Influence of Project-Level Characteristics and Factors on Innovation and Value Creation in US Highway Public-Private Partnership Projects

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Abstract

Innovation is a popular topic that receives significant attention from both organizations and academics. This attention includes scholars, executives, public entities, and private organizations in the construction and infrastructure fields. Scholars have examined innovation in both construction and public-private partnerships (P3s). Despite this work, gaps remain – particularly regarding the impact of project-level factors on technical innovation in P3s. Hence, this dissertation contributes to the areas of infrastructure innovation and P3s using a three pronged approach. First, exploration of the literature identified 348 factors that drive or inhibit innovation in infrastructure projects. These factors were synthesized into 33 aggregate factors such as client, integration, and risk. Subsequently, case interviews with practitioners revealed 110 factors that influence innovation in P3 projects; these were further grouped into six main categories. Literature and practitioner perspectives were strongly aligned around four predominant factors influencing innovation in P3 projects: i) risk, ii) client, iii) procurement, and iv) project type. Second, a framework to identify and classify project level innovation was derived and tested using deviations from project baselines submitted as alternative technical concepts (ATCs) in four infrastructure project procurements. The developed framework provides the infrastructure and construction community with a replicable approach to assess technical enhancements in projects to determine whether they are innovative or not and if so the type of innovation. Application of the framework classified only 7 of 53 ATCs from the four projects as innovative. However, the remainder added significant value through cost savings, improved safety or operational efficiency. Lastly, a case study of six contemporary US highway P3 projects: i) Elizabeth River Tunnels in Virginia; ii) East End Crossing in Indiana; iii) North Tarrant Expressway segments 3A&B in Texas; iv) I-4 Ultimate Improvement in Florida; v) I-77 HOT Lanes in North Carolina; and vi) SH 288 Toll Lanes in Texas was conducted to determine the types of innovation found and to assess the influence of key project characteristics on P3 technical innovation. Technical enhancements proposed by concessionaires were assessed using project documentation and semi-structured interviews with 23 experienced public and private sector project participants. Innovations were uncovered, albeit limited. Procurement, project type, and payment mechanism (demand risk/traffic risk) were the key project characteristics influencing innovation. Further, these same characteristics promoted added-value in the form of increased safety, reduced project durations, and decreased project costs. Together, the three studies advance our understanding of the effect of project attributes on technical innovation and value creation in infrastructure public-private arrangements.

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General Audience Abstract

Governments around the world are using public-private partnerships (P3s) to provide needed infrastructure. They often claim that the involvement of the private sector in the delivery of infrastructure will generate various benefits, particularly innovation. However, public agencies and private infrastructure developers provide limited evidence of innovation outcomes. While academic scholars have explored the topic, the studies are limited and have generated alternative results. This dissertation contributes to the areas of infrastructure innovation and P3s with three independent but interrelated studies. First, the exploration of the literature and the perspectives of 23 experienced project participants identified four predominant factors that influence the occurrence of innovation in P3 projects: i) risk, ii) client, iii) procurement, and iv) project type. Second, a framework to identify and classify project level technical innovations in a replicable and transparent manner was developed and tested. Lastly, a multi-case study approach was adopted to determine the types of innovation found and to assess the influence of key project characteristics on P3 project technical innovation. Project documentation was assessed and interviews were conducted with public and private participants in six contemporary US highway P3 projects. Technical innovation was found within the cases, albeit limited. Demand risk and involving the private partner early were two of the most influential project characteristics on technical innovation. Further, these two characteristics promoted added-value technical enhancements through increased safety, reduced project durations, and decreased project costs.

Dedicated to my parents, Edwin González Cabán and Ana G. Montalvo Vázquez

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Preface

Contributions of co-authors of each manuscript in this dissertation:

Chapter 2: Factors Influencing Innovation in Public-Private Partnership Projects

- González, E. E.: conducted the research and was lead author

- Garvin, M. J.: advised on research design and implementation; reviewed, and copyedited the manuscript

Chapter 3: Development of a Framework for Assessing Innovation in Infrastructure Projects with Application to Alternative Technical Concepts

- González, E. E.: conducted the research and was lead author

- Garvin, M. J.: advised on research design and implementation; reviewed, and copyedited the manuscript

- Ghadimi, B.: served as second rater in the study

Chapter 4: Influence of Project Characteristics on Technical Innovation and Value Creation in P3s: Evidence from US Highway Case Studies

- González, E. E.: conducted the research and was lead author

- Garvin, M. J.: advised on research design and implementation; reviewed, and copyedited the manuscript

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1 Chapter 1: Introduction

1.1 Innovation in Public-Private Partnerships

Innovation is a popular topic that receives significant attention from both organizations and academics. This attention includes scholars, executives, public entities, and private organizations in the construction/infrastructure field. The nature of the industry, which is project-oriented with complex supply chains and relationships that often are formed temporarily for a specific project, creates opportunities and challenges for the potential occurrence of innovation.

Public-private partnerships (P3s) arguably are among the most complex project environments in the industry; regardless, one of the most frequently touted benefits of P3s is innovation. The prevailing rationale for their utilization is captured quite well by the Federal Highway Administration (FHWA, 2012): "Public agencies pursue P3s for a variety of reasons, including access to private capital, improved budget certainty, accelerated project delivery, transfer of risk to the private sector, attraction of private sector innovation, and improved or more reliable levels of service" (p. 1-1).

The principal justification for the utilization of P3s is that they deliver higher Value for Money (VfM) for citizens, and innovation is seen as a key driver of VfM. Indeed, scholars, public agencies, and government bodies often point to innovation as a key benefit of P3s. For instance, Tang et al. (2010) argue that public services will benefit from the proper use of private sector skills, experience, technology, and innovation.

Scholars have examined innovation in both construction and P3s: studies have explored the factors that act as drivers or inhibitors of innovation (Bossink, 2004; Eaton et al., 2006); other work (Gambatese and Hallowell, 2011a; Tawiah and Russell, 2008) has focused on identifying and classifying innovation; and additional studies (Tatum, 1989; Leiringer, 2006) have examined how factors impact innovation at the project level. Despite this work, gaps exist. For instance, past work has identified factors that generally influence innovation in construction projects, but a comprehensive synthesis of these factors does not exist and past research has not pinpointed which factors are most significant for P3s. In addition, the research focused on connecting specific innovation factors and infrastructure project[1] innovation outcomes generally lacks transparency in the methods for identifying and assessing project-based innovation and relies to a great extent on anecdotes.

Given the importance of innovation in the VfM philosophy for P3s, better understanding of P3 innovation is a necessity. Consequently, the overarching objective of this research is to advance the state of knowledge with respect to infrastructure project-based innovations within P3 arrangements – although secondary contributions are more generally made in the area of infrastructure project innovation. To realize this objective, this research focused on three main areas of inquiry: (1) what factors drive or inhibit innovation in infrastructure projects and how do they influence P3s; (2) how can infrastructure project-based innovations be transparently and systematically identified and classified (i.e. measured); and (3) is innovation present or absent in P3 projects - if present, what is the class of the innovation and how are key factors influencing innovation in P3 projects. The setting for the research is the United States highway P3 market.

1.2 Project-Based Innovation in Public-Private Partnerships

This research provides a better understanding of project-based innovation within P3 arrangements. The first step entailed the identification and synthesis of factors that act as barriers and enablers for the occurrence of innovation in infrastructure projects. The body of knowledge in this area is rather rich, but it is fragmented. Several authors (Blayse and Manley, 2004; Bossink, 2004) have explored factors of innovation within the construction industry. For example, Blayse and Manley (2004) identified six factors that they argue are the main drivers or inhibitors of innovation, but their rationale for emphasizing these six factors is unclear. Other authors (Eaton et al., 2006; Russell et al., 2006) have explored factors and used them as a benchmark to identify the potential for innovation in P3 projects. While overlap exists among the broader construction and the P3 specific literature focused on innovation factors, a comprehensive synthesis of this literature does not exist; moreover, the relative importance of such factors within a P3 arrangement remains unexplored (Eaton et al., 2006). Hence, a need

[1] Throughout this dissertation, the term "infrastructure project" is used to characterize the nature and context of a project; the term "construction project", while quite similar, sometimes only implies the construction or design & construction phase of a project's lifecycle.

existed to synthesize this rich body of literature on factors that stimulate or impede innovation in infrastructure projects while also identifying their relative influence in P3s.

In addition, some literature has focused on linking specific factors with innovation in infrastructure or P3 projects, but the methods employed for identifying and measuring innovation are quite unclear. For instance, some scholars have explored ways to classify innovation (Garcia and Calantone, 2002; Rowley et al., 2011), while others have also measured innovation (Gambatese and Hallowell, 2011a; Leiringer, 2006; Tawiah and Russell, 2008). In particular, the latter studies describe "measurement" frameworks generally; however, their approaches lack clarity, so replicating their results is difficult, which limits the confidence and value of their work to future researchers. Consequently, investigating innovation within infrastructure projects (and P3s) required development and testing of a framework that allowed assessment of innovation in a replicable and transparent way.

