5)).*

Table 12 - Project Performance of Surveyed Projects

Project Type	**Projects Reviewed**	**Total Project Value ($)**	**Average Cost Savings (%)**	**Average Schedule Savings (%)**
Lump Sum	6	$ 135,785,944.90	-3.97%	-4.57%
GMP	4	$ 283,892,759.71	-1.95%	-5.13%
IPD Type	11	$ 383,685,269.57	1.25%	-0.33%
Total	21	$ 803,363,974.18	neg values: over budget/behind schedule	

Note: Project data were provided by the general contractor for Lump Sum and GMP projects, while project data were provided by project owners for IPD projects.

To test the third proposition, a combination of data from survey results for Propositon1 and project results from each of the projects were analysed. The established models demonstrated that levels of effort are incentivized differently between contract types, and between the different agents. For this proposition to be true, therefore, a relationship between effort, savings, and contract type would exist in the real-world data. To establish cost savings, cost savings were measured as a percentage of the difference between final costs to the original cost budget (Gransberg et al., 2003).

$$Percent\ saved\ \%\ (\$\ dollars) = (-100) \times \frac{Final\ Project\ Costs - Original\ Project\ Estimate}{(Original\ Project\ Estimate)}$$

Equation 6 - Project Cost Savings (%)

For the schedule savings, the difference between the final project duration to the original project schedule duration (Gransberg et al., 2003).

$$Percent\ saved\ \%\ (weeks) = (-100) \times \frac{Final\ Project\ Duration - Orig\ Project\ Schedule\ Duration}{(Original\ Project\ Schedule\ Duration)}$$

Equation 7 - Project Schedule Savings (%)

Ordinary Least Squares (OLS) regression model with interactions was used to predict and confirm individual effort to the group level effort, and also the project level effort to project level cost or schedule savings. Data analysed included project performance (Table 12) and individual and observed level of effort responses (Table 13).

Results and Discussion

Proposition 1 & Proposition 2

Table 13 summarizes the survey results for mean response using a 5-point Likert scale of self-assessed levels of effort as well as assessed level of effort by the alternate agent by contract type.

Table 13 – Proposition1 Mean Rankings

Proposition1 Mean Rankings								
	Mean For All Types		Mean For All Lump Sum		Mean For All GMP		Mean For All IPD	
	Self Ranked	Observed by alt agent	Self Ranked	Observed by alt agent	Self Ranked	Observed by alt agent	Self Ranked	Observed by alt agent
Designer	3.70	3.72	4.00	3.17	3.20	4.14	3.75	3.74
Contractor	3.81	3.59	3.67	2.67	4.00	3.60	3.78	3.94

The overall self-reported mean for effort between all project types of the prime designer was (3.70) and prime contractor (3.81). The observable effort as scored by the alternate agent for the prime designer was (3.72) and prime contractor (3.59). In looking at these means, it is notably that general contractors not only scored their own effort higher than the architects did, they also scored the other party higher than architects did. It is also interesting that contractors observed a higher level of effort in architects, than was self-scored by the same group, while the reverse was not true. Finally, the mean of the perceived effort of the other was lower than the mean for self, in both cases.

The scores vary across project type. Figure 8 and Figure 9 show mean self-assessed and observed in other levels of effort with a 95% confidence interval error bar. Comparing these means reveals different relative levels.

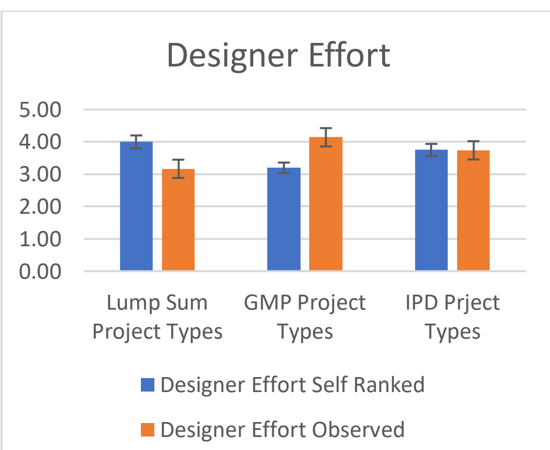

Figure 8 – Proposition1 Designer Effort

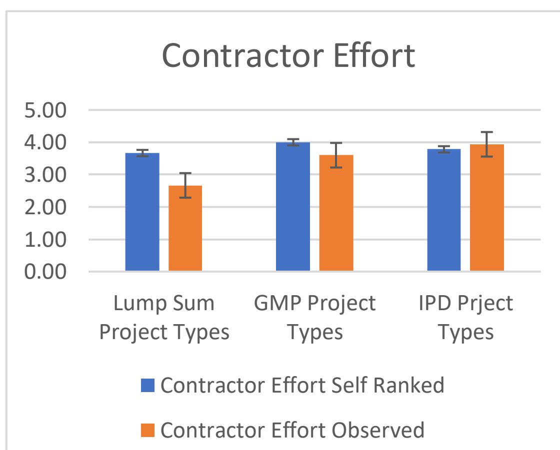

Figure 9 – Proposition1 Contractor Effort

Results shown in Figure 8 and Figure 9 vary between both the agents and the contract type. Lump Sum scores were lower for observed levels of effort and the self-ranked score of the contractor than other contract types. Namely, the mean self-ranked values for GMP project types for the designer and contractor were (3.20) and (4.00) respectively, and the mean value observed from the alternate agent were (4.14) and (3.60) respectively. For IPD project types, the self-ranked mean value for the designer was (3.75) and (3.78) for the contractor. The mean value of the observed effort from the alternate agent was (3.74) for the designer and (3.94) for the contractor.

When looking at lump sum scores in Figure 8 and Figure 9, a significantly higher the self-assessed value is provided by both agents compared to observed effort. Overall, GMP and IPD type projects have higher mean values for both self-assessed and observed than Lump Sum. Interestingly, the values for both the designer and contractor show less difference for the IPD type contractors compared to the other contract types.

Additionally, in the Lump Sum contract types the values for observed effort are less than the self-reported values. This perception is expected by the Lump Sum projects types, specifically it is rational to provide low effort for Lump Sum project types and it is assumed/observed that the alternate agent will provide low effort. However, it is also typical in the sequential prisoner's dilemma for an agent observing low effort to reciprocates low effort. In these cases, the agent is perhaps engaging in some sort of compensating behaviour. This difference is also seen in Figure 5, with the general contractors observing a higher level of effort than was self-scored by the architects for the lump sum and GMP contract types. The implications of the interactions between the agents will be explored more in Proposition2. Based on the variations in effort by contract type, Proposition1 and Proposition2 can be accepted.

Proposition3 attempts to prove that effort levels are correlated with profit and schedule metrics between contract types. The established models demonstrated that levels of effort are incentivized differently between contract types, and between the different agents. For this proposition to be true, a relationship between effort, savings, and contract type would exist.

Group level effort predicting individual effort:

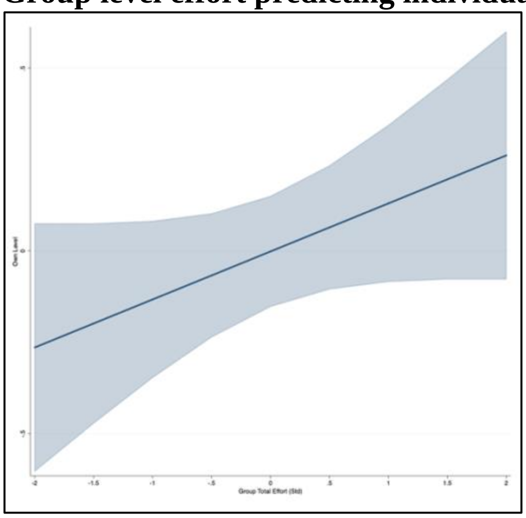

Figure 10 - Group Effort Predicting Individual Effort

Figure 10 shows the relationship of group effort to individual effort. Although the results were not statistically significant ($p>0.01$), there appears to be a positive trend between group level effort and that of the individual. Sample size may be a limiting factor statistically.