As discussed previously, innovation is viewed as integral to the value proposition of P3s. Yet, the archival literature exploring this topic is limited, and various studies have drawn different conclusions (Gonzalez and Garvin, 2016).[2] For instance, Leiringer (2006) explored the relationship between P3 innovation and four factors: design freedom, collaborative working, risk transfer, and long-term commitment; he did not uncover innovation, although his work indicated that the potential for innovation was present. On the other hand, Rangel and Galende (2010) examined the impact of certain factors on innovation (including those explored by Leiringer), and they did uncover innovation. Accordingly, further investigation of this issue was necessary to both advance the state of knowledge and to provide additional evidence for interested stakeholders, i.e. the general public and legislators, of whether the innovation that P3 advocates and theorists are promising is occurring.

Indeed, innovation within infrastructure projects and P3s has attracted significant recent attention, but gaps in knowledge remain. Many authors have explored the factors that stimulate or stifle innovation potential, but a synthesis of these factors is still lacking. Additionally, limited research addresses how these factors influence innovation in P3 infrastructure projects. While researchers have also classified and assessed infrastructure project innovation, this work lacks the required transparency to replicate and corroborate findings and conclusions. Finally, given the sparse and differing results from prior research examining innovation in P3 projects, this

[2] The majority of this literature also suffers from the replicability issue just described as well.

research is timely and pertinent since it provides a more comprehensive understanding of innovation in P3s.

1.3 Research Approach and Dissertation Organization

Accordingly, this research addressed these issues through a phased and integrated research approach as shown in Figure 1.1 (depicted as pieces of a puzzle). The first phase of the research involved three efforts: Phase 1A that synthesized infrastructure project innovation factors; Phase 1B which developed a framework to identify and classify infrastructure project innovation, and Phase 1C that tested the framework developed in Phase 1B. Phase 2 of the research utilized case studies to further investigate innovation in P3 projects. Involvement of human subjects in the case studies was approved under IRB # 16-963.

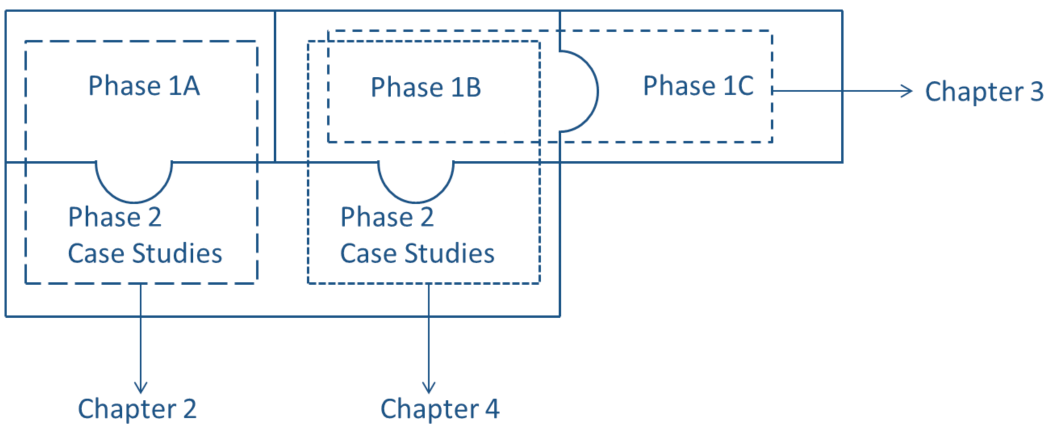

Figure 1.1: Reinforcing Studies in this Dissertation (self-created)

The relationship and outcomes of the different phases and efforts are described below.

- Phase 1A and Phase 2: In Phase 1A, the goal was to identify previous archival work that has explored factors that act as drivers or inhibitors of innovation in infrastructure projects and synthesize this work to better understand the stimulants and barriers that could impact the occurrence of innovation. Phase 2 employed case studies to better understand and identify the relative importance of the factors in P3s. The following questions were answered: **What factors are identified in the literature as drivers or inhibitors of innovation in infrastructure projects?**

Which factors of innovation are influencing P3 projects? The outcome is *Chapter 2: Factors Influencing Innovation in Public-Private Partnership Projects.*

- Phase 1B and 1C: Phase 1B addressed the issue of replicability and transparency of previous investigations. I developed a framework that allows the identification, assessment, and classification of innovation in infrastructure projects. In Phase 1C, I tested the framework using alternative technical concepts (ATCs), a competitive process where alternative concepts that deviate from the procuring agency's baseline specifications are proposed by qualified respondents for approval. This allowed the demonstration of the framework within a "controlled environment". The following questions were answered: **How can project-based innovations be transparently and systematically identified and assessed?** The outcome is *Chapter 3: Development of a Framework for Assessing Innovation in Infrastructure Projects with Application to Alternative Technical Concepts.*
- Phase 1B and Phase 2: Using the framework designed in Phase 1B and the case studies employed in Phase 2, I explored if innovation was found and how project characteristics influenced innovation outcomes in P3 projects and in the US highway P3 market. This work complements prior investigations by answering the following questions: **What types of technical innovation are found in US P3 projects? How are project characteristics influencing technical innovation in P3 projects?** The outcome is *Chapter 4: Influence of Project Characteristics on Technical Innovation and Value Creation in P3s: Evidence from US Highway Case Studies.*

2 Chapter 2: Factors Influencing Innovation in Public-Private Partnership Projects[3]

2.1 Abstract

Public-private partnerships (P3s) and private finance are frequently viewed as part of the solution to the infrastructure gap. P3s arguably are among the most complex project environments in the industry, and one of the most frequently touted benefits of P3s is innovation. Scholars have examined innovation in both construction and P3s; studies have explored the factors that act as drivers or inhibitors of innovation or have examined how factors impact innovation at the project level. Despite this work, a comprehensive synthesis of this rich body of work does not exist – to our knowledge. Further, the relationship between these factors and innovation within P3 arrangements is not fully understood. Consequently, a review of the literature was performed to provide a synthesis of the factors that drive innovation in infrastructure projects. Subsequently, 23 case interviews were conducted with public and private representatives involved in six P3 highway projects to ascertain the factors that practitioners see as influential in P3 projects. These factors were classified into six main categories: i) procurement, ii) public client, iii) private company, iv) risk, v) project type, and vi) external. Strong alignment was found between factors identified in the literature and factors identified by P3 practitioners in the procurement, client, and risk categories. Consequently, emphasis in these areas in research and practice may improve P3 innovation outcomes. For instance, owners should focus on the procurement phase to stimulate and incentivize private participant creativity and innovation. Further, additional future research should specifically explore how these factors are either promoting or inhibiting innovation in P3 projects.

2.2 Introduction

Innovation is driven primarily by: i) market forces and ii) forces of progress (Kline and Rosenberg, 1986). Society demands more and better services and products, to address ever increasing complex problems and issues (Altshuler and Zegans, 1990). In response, private companies have a drive and motivation to be innovative (Goodrum and Haas, 2000) to lower cost, increase productivity, create competitive advantage, and increase market share or create

[3] González, E. E., and Garvin, M. J. (2017). "Factors Influencing Innovation in Public-Private Partnership Projects." *Journal of Management in Engineering*, (in preparation).

new markets (Gambatese and Hallowell, 2011b). The forces of progress on the other hand, science and technology, push the creation of new products or the modification of existing ones. Abernathy and Clark (1985) explain: “technological innovation has been a powerful force for industrial development, productivity growth and indeed, our rising standard of living throughout history” (p. 3). It is basically, a ‘pull’ by society and ‘push’ by technology.

Given these forces, it is not surprising that scholars in many disciplines have explored various facets of innovation. Infrastructure/construction is no exception. In particular, numerous authors (e.g., Tatum, 1984; Blayse and Manley, 2004; Bossink, 2004) have examined the factors, either enablers or inhibitors, of innovation in the construction industry. For instance, some research (Gambatese and Hallowell, 2011a) has explored leading indicators like: owner influence, innovation champions, collaboration, and integration; while other research (Gambatese and Hallowell, 2011b) has focused on motivating factors such as: cost, productivity, and market share; while others (Tatum, 1984) have studied both.

Others have looked more specifically at what drives innovation in the construction industry. Tatum (1989) examined this issue in the late 1980s indicating that some of the driving forces for construction companies to innovate in the United States (US) were: i) owners demanding “more construction for the money” (p. 603), ii) privatization and deregulation, iii) more complex construction requiring new technologies and approaches, iv) new technologies that allow higher production, and v) the size of the US market that attracts international companies and the competition that this creates. Subsequently, Nam and Tatum (1997) highlighted how the owner is not just the buyer but an important player during project execution. Hence, they viewed the owner’s risk sharing, commitment to innovation, and leadership as an influence to promote integration of project participants and critical for a successful innovation process in a project. Similarly, Miozzo and Dewick (2002) in their examination of the relationship between corporate governance and innovation highlighted the important role that governments could have in innovation by promoting collaboration and supporting alternative procurement relations. Procurement processes are the means used by governments to buy their products and acquire their assets. Finally, Eaton et al. (2006) found that construction companies want to innovate given the pressure they receive from clients to reduce costs and accelerate construction.

A shift in the position of the government has occurred where it is not acting as simply a buyer, but it is more involved in the process as mentioned by Nam and Tatum. This perspective is reinforced by Akintoye and Main (2012), who argued that innovation through procurement is needed now more than ever given the push for enhanced Value for Money (VfM), more complex projects, stronger competition among potential vendors/bidders, and pressure from legislative demands. They mentioned integrated procurement methods such as P3s have been associated with delivering innovation through process improvement since these methods engender trust, cooperation, and teamwork, which enable focusing on project objectives. Some authors have also studied factors of innovation in the context of P3s (Eaton et al., 2006; Russell et al., 2006); however, the relative significance of innovation factors within P3s has received limited attention.

Indeed, past work has identified innovation factors within infrastructure projects and P3s, yet no comprehensive synthesis of this body of work is found in the literature. Further, the relative influence of such factors on innovation in P3 arrangements is not well understood. This research seeks to remedy these circumstances by synthesizing and categorizing innovation factors in infrastructure projects while also identifying which factors impact innovation in P3s.

2.2.1 Research questions

In order to better understand and synthesize the factors that drive or inhibit innovation in infrastructure projects and P3s and identify the factors influencing innovation in P3s, the following research questions were posed:

- **What factors are identified in the literature as drivers or inhibitors of innovation in infrastructure projects?**
- **Which factors of innovation are influencing P3 projects?**

2.2.2 Research approach

The research approach consisted of two phases. In the first phase, a thorough literature review was performed to identify the factors that stimulate or stifle innovation in infrastructure/construction. Search queries were done in *Compendex from Engineering Village*, a database that consists of over 5,000 journals from 1884 to the present (Elsevier, 2016). The search strings consisted of three elements: i) “factors” and its proxies (synonyms or antonyms); ii) “innovation”; and iii) “context” such as construction, projects, etc. The search was narrowed by only examining archival literature that was in the English language. The following is a non-exhaustive listing of the search queries:

- *Drivers* AND *innovation* AND *construction* (or *projects* or *public private partnerships* or *PPPs*)
- *Stimulants* AND *innovation* AND *construction* (or *projects* or *public private partnerships* or *PPPs*)
- *Impediments* AND *innovation* AND *construction* (or *projects* or *public private partnerships* or *PPPs*)

The title and abstract of the papers identified in the search queries were read to identify their relevance to factors that drive or inhibit innovation in construction, project delivery, or P3s. Papers not related to the construction industry (e.g., automotive industry), not addressing factors that drive or inhibit innovation, and papers that specifically discussed factors to implement specific technologies or products (e.g., 4D BIM adoption, ergonomic innovations, lightweight dense/porous PCM-ceramic tiles, etc.) were not selected for further review. The remaining papers received a full review to identify innovation factors; papers cited within a remaining paper that were referenced as a source of innovation factors, either specific or broad-based studies, were also identified; these were subsequently reviewed as well. This is similar to a "snowball" approach, i.e. a paper was identified using the search queries, and relevant citations within the paper were then explored and analyzed. Subsequently, the factors identified were categorized following the precedent by Eaton et al. (2006); arranging the factors focused on the different levels: Job Role level, Project level, Organization level, and External Environment level.

In the second phase, case studies were used to identify factors influencing innovation in the P3 project environment based on the results of 23 interviews with personnel involved in the case projects. Purposely, the interviewees were not aware of the literature synthesis results while being interviewed, which strengthens the evidentiary basis (Yin 1994). Further, selection of the cases was deliberate (Taylor et. al. 2011). First, a project had to qualify as a P3; Garvin and Bosso (2008) proposed that "a P3 is a long-term contractual arrangement between the public and private sectors where mutual benefits are sought and where ultimately (a) the private sector provides management and operating services and/or (b) puts private [equity] at risk" (p. 163).

Using this definition, then the contemporary US P3 highway project population is 28, considering projects from 1993 to the present that have reached financial close.

Next, projects implemented in the 1990's that were atypical of the current US P3 market and leases of brownfield assets where significant design & construction stages were limited were discarded. Similarly, projects that were not currently under construction were also discarded since activities or circumstances that might influence innovation were likely not easily recalled by human subjects or were undocumented. From the remaining projects, the access to project documentation and project personnel guided the selection of cases. Table 2.1 presents the six selected cases. These cases are similar across attributes, but have variation by jurisdiction, project type, scale, procurement approach and payment risk; these similarities and differences enrich the data acquired from the case interviews.

Table 2.1: Selected Case Study Projects

Factor / Projects	Financial Close	Jurisdiction	Project Type	Scale (Contract Value $100K)	Procurement Approach	Payment Risk
Elizabeth River Tunnels (ERT)	April 2012	Virginia	Fixed Crossing	2,100	Predevelopment agreement	Demand Risk
East End Crossing (EEC)	March 2013	Indiana	Fixed Crossing	763	Competitive	Availability Payment
N. Tarr. Exp. 3A&B (NTE)	September 2013	Texas	Managed Lanes	1,350	Predevelopment agreement	Demand Risk
I-4 Ultimate Imp. (I4)	September 2014	Florida	Managed Lanes	2,323	Competitive	Availability Payment
I-77 HL Charlotte (I77)	May 2015	North Carolina	Managed Lanes	655	Competitive, but only one bidder submitted a proposal for the project	Demand Risk
SH 288 Toll Lanes (SH288)	May 2016	Texas	Managed Lanes	800	Competitive	Demand Risk

Semi-structured interviews were conducted with 23 public and private sector participants in the case projects in 26 interviews as depicted in Table 2.2; interviewees had an average of 26 years of experience in the industry, and all held positions of responsibility in the case projects. Participants from the private organizations held positions such as bid directors, project SPV CEOs, and project development/sponsor technical directors. Public participants were personnel directly involved in proposal evaluations and negotiations. Interviews were transcribed, and QSR Nvivo software was used to code interview transcriptions to manage the reliability of the findings (Taylor and Levitt, 2007). To analyze the interview transcripts, content analysis techniques were employed (Miles et al. 2014). This approach involved a two-step coding process that allowed the inductive derivation of aggregate factors found in the data. In the first coding, specific factors were identified from the interview data, and in the second coding these were grouped into general themes.

Table 2.2: Project Interviews[4]

Project	**Public**	**Private**
ERT	4	2
EEC	1	2
NTE	2	2
I4	2	3
I77	1	2
SH 288	2	3
Total	**12**	**14**

Finally, the factors identified in the case interviews and the factors synthesized from the literature were arrayed together to identify linkages between the two factor sets. Areas of alignment indicate a potential union between academic and practitioner perspectives with respect to P3 innovation enablers or inhibitors.

[4] Three interview participants had direct knowledge of two different projects, so these participants were interviewed about their perspectives on both projects; hence, interviewees numbered 23 whereas 26 interviews were done.

2.2.3 Innovation definitions

To identify the factors that promote or inhibit innovation, definitions of innovation were first examined. The academic community has not settled on a single definition of innovation. Baregheh et al. (2009) highlighted this when performing a synthesis of the definitions of innovation used in multidisciplinary research. They identified 60 different definitions, 13 of these in technology, science, and engineering. They suggested a multidisciplinary definition of innovation as follows: "*Innovation is the multi-stage process whereby organizations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace*" (p. 1334). More recently, Maghsoudi et al. (2016) provided a synthesis of the definitions of innovation used in 20 construction industry research papers. Of these, Slaughter (1998) provided a definition of innovation that is generally accepted in the construction industry: "the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change" (p. 226). Interestingly, Maghsoudi et al. (2016) found that few researchers have included the notion of risk in their definitions – Ling (2003), however, was an exception: "*a new idea that is implemented in a construction project with the intention of deriving additional benefits although there might have been associated risks and uncertainties. The new idea may refer to new design, technology, material component or construction method deployed in a project*" (p. 635).

A recent work by Antillon et al. (2016) provided a definition of innovation used in research exploring P3 projects: "*implementation of a new or significantly improved technological change, in product or process design, that strategically benefits or improves the long-term lifecycle performance of a project*" (p. 3). Brockmann et al. (2016) studying innovation in megaprojects defined innovation as:

> "*changes leading to an improved input–output relationship for products and processes as well as within the technical, management, or legal organization of a project that can be evaluated monetarily. These changes have different levels of impact and they can be new to a company, the construction industry, or the world, and they may take the form of an incremental, modular, architectural, system, or radical change. Champions can belong to the top management, the bid team, or the project (management, construction, engineers, or work crews)*" (p. 2).

These examples highlight several similarities in the definitions used by researchers. All of them include the concept that an innovation has to provide a *change or improvement* in an *implemented process or product*. They also incorporate the concept of an innovation's *novelty or newness* to one or more of *the involved stakeholders*. The differences in their definitions are likely due to the influence of the context of each research environment. For example, Antillon et al. (2016) were studying technical improvements in lifecycle performance, while Brockmann et al. (2016) were studying technical, management, or legal improvements.