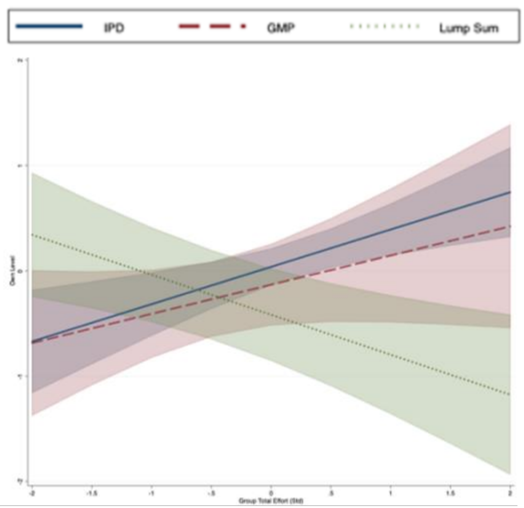

Figure 11 - Group Effort Predicting Individual Effort by Contract Type

Figure 11 shows the relationship of group to individual effort based on contract type. For IPD contract types a positive and significant association exists between group and individual level effort ($b=0.35$, $p<0.01$). A statistically significant association between group level effort and individual effort could not be established ($p>0.01$) for the GMP project types. This again could be from the sample size, but a positive trend exists that appears to be distinct from Lump Sum contract types, which show a negative, significant association between individual and group effort ($b=-0.38$, $p<0.05$). Such results for Lump Sum contract types seem to reinforce an agent's proclivity to use backward induction by free riding on the alternate agent's high effort, but also confirms the lower effort noted in Figure 8 and Figure 9.

Effort predicting cost and schedule savings

The following figures show the relationship of group effort to cost and schedule project outcomes.

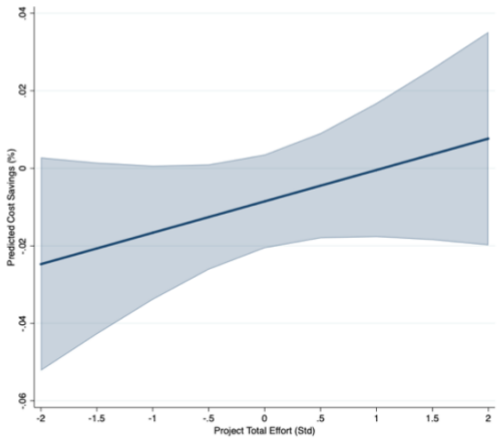

Figure 12 - Group Level Effort to Cost Savings

Results in Figure 12 show a positive trend between group effort and cost savings. However, the association is not statistically significant (p>0.01).

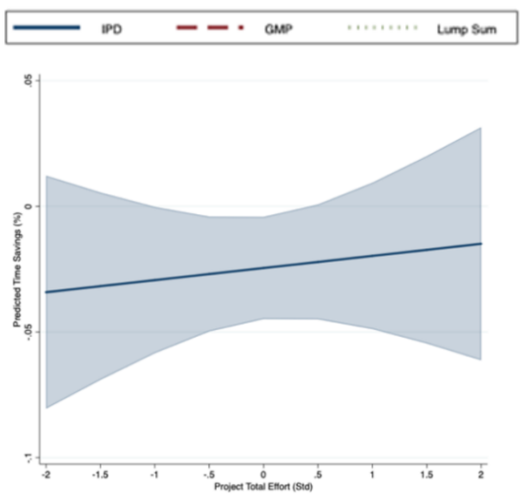

Figure 13 - Group Level Effort to Schedule Savings

Figure 13 show a positive trend between group effort and schedule savings. However, the association is less strong than cost, and is not statistically significant (p>0.01). Notably, these associations also vary based on contract type.

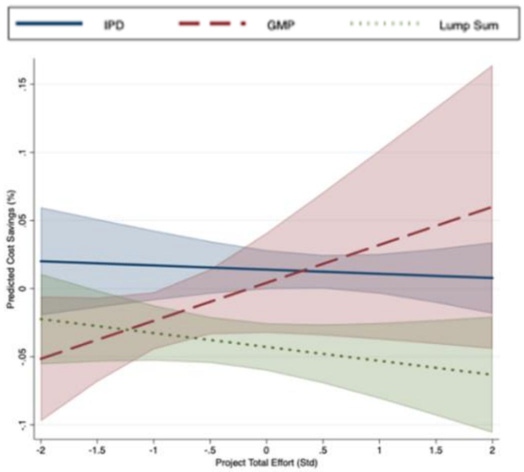

Figure 14 - Project Level Group Effort to Cost Savings

Results (Figure 14) for IPD contract type show a null association between group effort and cost savings (p>0.01). These results are identical for GMP and Lump Sum project types.

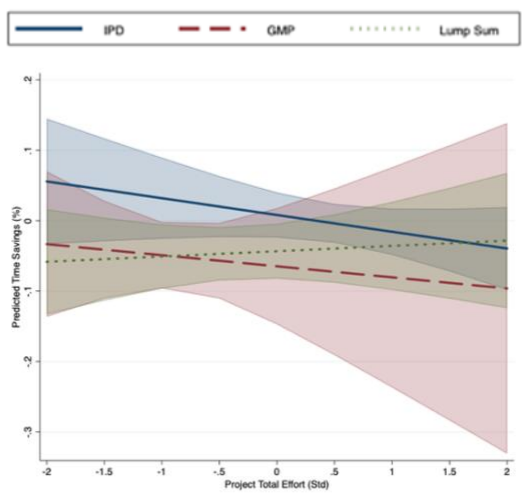

Figure 15 - Project Level Group Effort to Schedule Savings

In reviewing schedule savings Figure 15, results were not significant (p>0.01) but appear to show a negative trend between group effort and cost savings for IPD. GMP and Lump Sum contract types were also not significant for, and visually appear to show a null relationship. As stated previously, sample sizes likely affect the significance of these results. Nevertheless, interesting patterns for these associations begin to emerge. For example, it appears in Figure 14 that group effort is a null relationship for predicting cost savings in IPD projects, but that cost in

GMP and Lump Sum project types has distinct, divergent relationships to effort. Furthermore, it appears in Figure 15 that group effort is a null relationship for predicting cost savings in Lump Sum projects, and that schedule for GMP and IPD project types has a negative relationship to effort.

Though none of these associations were statistically significant, they do appear to suggest a trend with schedule and cost savings. This is noteworthy, and partially supports proposition3.

3.6 Conclusion

This research developed conceptual models to examine the relationship of an agent's effort to profit in construction. These models were informed by aspects of game theory and were further examined using survey data assessing levels of self-reported effort and the observed effort of other agents on construction projects. The research generally confirmed that i) effort levels of contracted agents vary based on contract types, ii) effort levels can changed based on the perceived effort level of the agent, and iii) increased levels of effort are associated with increased schedule and cost savings. Specifically, these findings suggest that increased effort levels may be incentivized and associated with cost savings for the more collaborative, GMP and IPD project types.

The presented conceptual models illustrated the benefit to a project owner and to the designer or contractor when contract incentives promote high effort. The GMP project type promoted increased effort levels from the prime contractor when compared to Lump Sum project types, but this high effort came at greater risk to the prime contractor due to the lack of explicit contract incentives for the prime designer. In comparison, IPD project types promoted even higher effort than the GMP project type based on the equal risk sharing of low effort with the prime designer.

Sharing of project risks and incentives are not new, but the application of this methodology to promote project effort could have interesting industry applications. Highly collaborative projects, such as the IPD project types, should promote the contractual application and monitoring of project effort as it relates to project outcomes. There is a risk to the project team, and especially the project owner, that intermittent low effort by project participants could increase the risk of free riding behavior or worse, adverse project outcomes. Monitoring project behaviors as well as project metrics could assist in lowering this risk.

3.7 Recommendation for Future Research

Based on the research presented, future research could include further defining the assumptions made. This would include defining and reviewing low effort strategies compared to the accepted standard of care, especially between different trades and designers. Presenting low effort projects compared to high effort projects would be of interest to the industry to illustrate the presented concepts. Other potentials include expanding the theoretical models to include multi-agent games, and/or exploring strategies between architects and engineers, or general contractor and sub-constructors.

CHAPTER IV

DEFINING AND MEASURING EFFORT

4.1 Introduction

The transition in the construction industry to more collaborative agreements has led to contractual incentive structures that have moved from punitive to profit enhancing. Level of effort supplied by employees and contractors is critical to the performance of projects that act more like an organization (Van Dijk, Sonnemans, & Van Winden, 2001). These contract structures encourage the ". . . explicit effort(s) to align the operating system (of the project) with a collaborative organizational structure and commercial terms that support Project-wide optimization" (ConsensusDocs, 2013). While ConsensusDocs may be the strongest example, similar intent is expressed in other collaborative agreements, such as the AIA C191 or AIA C193. Historically, definitions of efforts are ambiguous or serve as a euphemism for more traditional project metrics, such as cost and schedule. This is, in part, due to the general lack of consensus by industry regarding the meaning of effort or its disentanglement from other project metrics (Brown & Leigh, 1996). Definitions of efforts may be at the project level or at the personal level, either of which generally lack adequate measure and, therefore, may constraint project teams (Weimar & Wicker, 2017). This paper will provide a clear, synthesized definition of effort and a systematic method to measure it.