2.3 Synthesis of Factors in the Literature

All search strings uncovered 197 papers in total. Of these, 23 papers were selected for a full review. From these 23 papers, 40 additional papers were identified (via the "snowball" approach). This produced a set of 63 papers (23 by search queries and 40 by "snowball"). Analysis and review of the 63 papers was completed, and 348 factors were identified. After identifying and analyzing the 63 papers, no additional papers or factors were identified, so it was determined that saturation was reached and the search stopped. The analysis and review of the 348 factors allowed: i) the identification of factors that were repeated in several papers and ii) the aggregation of factors of a similar nature. The factors were aggregated to the 33 factors shown in Table 2.3. For example, factor 4a in Table 2.3, *Incentives/penalties* captures the following nine factors identified in the literature: "Innovation rewards" (Goodrum and Haas, 2000), "Subsidies for innovative applications and materials" (Bossink, 2004), "Lack of rewards and recognition" (Eaton et al., 2006), "Penalties for inadequate project performance" (Russell et al., 2006; Tawiah and Russell, 2008), "Subsidies for innovative applications and materials" (Yitmen, 2011), "Innovation incentives" (Hoppe and Schmitz, 2013), "Lack of incentives" (Pellicer et al., 2014), "Building a strict incentive system" (Liu et al., 2016), and "Reward schemes" (Ozorhon et al., 2016; Ozorhon and Oral, 2017). The factors are ordered by the number of archival papers that discuss the factor for driving or stifling innovation. Factors that were identified the same number of times in the literature are listed alphabetically.

Table 2.3: Factors that Stimulate or Stifle Innovation

#	Innovation Factor (ranked by number of papers discussing factor)	Authors
1	Company support and motivation	Goodrum and Haas, 2000; Ling, 2003; Bossink, 2004; Park et al., 2004; Eaton et al., 2006; Miller et al., 2009; Gambatese and Hallowell, 2011a; Gambatese and Hallowell, 2011b; Yitmen, 2011; Chan et al., 2014; Pellicer et al., 2014; Xue et al., 2014; Brockmann et al., 2016; Demirdöğen and Işık, 2016; Liu et al., 2016; Ozorhon et al., 2016; Liu and Chan, 2017; Ozorhon and Oral, 2017
2a	Champion	Tatum, 1984; Nam and Tatum, 1997; Winch, 1998; Goodrum and Hass, 2000; Blayse and Manley, 2004; Bossink, 2004; Park et al., 2004; Miller et al., 2009; Gambatese and Hallowell, 2011a; Ozorhon et al., 2014; Pellicer et al., 2014; Xue et al., 2014; Ozorhon et al., 2016; Ozorhon and Oral, 2017
2b	Client	Blayse and Manley, 2004; Bossink, 2004; Eaton et al., 2006; Miller et al., 2009; Gambatese and Hallowell, 2011a; Kulatunga et al., 2011; Yitmen, 2011; Pellicer et al., 2014; Uyarra et al., 2014; Brockmann et al., 2016; Havenvid et al., 2016; Liu et al., 2016; Ozorhon et al., 2016; Ozorhon and Oral, 2017
2c	Employee experience and motivation	Goodrum and Haas, 2000; Ling, 2003; Bossink, 2004; Eaton et al., 2006; Russell et al., 2006; Tawiah and Russell, 2008; Miller et al., 2009; Pellicer et al., 2014; Ozorhon et al., 2014; Xue et al., 2014; Brockmann et al., 2016; Kimmel et al., 2016; Liu et al., 2016; Ozorhon et al., 2016
3a	Collaboration	Roberts, 1988; Aghion and Tirole, 1994; Bossink, 2004; Eaton et al., 2006; Leiringer, 2006; Gambatese and Hallowell, 2011a; Yitmen, 2011; Lloyd-Walker et al., 2014; Uyarra et al., 2014; Xue et al., 2014; Liu et al., 2016; Ozorhon et al., 2016
3b	Integration/lack of integration	Tatum, 1984; Gann and Salter, 2000; Dubois and Gadde, 2002; Bossink, 2004; Eaton et al., 2006; Russell et al., 2006; Taylor and Levitt, 2007; Tawiah and Russell, 2008; Gambatese and Hallowell, 2011a; Sheffer and Levitt, 2012; Ozorhon et al., 2014; Liu et al., 2016
3c	Knowledge management/lessons learned	Blayse and Manley, 2004; Bossink, 2004; Eaton et al., 2006; Miller et al., 2009; Gambatese and Hallowell, 2011a; Murphy et al., 2011; Yitmen, 2011; Serpell and Alvarez, 2014; Xue et al., 2014; Liu et al., 2016; Ozorhon et al., 2016; Yepes et al., 2016

#	Innovation Factor (ranked by number of papers discussing factor)	Authors
3d	Procurement	Tatum, 1984; Goodrum and Hass, 2000; Blayse and Manley, 2004; Eaton et al., 2006; Russell et al., 2006; Edler and Georghiou, 2007; Tawiah and Russell, 2008; Miller et al., 2009; de Valence, 2010; Akintoye and Main, 2012; Hoppe and Schmitz, 2013; Uyarra et al., 2014
4a	Incentives/penalties	Goodrum and Haas, 2000; Bossink, 2004; Eaton et al., 2006; Russell et al., 2006; Tawiah and Russell, 2008; Yitmen, 2011; Hoppe and Schmitz, 2013; Pellicer et al., 2014; Liu et al., 2016; Ozorhon et al., 2016; Ozorhon and Oral, 2017
4b	Risk	Tatum, 1984; Bossink, 2004; Eaton et al., 2006; Leiringer, 2006; Russell et al., 2006; Tawiah and Russell, 2008; Miller et al., 2009; Roumboutsos and Saussier, 2014; Uyarra et al., 2014; Liu et al., 2016; Ozorhon et al., 2016
4c	Technology	Tatum, 1984; Goodrum and Haas, 2000; Bossink, 2004; Miller et al., 2009; Yitmen, 2011; Ozorhon et al., 2014; Pellicer et al., 2014; Serpell and Alvarez, 2014; Xue et al., 2014; Ozorhon et al., 2016; Ozorhon and Oral, 2017
5	Regulations and standards	Tatum, 1984; Goodrum and Hass, 2000; Gann and Salter, 2000; Miozzo and Dewick, 2002; Blayse and Manley, 2004; Bossink, 2004; Eaton et al., 2006; Miller et al., 2009; Ozorhon et al., 2016; Ozorhon and Oral, 2017
6a	Communication	Tatum, 1984; Goodrum and Hass, 2000; Bossink, 2004; Eaton et al., 2006; Leiringer, 2006; Gambatese and Hallowell, 2011a; Xue et al., 2014; Liu et al., 2016
6b	Culture	Blayse and Manley, 2004; Dikmen et al., 2005; Barlow and Koberle-Gaiser, 2008; Pellicer et al., 2014; Serpell and Alvarez, 2014; Xue et al., 2014; Ozorhon et al., 2016; Ozorhon and Oral, 2017
6c	Exogenous	Gann and Salter, 2000; Goodrum and Haas, 2000; Dikmen et al., 2005; Eaton et al., 2006; Miller et al., 2009; Xue et al., 2014; Liu et al., 2016; Ozorhon et al., 2016
6d	Research and development	Bossink, 2004; Dikmen et al., 2005; Manley and McFallan, 2006; Miller et al., 2009; Gambatese and Hallowell, 2011a; Yitmen, 2011; Serpell and Alvarez, 2014; Demirdöğen and Işık, 2016
7a	Competition	Goodrum and Hass, 2000; Steil et al., 2002; Eaton et al., 2006; Russell et al., 2006; Tawiah and Russell, 2008; Ozorhon et al., 2016; Ozorhon and Oral, 2017