Defining project "effort" draws a clear delineation between more traditional project goals: cost, schedule, quality (noted herein as "traditional project goals") (Cox, et al., 2003; Toor & Ogunlana, 2010). It is reasonable to assume that the use of the term "effort" (to include "best efforts", "reasonable efforts", etc.) in contract language and in an owner's condition of satisfaction, is not only carefully chosen by the authors of those documents but also carries some significance to that audience as well (Whittaker et al., 1989). The significance of the definition does not stop at the contractual language, but also continues in the interaction between the collaborative agreement members (Mulholland & Clevenger, 2021).

As project team members who represent separate companies with distinct interest collaborate, there is a risk of an imbalance of contribution, engagement, and participation in the endeavors and success in achievement of project goals. In collaborative agreements achievement of project goals can carry an incentive that may or may not affect the profit of the companies participating in the collaborative agreement. In these agreements, project participants are incentivized based on the total project success in achieving the project goals regardless of individual contribution. The agency that is implicit in these contracts allows for participants to choose less then optimal contribution; known in literature as "free-riding" (Itoh, 1991). To discourage this, monitoring contribution and evaluating performance in multi-agent situations is an effective solution (Kandel & Lazear, 1992; Knez & Simester, 2001; Sappington, 1991). Current iterations of collaborative agreements, though, do not substantively add language specific to individual contribution and performance evaluation (Mulholland & Clevenger, 2021). Nor is there specific research on how best to evaluate contribution in construction project teams when agency of the individual is coupled with diverse scopes and skills. Underlying factors that may explain performance differences between project delivery/contracting methods are not widely addressed in literature (Franz, Leicht, Molenaar, & Messner, 2017b). Therefore, the purpose for this research is to propose a method to evaluate design and construction project member effort contribution. Specifically, that Collaborative Effort shows an association to traditional project outcomes. This research provides data and analysis specific to effort and performance of project teams and the perceptions of individuals on those teams. Data were obtained from both collaborative and non-collaborative project types. Through this process, effort required on collaborative projects (herein called “Collaborative Effort”) is evaluated.

4.2 Literature Review

Limited research exists for the definition and measurement of effort in the fields of construction and engineering. In general, there is a lack of research into how effort is measured directly (Yeo & Neal, 2004). However, the authors begin with a review how effort is defined and measured within other academic fields to establish a basis for a measurable definition for construction.

Exercise/Sports Science

In the field of exercise and sports science, effort has been quantified based on both an individual attribute and that of the contribution to a team’s success. Weimar and Wicker compared effort of individuals to the performance of teams in professional soccer. No concrete definition of effort was given, but effort was measured as the individual’s contribution to the team’s success. Sarrazin et al. reviewed activity levels of the participants. Effort was conceptualized as the amount of energy resources provided for a task, with maximum heart rate acting as the proxy for this measurement (2002). Findings confirmed that exerted effort depends on how difficult the task is and the perception of an individual’s ability. Groslamber and Mahon reviewed studies on perceived exertion and biometric information (heart rate among others) to understand individuals' physiological effort on various age groups. In the study, effort was separated into a quantification of estimated effort and physiological effort based on a reported value (Groslamber & Mahon, 2006).

Pageaux worked to define and measure effort building on an existing definition of effort as: ". . . the conscious sensation of how hard, heavy, and strenuous a physical task is"(2016). He noted that "physical task" could be replaced with "mental task" for cognitive activities. Pageaux also provided guidelines on the measurement of effort, which included self-reporting psychophysical scales (no effort/exertion to maximal exertion/effort on a 0-20 scale) in conjunction with participant biometrics (heart rate, oxygen consumption, etc.). Interestingly, Pageaux noted the importance of perceived effort as it relates to anchoring to past experiences compared to current endeavors. This was noted as an important differentiation, as the perception of effort played a crucial role in endurance, performance, engagement, and behavior (Pageaux, 2016). Mulholland and Clevenger surmised that Pageaux's explanation of effort as a cognitive feeling of work associated with voluntary actions suggests that effort may involve actions beyond the minimum requirement (2019a).

Education

In the field of Education and Educational Psychology, researchers frequently view effort as an attribute of motivation and engagement. Schunk viewed effort as enhancing an individual's ability, and being influenced by the personal traits of motivation and personal drive (1991). Based on a synthesis of existing research, Brookhart (1997) inferred effort as the cognitive exertion when trying to understand and apply learned concepts. Beliefs and Bong (2004) assessed student’s self-reporting of effort, and noted that a student’s active interest in the subject, academic engagement, and involvement were characteristics of effort.

Psychology

The field of psychology provides insights into the motivation of effort and measurements for teams and individuals. Heyman and Ariely (2004) experimented with the relationship of effort that is compensated for compared to effort that is performed altruistically. The experiments measured effort in ability to perform tasks and solve puzzles. The authors found that payments for exerted effort can influence the propensity to exert effort.

Inzlicht et al. defined effort as the intensification of either mental or physical activity in the service of meeting some goal, and is distinct from demand or difficulty (2018). The authors went on to differentiate effort from motivation, explaining that motivation is a behavior drive while effort is the amplitude of behavior (2018). Inzlicht et al. also offered that effort is costly, visible to offers, cannot be faked, and can break down when demands are too high and/or when incentives are too low. For an incentive-based contract, this last statement offers caution when completing a contract’s Conditions of Satisfaction and the Risk/Reward contract structure. This is not to say that promoting effort should be avoided, as Inzlicht et al. went on to note that the more effort is exerted, the more value that is assigned to that task retrospectively. In addition, people generally generate positive associations with effortful actions (Inzlicht et al., 2018).

Kurzban, in his explanation in the cost of effort, explained that the decision to exert effort is a cost-benefit analysis performed by the individual and is continually being evaluated (2016).

Kurzban offered no measurement of effort, but the designation as a behavior of choice with limits is important regarding collaborative agreements. Sandra and Otto's research was in general agreement with this and found that incentives played a role in expending effort by offsetting the cost of cognitive processing resources (2018).

Rich, Lepine, and Crawford researched employee performance in part by a self-reported level of effort (2010). The authors noted that that personal engagement (investment of energies) into work roles contributes to organizational goals over extended periods of time. Furthermore, Rich, Lepine, and Crawford note that job engagement is dependent on effort. Brown and Leigh conducted similar research on engagement and effort, looking at effort's role in employee perception of the organizational environment. In their work, they posit that job involvement is positively related to effort, with effort being described as the self-reporting mediating behavior by which motivation is translated into successful accomplishment of work (1996). Their findings indicate a relationship between employee engagement and effort, to that of the overall success of a project.

In research related to a person's response to workload, Hart and Staveland noted the difficulty in measuring mental effort directly, because it occurs between measurable stimuli and measurable response (Nikolaev & Olimpiev, 1988). In their work on the design of NASA's Task Load Index, effort was defined as the amount of mental and/or physical activity required for a task or goal. This self-reported measurement was found to be highly correlated to an individual's overall workload or time pressure felt. Interestingly, additional studies show that when an individual's workload is reported as high, mitigation techniques can include lowering standards, shedding tasks, and/or refusing to exert greater levels of effort.

Yao and Neal conducted repeated task experiments on volunteers to understand the perceived level of effort, and found that effort changes over time with experience, ability, and goal orientation (2004). Effort was defined as how hard an individual self-reported their perceived level of exertion.

Economics

The field of economics provides a nuanced definition of "effort" building on simpler unit-based definitions. Charness et al. (2018, P.75) gave the following definition ". . . effort could be physical, as in folding pieces of paper and stuffing envelopes, cognitive, as in solving a series of math equations, or creative, as in writing stories or packing quarters,". This definition highlights the difficulty in providing a simple definition of effort and insight into the multiple dimensions of "effort". Carness et al.'s definition suggests there are limitations to a simple unit-based definition given the number of dimensions involved. Leibenstein (1982) supported additional dimensions and note a dichotomy with regard to effort by writing the following with regard to contracts:

> Employment contracts are incomplete since remuneration is usually well specified, but effort is not. Agents (employees), in principal-agent relations, need not behave exactly as the principal's wish. As a consequence, some effort discretion exists. Hence, firm members can choose, within bounds, the amount of effort they put forth. The productivity outcome

> depends in part on effort choices made by firm members, and in part on the wage and work condition choices made by the firm. (p. 92)

Leibenstein went on to explain that employees consider effort level in terms of pace, quality, and choice of activities when deciding how much effort to expend.