#	Innovation Factor (ranked by number of papers discussing factor)	Authors
7b	Influence of lifecycle on design	Tatum, 1984; Kline and Rosenberg, 1986; Nam and Tatum, 1992; Ball et al., 2000; Goodrum and Hass, 2000; Raisbeck, 2009; Ozorhon et al., 2016
7c	Partnering	Barlow, 2000; Blayse and Manley, 2004; Bossink, 2004; Serpell and Alvarez, 2014; Brockmann et al., 2016; Liu et al., 2016; Ozorhon and Oral, 2017
7d	Project type and scale	Blayse and Manley, 2004; Russell et al., 2006; Tawiah and Russell, 2008; Miller et al., 2009; Uyarra et al., 2014; Brockmann et al., 2016; Ozorhon et al., 2016
7e	Specifications	Tatum, 1984; Ball et al., 2000; Eaton et al., 2006; Russell et al., 2006; Tawiah and Russell, 2008; Uyarra et al., 2014; Ozorhon et al., 2016
8a	Certainty/uncertainty	Altshuler and Zegans, 1990; Teisman and Klijn, 2004; Dikmen et al., 2005; Hartmann, 2006; Russell et al., 2006;Tawiah and Russell, 2008
8b	Opportunity to reuse innovation	Tatum, 1984; Goodrum and Hass, 2000; Blayse and Manley, 2004; Russell et al., 2006; Tawiah and Russell, 2008; Liu et al., 2016
9a	Complexity	Denhardt, 2003; Russell et al., 2006; Tawiah and Russell, 2008; Brockmann et al., 2016; Ozorhon and Oral, 2017
9b	Continuance of traditional roles	Nam and Tatum, 1992; Winch, 1998; Eaton et al., 2006; Miller et al., 2009; Ozorhon et al., 2014
9c	Market	Kline and Rosenberg, 1986; Roberts, 1988; Bossink, 2004; Miller et al., 2009; Yitmen, 2011
9d	Organizational structure	Hobday, 1998; Jones and Saad, 2003; Blayse and Manley, 2004; Davies and Salter, 2006; Serpell and Alvarez, 2014
9e	Socioeconomic and environment	Russell et al., 2006; Tawiah and Russell, 2008; Xue et al., 2014; Ozorhon et al., 2016 ; Ozorhon and Oral, 2017
10	Contracts	Tatum, 1984; Eaton et al., 2006; Leiringer, 2006; Uyarra et al., 2014
11	End user	Miller et al., 2009; Demirdöğen and Işık, 2016; Liu et al., 2016
12a	Contract timing	Antillon et al., 2016; Ozorhon et al., 2016
12b	Long term nature of contracts	Roumboutsos and Saussier, 2014; Uyarra et al., 2014
12c	Supply chain	Bossink, 2004; Eaton et al., 2006

2.3.1 Factors of innovation

The factors uncovered in the literature review, which were discussed in ten papers or more, are considered further. An explanation of each of the 33 factors, as well as their definitions, can be found in Appendix A. The vast majority of the papers identified are published in high quality and high impact journals. A list with the citations of the papers identified and the impact factor of the journals is provided in Appendix B.

2.3.1.1 Company support and motivation

As a counterpart to the client, the companies involved have a drive and motivation to be innovative (Goodrum and Haas, 2000) to lower cost, increase productivity, create competitive advantage, and increase market share or new markets (Gambatese and Hallowell, 2011b). In order to do this, upper management has to be committed (Liu et al., 2016) to the innovation process and supportive (Goodrum and Haas, 2000; Gambatese and Hallowell, 2011a) of employees. They show their commitment and support by: being open to new ideas (Eaton et al., 2006), having employee recognition programs (Eaton et al., 2006; Gambatese and Hallowell, 2011a), establishing conflict resolution strategies (Liu et al., 2016), and providing the necessary resources (Miller et al., 2009). Companies also promote innovation by being responsive to internal and external changes (Liu et al., 2016), establishing clear and appropriate goals (Eaton et al., 2006), and having "explicit coordination of the innovation process" (Bossink, 2004).

2.3.1.2 Champion

A shift in the position of the government has occurred where it is not acting as simply a buyer, but it is more involved in the process as mentioned by Nam and Tatum (1997). An important role needed inside governmental agencies and private companies to promote innovation, is the role of the innovation champion (Tatum, 1984; Nam and Tatum, 1997; Winch, 1998; Goodrum and Hass, 2000; Blayse and Manley, 2004; Bossink, 2004; Miller et al., 2009; Gambatese and Hallowell, 2011a; Pellicer et al., 2014; Ozorhon et al., 2016). This champion needs empowerment (Bossink, 2004) and must be an effective leader (Ozorhon et al., 2016). According to Nam and Tatum (1997), the innovation champion needs two characteristics, technical competence and authority. The technical competence enables the champion to overcome the uncertainty of innovation and the authority allows them to overcome the resistance to innovation.

2.3.1.3 Client

The client could be the most important stakeholder to promote innovation, given its unique position to demand innovation (Bossink, 2004; Pellicer, et al., 2014; Ozorhon et al., 2016) in their requirements, its leadership (Liu et al., 2016), its influence (Gambatese and Hallowell, 2011a) and involvement (Bossink, 2004; Liu et al., 2016) in the project lifecycle. Although the government as a client could be more risk averse, it still demands innovation from construction companies to "improve quality, reduce costs and speed up construction processes" (Eaton et al., 2006). The client could also inhibit innovation by having low capabilities (Miller et al., 2009; Uyarra et al., 2014), lack of interest (Miller et al., 2009), and not having the knowledge to evaluate proposals and alternatives provided by the competing companies institutions (Bossink, 2004).

2.3.1.4 Employee experience and motivation

The employees need the support and commitment from their companies to be innovative. The employees must be challenged with interesting tasks (Eaton et al., 2006) and feel free to question (Goodrum and Haas, 2000) anything related to the project. The team needs diversity of experience (Goodrum and Haas, 2000; Eaton et al., 2006; Russell et al., 2006), and it must have enough freedom, autonomy (Eaton el al., 2006), and training (Bossink, 2004; Eaton et al., 2006; Ozorhon et al., 2016) to be creative.

2.3.1.5 Collaboration

Leiringer's (2006) work questions the collaboration in P3s given the "stringent fashion" in which contracts are written; similarly, others (Bossink, 2004; Eaton et al., 2006; Miller et al., 2009; Uyarra et al., 2014) discuss poor collaboration as an impediment to innovation. Aghion and Tirole (1994) exploring innovation in an incomplete contract framework, explain how partners are hesitant to share knowledge in research joint ventures if they cannot protect their intellectual profit, because by increasing the potential of success of the joint venture, they could be strengthening their future competitors. For Roberts (1988), the formal and informal collaboration of "critical role-players" is required for effective innovation to occur, while, Liu et al. (2016) mention how having partners that have experience in collaboration is a critical success factor of innovation. Eaton in the other hand sees a "lack of openness and trust" as a barrier to innovation.

2.3.1.6 Integration/lack of integration

Russell et al. (2006) list responsibility integration and procurement that promotes greater integration of life cycle phases as a potential for greater innovation. Others see integration as an important driver of innovation as well, "integration of design and build" (Tatum, 1984; Bossink, 2004) and "project team integration" (Gambatese and Hallowell, 2011a), while the "segmentation of project disciplines" (Eaton et al., 2006) is seen as an inhibitor of innovation.

Fergusson (1993) argues that the construction industry is fragmented in three ways: 1) vertically, different stages of the life cycle; horizontally, disciplines or trades; and 3) longitudinally, through time with different companies working on different projects. Later, Fergusson and Teicholz (1996) found that vertical and longitudinal integration allowed higher quality. Building on Fergusson's work, Sheffer and Levitt (2012) look at two types of innovations; 1) modular, which match current industry standards and processes; and 2) integral, which challenge current standards and require new interfaces and processes. They found "clear support for the widely-held view that team integration is beneficial to project outcomes." They mention horizontal integration eliminates longitudinal fragmentation and that horizontal and vertical integration can help align the interests of the different firms. Theoretically, horizontal and vertical integration is found in P3 arrangements, which ought to spur innovation.

Dubois and Gadde (2002) characterize the construction industry as being composed of activities that are tightly and loosely connected. When these connections are loose, there is no communication between activities, resulting in a lack of learning and innovation. They argue that long term relationships beyond single projects are necessary to foster innovation, creating tighter couplings that may enhance opportunities for innovation. However, according to findings from Guevara and Garvin (2015), repeat relationships are not necessarily happening in the US and Canadian markets. They mapped the markets for the last 20 years to explore the participation and integration of private firms and found that most of the interactions are not recurrent and companies that work together on one project often compete against each other in subsequent projects.

2.3.1.7 Knowledge management/lessons learned

The use of tools to compile previous experiences in other projects and use it in new projects is an important factor of innovation. Information gathering, the "creation of knowledge networks" (Bossink, 2004), and "sharing of ideas in the industry" (Eaton et al., 2006) are seen as important drivers of innovation because they allow the industry to learn from previous success and failures. The codification of this knowledge is seen also as an important driver to promote learning across the industry (Blayse and Manley, 2004; Miller et al., 2009; Gambatese and Hallowell, 2011a; Ozorhon et al., 2016).

2.3.1.8 Procurement

Procurement processes are the means used by governments to buy their products and acquire their assets. Akintoye and Main (2012), argued that innovation through procurement is needed now more than ever given the push for enhanced VfM, more complex projects, stronger competition among potential vendors/bidders, and pressure from legislative demands. They mentioned integrated procurement methods such as P3s have been associated with delivering innovation through process improvement since these methods engender trust, cooperation, and teamwork, which enable focusing on project objectives. For Edler and Georghiou (2007) the demand for innovation, in the sense of a client that requests innovative solutions in their procurement of goods and services, is a key driver of innovation that is not fully utilized. They argue public procurement policies could aid in this regard, they define demand-side innovation policies the following way: "all public measures to induce innovations and/or speed up diffusion of innovations through increasing the demand for innovations, defining new functional requirement for products and services or better articulating demand."

For de Valence (2010), traditional procurement processes create transparent transactions on which the private sector is going to compete, but this acts as an inhibitor to innovation because the tender process is directly tied to a price on a specific product. If a bidder submits an alternative solution, it will be non-conforming with the original invitation to bid. While in a non-traditional procurement, like P3, the government can encourage more innovative solutions. The ability to evaluate different alternatives inside the procurement process is seen as a factor of innovation by several authors (Tatum, 1984; Russell et al., 2006; Miller et al., 2009). Additionally, Uyarra et al. (2014) mention the following barriers to innovation in procurement: "a lack of interaction with procuring organisations, the use of rigid as opposed to outcome-based specifications, low competences of procurers, a poor management of risk, poor feedback, a low appreciation of unsolicited ideas and previous private sector delivery history, and cumber-some pre-qualification procedures and conditions".

2.3.1.9 Incentives/penalties

The existence or lack thereof of incentives or penalty regimes in the contract agreement can serve as a driver or an inhibitor of innovation (Goodrum and Haas, 2000; Eaton et al., 2006; Pellicer et al., 2014; Ozorhon et al., 2016). Also subsidies during the procurement could act as drivers of innovations by promoting the use of "innovative applications and materials" (Bossink, 2004). But the use of these incentives during the procurement could generate a rent-seeking mentality from the private sector acting as an inhibitor to innovation (Hoppe and Schmitz, 2013).

2.3.1.10 Risk

The risks of the project are formally allocated within the contract. Proper risk allocation for the promotion of innovation is salient in several papers: Eaton et al. (2006) places "conservatism and avoidance of risk" as an impediment for innovation; Leiringer (2006) mentions that "innovation and risk go hand-in-hand"; and Russell et al. (2006) mention the "reasonableness of risk assignment" as a driver/inhibitor of innovation. But proper risk allocation is not potentially an inhibitor to innovation; risk itself could be inhibiting the occurrence of higher order innovations. Roumboutsos and Saussier (2014) argue the innovations will mainly be incremental, given they have lower risk, and the private is driven to lower the exposure to risk.

2.3.1.11 Technology

The lack of technology to address new requirements that challenge the existing practice in the constructions industry (Tatum 1984; Pellicer et al., 2014), as the introduction of new technology (Tatum, 1984; Ozorhon et al., 2016) are drivers of innovation. But the cost of these new technologies could be too high, making companies hesitant to adopt them and introduce them in the construction field (Miller et al., 2009) potentially inhibiting innovation.

2.3.1.12 Regulations and standards

The procurement process, as the acquisition of services or goods, is at the center of the provision of infrastructure. It is codified within the current regulations and standards followed in practice and approved by law. Miozzo and Dewick (2002) looking at the relationship between corporate governance and innovation highlight the important role that governments could have in innovation by promoting collaboration and supporting alternative procurement relations. Innovation stimulating regulations are seen as a driver of innovation (Goodrum and Haas, 2000; Blayse and Manley, 2004; Bossink, 2004; Ozorhon et al., 2016). Gann and Salter (2000) mention that government regulations and policies influence the direction of technological change; this influence could be promoted through procurement mechanisms that incentivize innovation, e.g. providing bonus points for innovative solutions in a procurement, or by having procurements that demand innovations (Edler and Georghiou, 2007). But if the regulations and standards are too rigid they could act as an inhibitor of innovation (Tatum, 1984; Eaton et al., 2006).

2.3.2 Factors that promote innovation in P3s

In addition to the general factors, those that were discussed in the specific context of P3s were also identified. Scholars have suggested that the characteristics of P3s may encourage innovation. For instance, Siemiatycki (2013) explained how P3s have attracted the favor of left and right leaning governments and how its proponents argued for massive investments that stimulate design innovation and shift risks from the taxpayers. Lawther (2003) mentioned the term public-private partnership is increasingly being used in more government related products and services because it connotes greater efficiency and quality than if the public sector was the sole provider. In this regard, Tang et al. (2010) argued that the government will benefit from the proper use of private sector skills, experience, technology, and innovation. The private sector brings commercial discipline in projects that have risks of cost and time overruns.

More specifically, Raisbeck (2009) argued that the transfer of design risk is an important source of innovation in P3s. This is one of the arguments of the benefits of P3s because different facets of the asset life cycle are incorporated into the design and savings are possible through the incorporation of maintenance and operation cost reductions with a more efficient design. But some argued against this, Davies and Salter (2006) in their examination of SPVs said they have created a "moveable feast" given the subcontracting that is done in the different stages of the life cycle. They contended there is less evidence for a new model of innovation; the government has just shifted the separation of design, construction, and operation from them, to the private sector without higher integration.

Several other exploratory studies have uncovered little evidence of innovation. Reeves (2003) explored the Irish P3 market, which has 134 projects in its pipeline. In his findings, he mentioned that the projects examined raise more questions about whether innovation and risk transfer were achieved with P3s instead of the traditional method. Ball et al. (2000) examined a high school in the UK delivered through the PFI process and came to a similar conclusion. They explained that advocates and promoters of the PFI indicated that although private finance is more expensive, this should be offset by private sector innovations in design and operational management. Barlow and Koberle-Gaiser (2008) drew similar conclusions and uncovered two potential factors that affected innovation in the PFI; first, the use of the public sector comparator (PSC) created pressure to drive cost down and hence reduced innovation, and second, the difference in culture between public and private parties hindered innovation, since interviewees in their study saw a "public sector mentality" that did not allow them to "think outside the box."

Two other studies (Eaton et al., 2006; Russell et al., 2006) have explored factors that drive innovation in P3s. Eaton et al. (2006) performed an empirical study of four PFI case studies in the United Kingdom and Portugal. They found that the amount of impediments surpasses the stimulants, thus stifling innovation. Russell et al. (2006) identified 22 factors that might act as drivers or inhibitors of innovation in P3s. Exploring the Confederation Bridge project in Canada they found evidence is more anecdotal and not significantly founded on documentation; hence, they did not achieve strong conclusions. They list responsibility integration and procurement that promotes greater integration of life cycle phases as potential stimulants for greater innovation in P3s. Others see integration as an important driver of innovation as well, “integration of design and build” (Tatum, 1984; Bossink, 2004) and “project team integration” (Gambatese and Hallowell, 2011a), while the “segmentation of project disciplines” (Eaton et al., 2006) is seen as an inhibitor of innovation.

Leiringer (2006) is another who did not uncover innovation in his work. He argued that in P3s construction contracts are written in a “stringent” fashion, so the way they are structured makes them inhibitors of innovation. He explained that the literature states that innovation and risk go hand-in-hand, and innovation brings uncertainty. He concluded that the common arguments for improved design freedom, collaborative working, risk transfer, and long-term commitment in P3s are questionable. Rangel and Galende (2010) proposed a model to study four characteristics in P3 contracts that could promote innovation: (1) type of risk assumed by the private party, (2) transfer of design responsibility, (3) provision of penalties against private party, and (4) competition between bidders. While this work was not explicitly linked with Leiringer’s research, it did further examine some of the factors linked to P3 performance that he concluded were questionable. Their results showed significant relationships between three of the characteristics (1, 3, and 4) and research and development (R&D) promoting innovation. They suggested that further studies are required to determine if these or other characteristics affect commercial or organizational innovation. Looking at the contracts and the specifications given to the private sector, Ball et al. (2000) found that an output specification approach is crucial for promoting innovation. As participant observers in a high school PFI project, they found the government to be more risk averse preferring to provide input specifications, which aligns with the previous observations of Teisman and Klijn (2004). According to Ball et al., at the outset the project was structured with output specifications, but as the project progressed the more prescriptive the government became. The authors concluded that this was one of the reasons why limited innovation was uncovered. In this regard, Gann et al. (1998) argued that according to conventional economic theory standards and technological innovation are opposed. But, exploring house energy efficiency they mentioned that in general, performance standards allow innovation, while prescriptive standards suppress the required creativity for innovation. The situation uncovered by Ball et al. in which the government wanted to return to a prescriptive specification approach can be explained by Eaton et al. (2006). They found senior management of PFI projects did not recognize the difference between the PFI and traditional procurement and treated them similarly, which was identified as an impediment for the occurrence of innovation.

2.3.3 Categorization of innovation factors

Some authors have also categorized innovation factors. Bossink (2004) studying innovation in construction networks categorized the drivers of innovation into four categories: i) environmental pressure, ii) technological capability, iii) knowledge exchange, and iv) boundary spanning. Environmental pressure comprises the influences that motivate organizations to innovate. Technological capability entails the “technical factors enabling organizations to develop innovative products and processes” (p.338). Knowledge exchange refers to the sharing of information within the organization and with other organizations in order to innovate. Lastly, boundary spanning “represents the initiatives to co-innovate across the boundaries of departments, organizations and partnerships” (p.338). Additionally, Bossink explained how these drivers are part of three management levels in the network of organization: intrafirm level, interfirm level, and transfirm level. Intrafirm refers to the individual organization; interfirm, to the project in which multiple organizations collaborate, and transfirm to the industry.