Treble, in a review of effort of British coalminers in the Victorian era, collected data on effort as the change in productivity across workers and location. (2001). This data included labor hours of work and the coalminers actual output. Moldovanu et al., in their research on status structure and social recognition in organizations, noted the cost of effort of an individual is equal to the proportion of a given effort to the ability of the individual (2007). Suggesting, if the cost of an effort is compared between two individuals, the less costly individual would be the one with the greater ability, all other things being equal. This may imply that project teams can leverage increased ability, on a effort per unit cost basis.

Kosfeld and Neckermann showed in a laboratory setting that in the presence of an award, agents can be motivated to increase effort (2011). Dubey and Wu performed related theoretical work looking at a Principal-Agent contract relationship, and noted that agents have a natural disutility for work and their effort levels correlate positively with output (2001). They noted that small output by an individual could result from low levels of work or bad luck despite hard work but that the probability of small output is reduced with higher levels of effort (2001). Van Dijk et al. observed that effort in real life settings has a social dimension and involves effort, fatigue, boredom, excitement (2001). Dutcher et al. acknowledged challenges related to measuring effort, specifically comparing measurements made in a laboratory setting to those made in nonlaboratory environments by stating actual, real-world mental or physical exertion can trigger certain types of behavior that experiments might not (2015).

Legal

The legal definition of effort has been divided into various qualifiers such as “best efforts,” “reasonable efforts,” and “commercially reasonable efforts,” but is often meant as the amount of time, resources, and conduct of the individual in completion of a task or goal (Paullin-Hebden & Itseumah, 2018; Sidnell & Knight, 2010). These efforts may or may not be comparable and can also include work of a supportive nature that may not result in a product or outcome (Davis, 1993). When comparing efforts, the Standard of Care of the activity is often used as a reference or proxy in this comparison.

Gross negligence in design or construction is sometimes used as a lower bound of the standard of care. Construction and design are complex activities, and no single entity has control over the entire process. A designer is not a warrantor of their design, so the purchaser of design services bears the risk of unforeseeable difficulties (William, Law, Wright, Boelzner, & Boelzner, 1995). Some jurisdictions do not require designers to exercise due care and skill beyond the limits of their own discipline (Hussin & Omran, 2009). While different risk management instruments such as warranties and insurance are used for issues pertaining to the standard of care and gross negligence, these strategies are not directly applicable to measuring effort.

Construction/Engineering Design and Project Management

When exploring the role of effort in pre-project planning, Hamilton and Gibson (1996) used qualitative analysis of effort to benchmark against project performance and found that increased pre-project planning effort positively affects the cost and schedule of a project. In the study no direct definition or metric was established for effort, but the authors asked the survey respondents to self-assess levels of effort during pre-project planning activities. Likewise, Han, Lee, and Peña-Mora (2012) identified "non-value-adding effort", and assumed that effort was a unit based activity measured in labor-hours or labor-days. Hanna and Skiffington (2010) implied effort as the totality of pre-construction planning tasks, and not necessarily a labor based metric. A similar study on construction planning completed by Shapira and Laufer (1993) used total labor-hours of various tasks to define effort. Lu et al. (2015) also used labor hours to define effort when looking at time-effort curves, and specifically noted effort to be the amount of chargeable service time used by participants. In short, the definition of effort in engineering and construction literature generally focuses on unit-based measurements.

Furthermore, in related research, the willingness to exert effort can depend on anticipated reciprocation from other team members and their overall ability (Azam & Yao, 2012; Dutcher et al., 2015) and thus can impact project teams (Knez & Simester, 2001). Perceived effort is assumed to be the amount of apparent effort provided by other project participants. Similarly, relative effort is dependent on the difficulty of the task or goal in comparison to the resources available and experience of individuals (El-Gohary, Aziz, & Abdel-Khalek, 2017; Moldovanu et al., 2007; Yeo & Neal, 2004) Effort can also be productive and non-productive, but for this research all self-assessed effort is assumed to be productive. The perception of effort can also change over time, and in relation to other choices of effort (Charness, 2018).

In summary, no unified definition or measurement of effort has been established within construction and engineering and will continue to evolve through this research, particularly as they relate to collaborative contract agreements. For this study, collaborative effort is distinctly and initially defined as:

Collaborative Effort: the amount of decisive intensification of mental or physical activity in the service of meeting a design requirement, project goal, project requirement, project milestone or task.

4.3 Research Objective

To validate the definition and measurement of Collaborative Effort on commercial construction projects using collaborative and non-collaborative contract agreements. The motivation/research statement is broken down to three proposition statements:

Proposition_1: Collaborative Effort does allow for distinct measurement

Proposition_2: Collaborative Effort is associated with group effort, specifically based on contract type

Proposition_3: Collaborative Effort shows an association to project cost and schedule outcomes.

4.4 Research Methodology

To address the research statement, a two-phase approach was taken to conduct the research. Phase I included a literature review and data collection. Previous research has generally quantified effort through measurement of discrete tasks and/or tasks that were an assumed proxy for effort of the individual or their contribution to a team or organization. For project teams working on collaborative construction and design projects, observable effort may influence other project members and, therefore, may be self-enforcing. To establish measurement for collaborate effort related to construction and design it is necessary to build upon and extend similar research (Brown & Leigh, 1996; Inzlicht et al., 2018; Yeo & Neal, 2004) as well as collect data from individuals working on representative construction projects.

Data collection and analysis for these projects was performed in two parts 1) cost and schedule data was collected and reviewed from completed construction projects and 2) retrospectives self-assessment surveys by project participants were completed and analyzed. The survey instrument developed and implemented for the participant self-assessments utilized questions and topics adapted from previous research as well as additional new questions. Project retrospective surveys were conducted in Qualtrics and the statistical analysis was performed in Stata.

Project cost and schedule outcomes were reported by project teams and are summarized in Table 14. Three separate project delivery/contract types were reviewed: Lump Sum, Guaranteed Maximum Price (GMP), and Integrated Project Delivery (IPD). Projects classified as Lump Sum were Design-Bid-Build projects that utilized a lump sum price contractual agreement. Specifically, Lump Sum projects included in this research used the AIA A101/201 contract. GMP projects utilized a guaranteed maximum price contract with the general contractor, with all the projects utilizing the Construction Manager at RISK AIA A133/201 contract. It is typical for GMP projects to have the early involvement of the general contractor during the preconstruction process to help reduce risk (Bilbo et al., 2015a). For both the Lump Sum and GMP project types, the architect had a separate agreement with the owner and these agreements were not reviewed as part of this research. IPD Type projects included both Design-Build (n=5) and IPD (n=6) projects that included common methodology such as relationship and timing of engagement with designers and contractors, namely shared profit at risk with project participants, and scheduling practices common to integrated teams (Hanna, 2016; Kulkarni, Rybkowski, & Smith, 2012b).

Description of the Data

For the analysis, 21 separate projects were reviewed (see Table 14), with a total of 121 project participants responding to the project survey (

Table 15) via the online tool. Project information was solicited from project participants regarding size of project, date of project completion, and location. All projects were commercial construction, with the majority being in the healthcare industry. Project participant survey respondents were generally project management or design staff, with only a few (< 5%) non-office/field labor. More complete demographics are provided in Table 15.

Table 14 – Project Information

Project Type	Projects Reviewed	Total Project Value ($)	Average Cost Savings (%)	Average Schedule Savings (%)
Lump Sum	6	$ 135,785,944.90	-3.97%	-4.57%
GMP	4	$ 283,892,759.71	-1.95%	-5.13%
IPD Type	11	$ 383,685,269.57	1.25%	-0.33%
Total	21	$ 803,363,974.18	neg values: over budget/behind schedule	

Table 15 – Survey Participant Demographics

Project Demographics							
N=	**121**	**Female**	**Male**	**Avg. Experience (yrs)**	**Lump Sum**	**GMP**	**IPD**
Architect		6	21	21.00	6	5	16
Engineer/Sub-Consultant		3	11	22.14	0	3	11
General Contractor		5	31	20.69	6	7	23
Sub-Contractor		2	32	20.65	2	4	28
Owner/Owner Rep		3	7	18.20	1	1	8
	Totals	19	102		15	20	86

Project Survey Data

As noted, 121 project participants completed the survey. Survey questions, the variable assumed as being tested, and the corresponding Likert scale used are shown in Table 16. Survey responses were downloaded to Microsoft Excel and grouped by project and contract type for further analysis in Stata.