Similar to Bossink’s three management levels, Eaton et al. (2006) categorized the factors that drive innovation within a network of organizations, but they identified four categories. First, the job role level refers to the individual person. Second, the project level refers to the project team. Third the organization level entails the factors outside the project team, but inside the organizations working on the project. Lastly, the external environment level refers to the factors outside the organizations working on the project. Russell et al. (2006) indicated that the 22 factors they identified would fit into the following five categories: i) Project-specific characteristics, ii) Commercial and business factors, iii) Project requirements, iv) Project risks, and v) Socioeconomic and political considerations. They explained that some of the 22 factors are under the direct control of the grantor of the project and others are fixed; for example, the authors described the different decisions made during procurement by a government agency as direct control; while the authors claim engineering and technical factors are fixed since they are part of the physical environment of the project. However, they explained that these can also be influenced by the grantor who directly or indirectly controls the project contract given the procurement strategy selected and contract creation. Later, Tawiah and Russell (2008) categorized the 22 factors in the five categories explained.

Given the categorizations of factors proposed and used by prior researchers and the composition of aggregate factors performed in this research, the network of organizations proposed by Eaton et al. (2006) provided a better fit. The 33 aggregate factors were categorized in Table 2.4 following the network of organizations structure; arranging the factors focused on the different levels: Job Role level, Project level, Organization level, and External Environment level.

Table 2.4: Categorization of Factors of Innovation

Job Role level	Project level	Organization level	External Environment level
• Champion • Employee experience and motivation	• Collaboration • Integration/lack of integration • Procurement • Incentives/penalties • Risk • Communication • Influence of lifecycle on design • Project type and scale • Specifications • Certainty/uncertainty • Complexity • Contracts • Contract timing • Long term nature of the contracts	• Company support and motivation • Client • Knowledge management/lessons learned • Culture • Research and development • Partnering • Opportunity to reuse innovation • Continuance of traditional roles • Organizational structure • Supply chain	• Technology • Regulations and standards • Exogenous • Competition • Market • Socioeconomic and environment • End user

This categorization highlights the importance of the project and organizational level factors that influence innovation. Interestingly, when this categorization is employed, only two of the aggregate factors are categorized at the job role level, but these two are among the highest in the factor ordering in Table 2.3. Additionally, there are several factors categorized at the external environment level, which highlights the influence of external factors to the project and the different stakeholders involved in the project that can affect the occurrence of innovation.

2.4 Synthesis of Factors from Case Interviews

A total of 110 factors were identified in the interviews. Figure 2.1 graphically portrays the factors discussed during the interviews; the line thickness indicates the number of interviewees who mentioned each factor as influencing innovation in P3s. The figure illustrates how different factors influence the six categories and how they influence innovation. It is important to highlight that the factors shown can act as barriers or enablers to innovation. For example, having confidentiality during the submission of alternative technical concepts was mentioned as promoting the submission of more creative ideas. If the process is not confidential this creativity and submission of ideas will be potentially inhibited because the private participants will be afraid their idea will be shared and they lose the idea and the potential competitive advantage they had by being the only ones with it.

The six main categories that drive value and innovation in P3s are discussed below. Interviews responses are indicated by quotations and attributed to the interviewee using I1, I2, I3, etc. If multiple references are listed, the quote is attributed to the first and corroborated by those following.

2.4.1 Procurement

Factors related to procurement were predominant among those cited by interviewees. In total, 25 factors related to procurement were named. Within this category, the specifications, more specifically having prescriptive instead of performance based specifications, was mentioned by nine interviewees as inhibiting a project's innovation potential; one interviewee commented: clients are "used to building pyramids the old fashioned way, there are twelve versions to build pyramids, they are only used to their pyramids… they're dinosaurs" (I22). This is a case in which a factor can act as an enabler or a barrier. When the specifications are prescriptive, they act as a barrier; when they are performance based, they act as enablers to creativity and innovation.

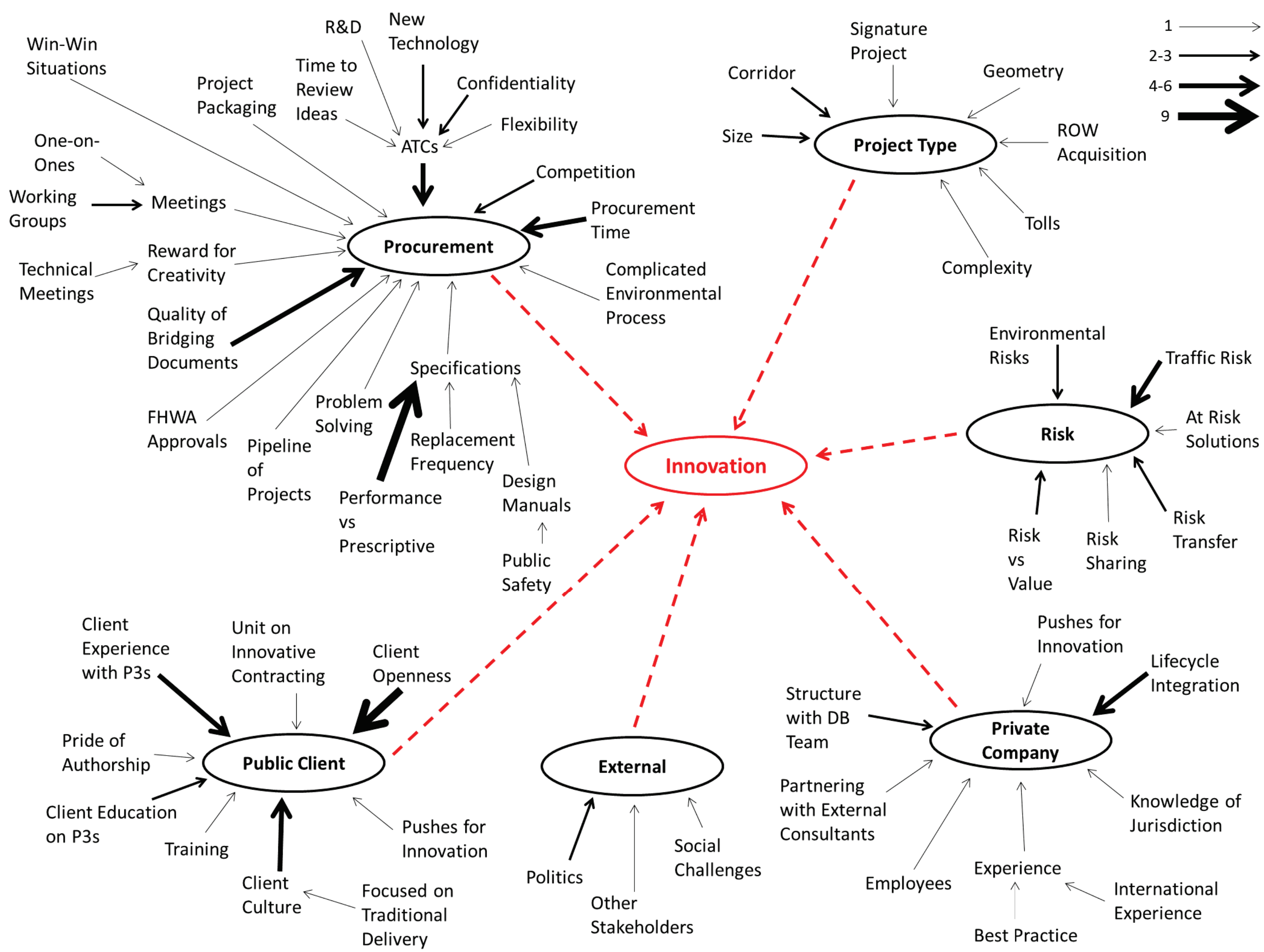

Figure 2.1: Map of Innovation Factors in P3 Projects Cited by Interviewees (self-created)

Next, alternative technical concepts (ATCs), quality of bridging documents and procurement time were identified most frequently. For instance, ATCs and their confidentiality were seen as quite important:

> *"You worry about that in the next project. In the project that you are on, in order to win, if I don't have the aspect that my idea is confidential, I have no reason to present it and move it forward because if the DOT is going to take it and show it to my competition I just wasted my intellectual property for no value. Whether I have to worry about it on the next project, in the same aspect I might take something that my partner from one project onto the next and use it to my advantage the next time, that's the nature of the business we are in, but at the time dealing with the client we are with, confidentiality is the biggest thing to me"* (I22).

The "quality" (I23) of the different bridging documents used during the procurement phase influences how well the private sector understands what the public is requesting and what they are willing to accept as deviations or ATCs. Procurement time was cited since a sufficient amount of time for exchange of information between proposers and clients is necessary and allows the integration of more innovative solutions. If not enough time is provided during the procurement, the private sector has less time to formulate new and creative solutions for a project. The opposite is potentially true when sufficient procurement time is allowed. Finally, having early on meetings or workshops that include people with construction and operational knowledge (I20) was seen as significant; "one-on-ones provide clear direction from the client" (I8) and can enable innovation.