Table 16 - Survey Questions

Variable	**Survey Question**	**Likert Scale (1-5)**				
Total Effort	Compared to other projects, my level of effort exerted on this project was:	None at all (1)	A Little (2)	A moderate amount (3)	A lot (4)	A great deal (5)
Mental Exertion	Compared to other projects, how much mental exertion did this project demand:	None at all (1)	A Little (2)	A moderate amount (3)	A lot (4)	A great deal (5)
Engagement	On this project, my level of engagement was:	Very disengaged (1)	Somewhat disengaged (2)	Neither engaged or disengaged (3)	Somewhat engaged (4)	Very engaged (5)
Attention	How much of your work related attention did you devote to project goals, project requirements, and the project at large:	None at all (1)	A Little (2)	A moderate amount (3)	A lot (4)	A great deal (5)
Energy	On this project, I had devoted a lot of my energy on this project:	Strongly disagree (1)	Somewhat disagree (2)	Neither disagree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
Intensity	On this project, I had worked with intensity to accomplish the project goals and requirements:	Strongly disagree (1)	Somewhat disagree (2)	Neither disagree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
Work Hard	How hard did you have to work to accomplish your desired levels of performance?	Not very hard (1)	sliding scale between values			Very hard (5)

Data Analysis

Phase II consisted of analysis of the data obtain from project participants. Data was reviewed based on the following conventions:

Project Cost Savings

Cost savings were measured as a percentage of the difference between final costs to original cost estimate (Gransberg et al., 2003).

$$Percent\ saved\ \%\ (\$\ dollars) = (-100)\ \times \frac{Final\ Project\ Costs - Original\ Project\ Estimate}{(Original\ Project\ Estimate)}$$

Equation 8 - Project Cost Savings (%)

Project Schedule Savings

Schedule savings were measured as a percentage of the difference between final project duration to original project schedule duration (Gransberg et al., 2003).

$$Percent\ saved\ \%\ (weeks) = (-100)\ \times \frac{Final\ Project\ Duration - Orig\ Project\ Schedule\ Duration}{(Original\ Project\ Schedule\ Duration)}$$

Equation 9 - Project Schedule Savings (%)

Statistical Analysis of Survey Results

The following statistical analyses were performed as appropriate when comparing average survey responses to project data.

Pearson Coefficient: To understand if effort was a unique variable, a correlation analysis was performed using Pearson Coefficient (Table 17). The Pearson Coefficient (r) is used to measure the relationship (strength and direction of the relationship) between variables. The coefficient results in a value between -1 and 1. The strength of the values fall in four categories used for this research: $r < 0.1$ (no relationship), $0.1 \leq r < 0.3$ (weak relationship/correlation), $0.3 \leq r < 0.5$ (moderate relationship/correlation), $r \geq 0.5$ (strong relationship/correlation) (Ahn, Lee, & Steel, 2014; Raoufi & Fayek, 2018).

Factor Analysis: To test the uniqueness of effort's relationship to each survey question asked, a factor analysis was performed. Factor analysis is a statistical method used to describe variability among the observed variables, by means of unobserved variables or factors (Rigopoulos et al., 2013). This technique allows for interpretation of the consistency of a data set that can be used to interpret behaviors of an explanatory construct (Tinsley & Tinsley, 1987). Part of the factor analysis process is to first test the data to ensure it can be used for factor analysis. A Kaiser-Meyer-Olkin (KMO) computation was used for this test, to test the closeness of the relationship (on a scale from 0 to 1). For this research, a value greater than 0.6 is used to satisfy this requirement. The intention of a factor analysis was to reduce the complexity of the qualitative responses to find a possible unobserved (latent) factor of effort (Głuszak & Lešniak, 2015; Kulkarni et al., 2012b)

Ordinary Least Squares Regression: To compare average group effort and project metrics to that of individual effort, ordinary least squares (OLS) regression and OLS regression models with interactions were used to predict and confirm 1) individual effort to average group effort; and 2) project level effort to project level cost and schedule outcomes. OLS has been used in literature to test the best fit of the data in comparison to a predicted set of data (AbouRizk, Halpin, & Wilson, 1994; Roh, Sahu, Sharma, Datla, & Mehran, 2016).

4.5 Results and Analysis

Proposition1

To test if Collaborative Effort does or does not allow for distinct measurement, a correlation matrix using survey response data was generated. In particular, the matrix is intended to test whether individual respondents assess Effort consistently- as either distinct from or similar to- potentially comparable terms or characteristics related to performing project tasks.

Table 17 - Pearson Correlation Matrix for Effort-Related Predictors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Total Effort (1)	1.00						
Work Hard (2)	0.06	1.00					
Mental Exertion (3)	0.72 ***	-0.03	1.00				
Engagement (4)	0.36 ***	0.02	0.27 **	1.00			
Attention (5)	0.51 ***	0.16	0.44 ***	0.51 ***	1.00		
Energy (6)	0.60 ***	0.09	0.52 ***	0.58 ***	0.61 ***	1.00	
Intensity (7)	0.49 ***	0.13	0.40 ***	0.63 ***	0.66 ***	0.79 ***	1.00

*** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 18 - KMO 7-item factor analysis

Variable	7-Item Model KMO	6-Item Model KMO
Total Effort	0.79	0.79

Mental Exertion	0.75	0.76
Engagement	0.90	0.91
Attention	0.90	0.91
Energy	0.83	0.83
Intensity	0.79	0.79
Work Hard	0.52	
Overall	0.82	0.83

Table 19 - Factor loading and communalities

	Factor1	Factor2	Comm.
Total Effort		0.76	0.69
Mental Exertion		0.79	0.62
Engagement	0.73		0.48
Attention	0.60		0.54
Energy	0.72		0.75
Intensity	0.89		0.78

Note: Factor loadings < 0.3 are suppressed.

The results shown in Table 17 indicate that half of the effort-related predictors (mental exertion, attention, energy) had a strong positive relationship ($r \geq 0.5$) to effort and that all were significant at $p<0.001$. Engagement and intensity were shown to have a moderate relationship ($0.3 \leq r < 0.5$) and, again, were significant at $p<0.001$. No relationship was shown between "work hard" and effort based on $p<0.05$.

The factor analysis results were used to verify the closeness of the relationships between variables. The KMO results (Table 18) suggest that the empirical data are well suited for factor analysis with the exception of work hard (0.52). Based on the KMO results, the remaining six factors were used for the factor analysis. The factors were extracted by analysis with promox rotation (

Table *19*). The extracted factors based on their eigenvalue were total effort and mental exertion, and thus indicated to share a strong association to an underlying latent variable.

Based upon the above analysis, Collaborative Effort does allow for distinct measurement. Total effort responses were distinct from the other survey response. Responses to survey questions relating to Mental Exertion (Table 17) were most correlated to effort (r=0.72), and although the relationship is strong ($r \geq 0.5$) it is still distinct based upon the Pearson Correlation Coefficient. Interestingly, the lowest correlation to effort (Table 17) was Work Hard and was confirmed with the KMO test. This result may be affected by the demographics of the respondents whose role were primarily project management or design based and provides an opportunity for future research relating to responses that contain a higher percentage of non-project management staff.

Proposition 2

To test if Collaborative Effort of the individual is or is not associated with group effort, OLS regression was used to examine associations between survey results for average reported effort by all members of a group to that individual self-reported effort. Additionally, these interactions were used to examine the degree to which the relationship is moderated by the different contract types. Based upon previous findings when testing Proposition 1, Total Effort, Mental Exertion, and a joint factor utilizing both Total Effort and Mental Exertion were used to fully represent Collaborative Effort. Results comparing individual effort to average group effort for all survey respondents (n=121) are shown in Figure 16.

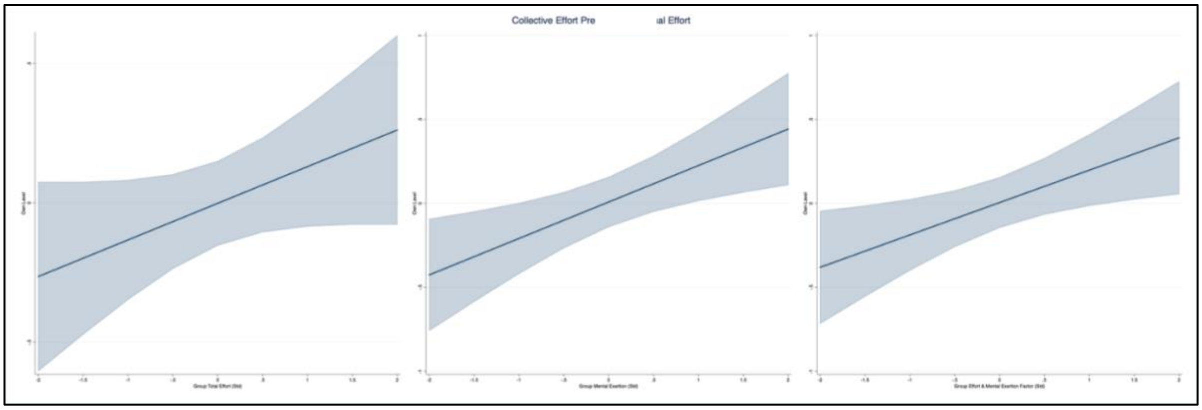

Figure 16 - Individual Effort to Group Effort

A positive trend is seen in Figure 16 (left) between individual effort and average group effort, however the association is not significant ($p>0.10$). Mental exertion showed a positive association with average group effort in Figure 16 (center) and was significant ($b=0.2$, $p<0.05$). The joint factor was positively associated with average group effort Figure 16 (right) and also was significant ($b=0.19$, $p<0.05$).

Next, OLS regression models with interactions were developed to compare responses between individuals and the average for the group of all individuals working on the same project type. Figure 17 shows results comparing individual Collaborative Effort to average group effort overlaid for groups of individuals working on Lump Sum (n=15); GMP (n=20); and IPD (n=86) projects.

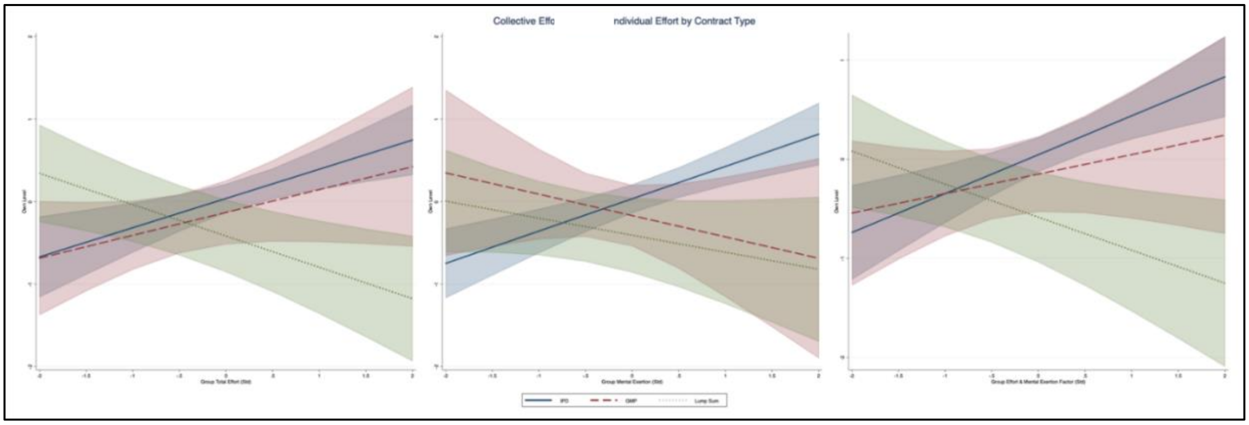

Figure 17 - Individual Effort to Group Effort by Contract Type

When reviewing results based on contract type, the association of individual effort to group effort is shown in Figure 17 (left). For IPD there was a positive and significant association between individual effort and group effort ($b=0.35$, $p<0.01$). This positive and significant association for individuals working on IPD projects was repeated for mental exertion Figure 17 (center), and the joint factor Figure 17 (right), ($b=0.39$, $p<0.001$ & $b=0.39$, $p<0.01$ respectively).

In these same figures, GMP contract types did not show a significant association between individual and Total Effort, Mental Exertion, or the joint factor ($p>0.10$). Notably, individual Mental Exertion was, in fact, to have shown a negative trend with the group's average for GMP contract types, although again, not significantly. Lump Sum contract types had significant negative associations between individual and average group levels for each, Total Effort ($b=-0.38$, $p<0.05$), and a joint factor ($b=-0.33$, $p<0.05$). There was no significant association for Mental Exertion ($p>0.10$).

These results mostly support Proposition 2, that Collaborative Effort of the individual is associated with group effort, thereby suggesting that the level of effort of a surrounding group is predictive of individual Collaborative Effort. Specifically, overall findings indicate that the association between individual Total Effort and group effort was not significant, but associations were significant for individual Mental Exertion and joint factor and the group. Based on the possible shared latent variable between effort and Mental Exertion, the findings indicate a predictive association between group level effort and individual effort.

Significant differences are seen between contract types. Specifically, individual effort is consistently positively associated with the level of effort of the group on IPD projects, whereas individual effort is consistently negatively associated with the level of effort of the group on Lump Sum projects. These results are, perhaps, intuitive. For Lump Sum contract types, there is potential risk of individuals decreasing their effort as others increase their effort, reinforcing the concept of individuals "free riding" on the efforts of others, particularly when the level of reward is fixed. This contrasts with the contractual framework and incentives structures of IPD type contracts, where a shared risk/shared reward system is established to encourage elevated effort. The results shown in Figure 17 support the effectiveness of such an incentive structure based on the positive relationship between the individual and group Total Effort, Mental Exertion, and joint factor on IPD projects. Findings for the GMP type projects were not significant, likely due to the small sample size.

Proposition 3

To test if Collaborative Effort of the individual is or is not associated project outcomes, the OLS method was used to draw associations between survey results for individual self-reported effort and cost and schedule project outcomes. Once again, based upon the findings from Proposition 1, Effort, Mental Exertion, and the joint factor utilizing both Total Effort and Mental Exertion were used to fully represent Collaborative Effort. Therefore, each of these measures were tested for an association to cost and schedule savings overall (see Figure 18) and to cost and schedule savings by contract type (see Figure 19).

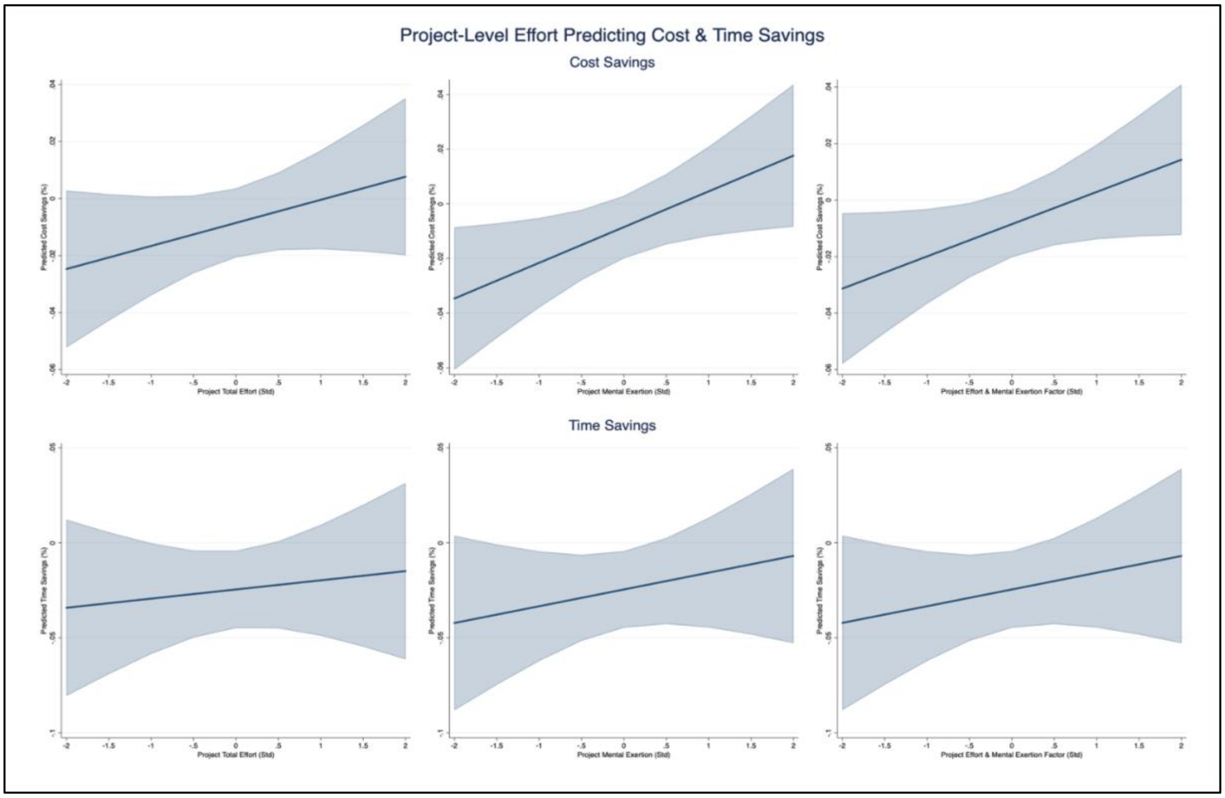

Figure 18 – Project Level Effort Predicting Cost and Schedule Savings

In Figure 18 (upper row, left) a positive trend is seen between the project group effort and cost savings, although the association was not significant ($p>0.10$). Mental exertion at the project level (Figure 18: upper row, center) showed a positive association with cost savings and was significant ($B=0.01$, $p<0.10$). The joint factor (Figure 18: upper row, right) appears to show a positive trend with the joint factor, but the association was not significant ($p>0.10$)

Project group effort to schedules savings (Figure 18: lower row, left) were not significant and appears to be only a slight trend or a null relationship. Mental exertion at the project level (Figure 18: lower row, center) to schedule savings appears to show a stronger trend but was not significant. Similarly, the joint factor (Figure 18: lower row, right) appears to indicate a trend but was not significant.

Next, an OLS regression was performed to compare responses between individuals and the project outcomes by project type. Figure 19 shows results comparing individual Collaborative Effort to project cost outcome (top) and project schedule outcome (bottom) overlaid by projects type consisting of Lump Sum (n=6); GMP (n=4); and IPD (n=11) projects.

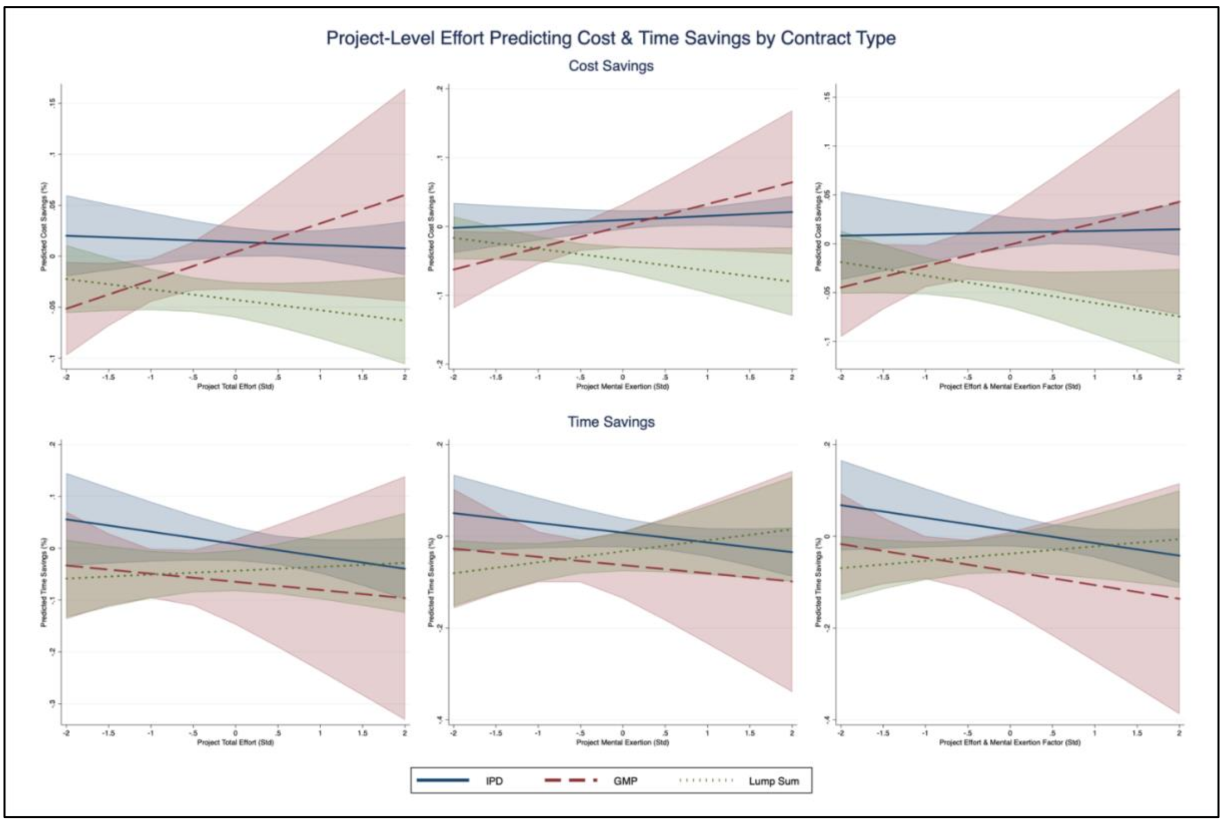

Figure 19 - Project Level Effort Predicting Cost and Time Savings by Contract Type

The OLS regression model with interations for cost and schedule savings by contract type (Figure 19) did not show a significant association with effort, mental exertion, and the joint factor (p>0.10). When reviewing results based on contract type, the association of cost savings to group Effort is shown in Figure 19 (upper row, left). For IPD project types there appears to be a null association between cost savings and group effort. A slight trend appears to be positive for IPD cost savings to group level Mental Exertion (Figure 19 upper row, center), but still not statistically significant. The trend for IPD project types appears to slightly decrease for cost savings of the Joint Factor (Figure 19 upper row, right), but also not statistically significant.

In these same figures, GMP contract types (Figure 19 upper row) did not show a significant association ($p>0.10$) between cost savings and Group Level Effort (left), Mental Exertion (center), or the Joint Factor (right). Nor was there a significant association between schedule savings (Figure 19 lower row) and group level Effort, Mental Exertion, or the Joint Factor ($p>0.10$) for the GMP contract types.

Similarly, cost and schedules savings for Lump Sum contract types (Figure 19 upper and lower rows) were not significantly associated with Group level Effort, Mental Exertion, and the Joint Factor. Though the analysis did not result in any statistically significant findings, Figure 19 appears to indicate that cost savings and group level Effort, Mental Exertion, and the Joint Factor for Lump Sum and GMP project types share a divergent association.

The results for proposition 3 somewhat support the positive associative trends across Colaborative Effort measures and project outcomes of cost and schudule, however, statistical signficance was not demonstrated. The general lack of statistical significance is likely a result of small sample sizes, and the observed divergence between contract types. However, observable trends by project type were generally similar within, but not across project outcomes of cost and schedule. Notably, results appear to be consistent in the divergant results of GMP and Lum Sum project level analsys to cost savings, while the IPD type projects show a null relationship. This may because of sample size, or because effort is incentivized differently according to project type.

Interestingly, though, is the differences in schedule-to-effort analysis (Figure 19 lower row). Again, though the results were not statistically significant it appears that a negative trend may exist between GMP and IPD contract types between schedule savings and group level Effort, Mental Exertion, and the Joint Factor Analsysis. The trend with Lump Sum contract types was dissimilar and it appears that a positive trend may exist between schedule savings and group level Effort, Mental Exertion, and the Joint Factor. This trend when reviewed with the project level results shown in Table 14 draws a possible consideration that schedule savings may have a dissimilar relationship to cost savings when associated to Effort and Mental Exertion.

4.6 Discussion of Results

For proposition 1, the Pearson correlation results show that effort is a unique variable. Significant values ranged from 0.36 (engagement) to 0.72 (mental exertion). Specifically, although there were strong correlations, it cannot be said that the values were identical to effort to deem the term undistinguishable. Interestingly, effort's most highly correlated value was to "mental exertion" and least was to "work hard." This alludes to a possible masked definition with this sample group that collaborative effort in a construction and design project leans towards more cognitive effort than physical effort. It should be noted that most respondents were architects, engineers, project managers and project lead for the general and sub-contractors. These positions, by their nature, are more connected to cognitive effort than physical effort.

Based upon results from the KMO (Table 18) and factor loading analysis (Figure 19), Mental Exertion and Total Effort appear to be related to the same latent construct. The r-value for Mental Exertion to Total Effort was strong, but not identical. Therefore, the factors cannot be used interchangeably, but the proportion of the variance between the two factors appear to point to a shared or overlapping meaning. From the KMO results, Proposition 1 cannot be accepted, but the results are mixed. In sum, Collaborative Effort is distinct from the other factors surveyed but does share a common thread with Mental Exertion.

Proposition 2 results generally shows that individual effort positively changes as group effort increases. Figure 16 shows this association across all project types, while Figure 17 shows this comparison based on contract type. In general, as a group's effort increases so must the individuals' effort, but this does not hold for every contract type. Specifically, when looking at Figure 17, Lump Sum has a negative relationship when comparing the individual's effort to the group's effort. This is an important distinction, as Lump Sum contract types can experience an imbalance of Collaborative Effort based on the structures of the contracts. In contrast, IPD has a contract type, where collaborative effort is incentivized. All three contract types showed differences in effort between the individual to the project group. Thus, Proposition 2 is not accepted.

The results for Proposition 3 show that project level effort is positively associated with cost and schedule savings. In short, as project level effort increases, cost savings also increase. Results suggest there is a strong positive trend for effort associated to cost savings and a positive but not as strong association for schedule savings. When separated by contract type, Figure 19, the results for cost savings to project effort indicate that GMP contract types were the only contract type of the three with positive associations. Reviewing Figure 19 in conjunction with Table 14 provides additional insight into how Collaborative Effort may work with the different contract types. For example, the project level effort to cost savings for IPD (Figure 19) resulted in a null relationship, but IPD contract types had the highest average cost savings of the contract types reviewed (Table 14). One explanation could be that for IPD survey respondents reported more effort than for other project types for the amount cost savings realized. In comparison, Lump Sum project types reported less effort and realized less project savings. Based on the results, Proposition 3 cannot be accepted.

4.7 Conclusions

When collaboration amongst teams is incentivized, an imbalance of efforts is a risk that may threaten positive outcomes. Team members free riding on the efforts of others and/or teams reducing their effort as a risk mitigation tool to a perceived threat to an incentive structure are all possible outcomes in collaborative projects. Monitoring cost and schedule outcomes are common in the construction industry, but often lag events that caused adverse outcomes. The intent of this research was to provide a methodology to name and monitor effort to assist providing an additional tool to monitor team performance in collaborative projects. Based on this research, a suitable definition was synthesized and tested. Results confirmed that amount of decisive intensification of either mental or physical activity or active involvement required in the service of meeting a design requirement, project goal, project requirement, project milestone or task, is a distinct and measurable metric, although related to other factors as well.

Results showed a predictive association between the effort level of a project team to that of the individual. Specifically, there was a greater effort of the project team and individual associated with IPD type projects than with Lump Sum type projects. This research did not show a significant association between effort and cost or schedule savings. However, although a significant association was not found, an associative trend was visible.

4.8 Limitations of Research

The presented research of included project specific data from 21 separate projects, and individual retrospective survey results from 121 respondents. The results presented are not generalizable but may be transferable to similar projects. Further, though some of the results were significant, the sample size of projects and subsequent individual contract types reviewed made detecting significance difficult. Finally, survey respondents were mostly project management and design staff, with few field/tradesman response data.

4.9 Recommendation for Future Research

Continued research around effort and Mental Exertion to the performance of design and construction teams is warranted. This would include additional project data, and inclusion of different project types. Survey responses could be augmented with the addition of field staff to offer an expanded or separate understanding of effort. This could include effort perception by gender, experience, and project role. Additionally, further exploration of productive and non-productive effort would be valuable to project teams.

CHAPTER V

CONCLUSIONS

5.1 Summary of Key Discoveries

Collaboration is not easy, but with effort it can be successful.

The original intent of this research was to assist with the selection of contracting and procurement strategies. Over time, this aim was refined to define and measure the amount and type of effort that was required to incentivize success on collaborative projects. Although the performance of design and construction project team members on highly collaborative projects appear to be higher than those working on traditional project types, these gains are based on project characteristics that are independent from the individual abilities of the project team members.

Every design and construction project contains unknown variables and challenges that require a level of collaboration, in addition to the contribution and abilities of the individual design and construction professionals. For this research effort was examined as the moderator between collaboration, by contract type, and performance. An illustrative example of the dichotomy between performance and effort can be seen between the 2004 Men's USA Olympic Basketball team, and the 1980 Men's USA Olympic Hockey Team.

The 2004 Men's Olympic Basketball team was made up, primarily, of NBA professionals and superstars, with an average age of 23.5years. Yet team barely won the bronze medal after losing four games. This contrasts to the Men's Olympic Hockey Team that were all college athletes (average age of team 22.1years) and finished undefeated to win the gold medal. It would be an oversimplification to point to a single cause of the Men's Basketball team's multiple losses compared to the Men's Hockey team's overall success, but it can be safely assumed that the record of both teams wasn't based on talent and experience alone. Jack McCallum reported on the Men's Basketball team in *Sports Illustrated* soon after a loss that the team did indeed try, but couldn't collectively address challenges that were present during the tournament (2004). This contrasts to what have been written about the US Hockey team in that even though the team had not been expected to win against the USSR team, the contribution of the US team's players were collectively able to address their opposition. The challenges that the either team encountered may have little in common with the design and construction process, but it does illustrate that results can be independent from effort and ability in a collaborative, team environment.

Such a separation between effort and ability motivated this research to address questions about how effort and ability are defined and monitored for design and construction teams. It is common in the commercial construction industry to rely on licensure requirements, performance specifications and/or the standard of care to assist in defining ability. Furthermore, effort and incentive structures are typically established using contract language based on standard contract forms. However, defining and monitoring effort is challenging, especially as project teams disseminate additional agency between team members. Through this research a method to define, monitor, and address contractual concerns specific to collaborative effort was provided.

5.2 Total Contribution

This dissertation followed a three-paper format to explore a central premise that the behaviour attribute, effort, is an important and discrete design and construction variable. Chapter 2 introduced the topic of effort by performing a content analysis of standard form contracts.

Findings in this chapter demonstrated that the majority of content in contracts common to commercial construction focuses on cost and schedule issues and not quality or effort concerns. This does not imply, necessarily, that these contracts do not adequately address quality or effort, only that cost and schedule issues are the focus. The chapter did note that project owners and project teams have an opportunity to expand and refine quality and effort expectations with additional contractual content.

Chapter 3 explored how different contract types elicit differing levels of effort based on the profit/incentive structures of the contract types. This analysis used aspects of game theory to provide conceptual models of the expected effort levels of rational contracted agents. From the conceptual models, data from the participants of different contract types in the real-world were used to validate the assumptions of the model. The intent of this chapter, and this research, was not to delineate the value of the different contract types, but to illustrate how contract types transfer the risk of low effort to those party to the contract, and potential subsequent impacts on project outcomes.

Based on the findings from Chapter 2 and Chapter 3, Chapter 4 synthesized a definition and method to evaluate collaborative effort. Projects were evaluated to confirm the association between collaborative effort and project outcomes. Findings showed a strong association between the effort of the project team and that of the individual. Trends were visible when effort was further evaluated against contract type and project metrics. Though some of these associations were not statistically significant, this may have been due to the limited sample size.

5.3 Practical Contribution

The practical contribution from this research is the finding that projects with elevated levels of collaborative effort tended to also experience greater positive project outcomes when compared to project with reduced levels of collaborative effort. Additionally, this research suggested that collaborative efforts of the design and construction teams are highly influenced by the contract type. Taken together, the practical application can be summarized that contract types highly influence the collaborative effort of project teams and project outcomes.

For industry, this could provide insight into not only procurement strategies but also selection of specific project team members. For highly collaborative projects, this research suggests that perceived level of effort is equally important as the individual effort provided by project participants. Project team members willingness to provide effort is based on the perceived reciprocation of effort expanded, and thus could affect project outcomes. The implication to industry is that in highly collaborative projects, the selection of project members should include their willingness to exert effort as well as their ability.

5.4 Theoretical Contribution

The theoretical contribution of this research provides a new paradigm to evaluate contracts and the impact that contract types have on the performance of design and construction teams. This research is important to the academic community because it exposes a possible latent variable that may influence the individual performance in and project outcomes of design and construction. There had been minimal research on this subject previously in the construction industry, even though the term “effort” is colloquial used in evaluation of project teams. As more research is conducted on the performance of different contracting methods, this research provides a new metric for normalizing project outcomes.

5.5 Limitations of Research

Findings from this research may be constrained by the limited sample size of survey data. A total of 21 different projects were sampled, with a total of 121 individual responses. Many of the associations were statistically significant, but some were not. It is assumed that the trends observed in the data may become significant if a larger sampled size were tested. However, due to multiple variables across typical construction projects, findings may or may not be transferable or generalizable.

5.6 Recommendation for Future Research

This research provides multiple avenues for future research. Chapter 2 displays the content priorities of standard form contract, which could allow future research to analytically test how content may influence the performance of individuals or outcomes of construction and design. For example, is there an associative relationship between contracts that provide additional content to quality or effort, and reduced claims? Future research could also review executed contracts from public and private entities to quantify amount of content that is modified from standard form contracts.

Chapters 3 and 4 provide additional research opportunities relative to project team performance. The problem of "free-riding" was briefly noted in Chapter 3, but future research could look at this problem on highly collaborative projects. Monitoring collaborative effort provides an avenue to explore such a relationship, and findings would be of value to the industry as well as academia.

Finally, topics explored in Chapter 4 provide multiple additional opportunities for future research. Specifically, how does collaborative effort change based on age/experience, gender, trade type, and seniority. The research gathered for this research suggested there were possible differences but were outside the scope of this research. Future findings could be used to inform team onboarding requirements and processes and would have both practical and theoretical implications.

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