2.4.2 Public client

Aspects related to the public client were also mentioned frequently. Foremost, the client's openness was mentioned by nine interviewees and in all six cases. Interviewees mentioned how an "owner's willingness to accept the innovation" (I1), "openness" (I6, I10), and "willingness to listen and approach every idea and tell clearly if something is acceptable or not" (I8, I21) were keys to promote innovation. In addition, owner experience was viewed rather significantly; representative comments included: an owner needs "people that understand innovation and aren't locked in the delivery aspects of a traditional project" (I16); "owner that understands the P3 process [and] is well educated" (I1), "education of personnel resources in this [P3] process"

(I18), and an owner's "experience with P3 delivery" (I6). The clients' culture was also seen as a factor that can act as a barrier or an enabler. Having specialized units or personnel with knowledge of P3s can break the "cultural inertia" (I17) and act as an enabler to innovation. Alternatively, "clients use of old concepts and ideas" (I3, I4) and a "culture of public sector focused on what they have done in the past" (I18, I21) because "they feel a loss of control" (I22) may inhibit innovation.

This indicates that a client's characteristics can influence innovation; clients need the requisite knowledge and experience in the delivery of P3 projects in order to maximize the potential value creation and innovation from the private sector. Moreover, its culture can impact the potential for innovation. Interestingly, these factors were mentioned by public and private sector representatives with active projects in leading and lagging states. This highlights that still in leading states a need exists for more experience on the delivery of P3 projects to maximize the potential for value creation and innovation.

2.4.3 Private company

In all six case projects, the SPVs were composed of participants from the same corporation. For example, the parent company or one of its subsidiaries is part of the design-build team and a sister company is part of the equity sponsors. From the interviews, it is apparent that they are integrated while pursuing the project during the procurement, but the companies seem segregated by their main responsibilities (eg. design, build, revenue). For example, who takes the lead during proposed technical enhancements may depend on its nature: "that depends on the ATC, if it regards purely construction elements, that [decision] will be made at the DBJV executive committee level" (I10, I6). An interviewee also mentioned that their company has "strong separation of responsibilities between design-build and the development part" (I6) and how this is important given the P3 principle of allocating risk to the party best suited to handle it. Regardless, the interviewee mentioned there are instances where collaboration is needed and important between the DBJV and the developer: "if it is a case of increased connectivity it requires very close coordinated work by both the developer and the design-build contractor and in our case we have the advantage that we have been working together in many, many projects so our way of collaboration is greatly streamlined" (I6). In such cases, integration between the different members of the SPV can act as an enabler.

Interestingly, the same interviewee mentioned how the effort is led by the SPV but depending on the task at hand, one of the partners will have more leeway on the final outcome given its expertise: "Ultimately, if we look at the hierarchy of players, there is the owner, underneath the SPV, and underneath the DB contractor with whatever consultants and advisors. Ultimately everything to some extent is led by the SPV, but depending on how we classify the ATCs, one or other player has a more important role." In all of the SPVs, there are partners who are mainly equity investors but they also collaborate and assess ideas being considered for submission: “Even if they are finance oriented, they most likely are managing a portfolio of infrastructure assets and I have learned that these firms that are managing these types of assets around the world, they themselves learned a lot about the quality of construction through their own management of these assets over the years of operating and maintaining them” (I19). Additionally, selecting the correct consultants also stimulates innovation: “partnering with external consultants in the specific area that allows the ferment of creativity” (I6).

2.4.4 Risk

In the area of risk, traffic risk (or demand risk) in a project can influence innovation: “all things equal demand risk will probably provide additional creativity” (I20, I10, I22, I23) because “in availability payment [projects] innovation is in cost reduction, connectivity innovations are lost” (I23, I10, I20, I22). Given this, a demand risk project will potentially have more innovations related to highway connectivity that can increase revenues through additional traffic. In an availability payment, the traffic risk is not present, so developers have little motivation to look at creative solutions that increase connectivity to the highway.

Risk management and transfer are key tenets of P3s. Not surprisingly it is also an important aspect for the enabling or stifling of innovation. An interviewee mentioned that some public sector clients still misunderstand risk transfer: “the notion of allowing the private sector to provide solutions that they are at risk for, not the client” (I8). Further, technical changes tend to have a ripple effect: “technical, commercial, and financial; everything is joined together. [It is a] classic system of systems approach, risks that are created by changing something [in the project]” (I3). Proper risk transfer may allow creative solutions to emerge; however, it can act as an inhibitor of innovation if the risk is allocated to a party that cannot handle the risk properly.

2.4.5 Project type

In the area of project type, size is potentially significant since it can act as an enabler or a barrier to innovation: “the project has to be large enough to make it worthwhile; I've never been a fan of smaller P3 projects because you don't have as much ability, in a small project you don't have the ability to innovate like you do in the big projects” (I1). The cases included four managed lanes projects and two fixed crossings. One of the interviewees mentioned that when the fixed crossing is a bridge, owners tend to be more prescriptive, which limits innovation potential; a bridge is seen as a signature structure and certain aesthetics have to be met. However, a tunnel, although it still has certain aesthetic elements, is mainly hidden from view and the private partners can propose more innovative concepts and ideas (I19). Managed lanes projects have their issues as well since they are developed in the median of existing corridors: “interstate, very busy, full day level of traffic F, highly urban, with very expensive right of way” (I7, I17, I22). Further, tight corridors limit value added technical enhancements to principally the optimization of the geometry and traffic (I22, I10).

2.4.6 External

External factors mentioned by the interviewees that influence P3 projects include politics, social challenges and other stakeholders outside the project. Given the high profile nature of P3 projects, it is not surprising that they will be highly exposed to political risks (I3, I1, I18). An interviewee mentioned: what “you really need on P3 projects is stable politics and that makes a huge difference on a project” (I1) in order to enable innovation. Another interviewee saw “political impediments” (I18) as an inhibitor of innovation.

Also, the inclusion of other stakeholders outside the project delivery, like the end users or “local stakeholders” is also important in order to provide creative ideas that solve problems or issues to the people that will use the asset the most. This is why another interviewee mentioned that it is important to be aware of the social challenges in order to innovate on the projects because “with P3s, you’re creating a service business” (I3).

2.5 Linking Case Factors and Literature Factors

Table 2.5 arrays the factors uncovered in the case interviews, which had at least two mentions, with those synthesized from the literature. The table is ordered by interview mentions of a factor and then case mentions – the logic being that the relevance of an innovation factor is higher for those with greater interview mentions and case coverage; if factors had the same amount of interview and case mentions, then they were listed alphabetically.

Table 2.5: Summary of Innovation Factors from Interviews and Literature

#	Interview Sub-Factors	Interview Mentions	Case Mentions	Interview Category	Factor from Literature	Category
1	Client openness	9	6	Public Client	Client	Organizational level
2	Performance vs prescriptive	9	3	Procurement	Procurement	Project level
3	Procurement time	6	6	Procurement	Procurement	Project level
4	Client culture	6	4	Public Client	Culture	Organizational level
5a	ATCs	5	4	Procurement	Specifications	Project level
5b	Lifecycle integration	5	4	Private Company	Integration/lack of integration	Project level
6	Traffic risk	5	3	Risk	Risk	Project level
7	Client experience with P3s	4	4	Public Client	Client	Organizational level
8	Quality of bridging documents	4	3	Procurement	Procurement	Project level
9a	Corridor	3	3	Project Type	Project type and scale	Project level
9b	Politics	3	3	External	Exogenous	External environment level
10a	Client education on P3s	2	2	Public Client	Client	Organizational level
10b	Competition	2	2	Procurement	Competition	External environment level
10c	Confidentiality	2	2	Procurement	Partnering	Organizational level
10d	Environmental risks	2	2	Risk	Risk	Project level
10e	New technology	2	2	Procurement	Technology	External environment level

#	Interview Sub-Factors	Interview Mentions	Case Mentions	Interview Category	Factor from Literature	Category
10f	Risk transfer	2	2	Risk	Risk	Project level
10g	Risk vs value	2	2	Risk	Risk	Project level
10h	Size	2	2	Project Type	Project type and scale	Project level
10i	Working groups	2	2	Procurement	Collaboration	Project level
11	Structure with DB team	2	1	Private Company	Organizational structure	Organizational level

Considering the categories from Eaton et al. (2006), there are 12 project level, six organizational level, and three external environment level factors. Out of the 21 factors with two mentions or more in the interviews, 16 are discussed in the literature as drivers of innovation in P3s. The other five, like competition, project size, and the use of new technology are more general construction or infrastructure innovation factors. Of the 21 factors shown; eight are related to procurement, four to risk, four to the client, and two to project type.

Strong alignment between the literature and practitioners is found in the procurement factor. This is not surprising as the procurement phase is key in the shaping of what will become the final project. The procurement process is where the public sector will need clear communications and collaboration with its future private partners to incentivize the integration of SPV members. Strong alignment is also present with regard to the public client. The owner/client is central to promote innovation; it was the second highest factor in both the literature review and in the case interviews. The client also controls the procurement process, the factor with strongest alignment between the literature and case studies. This is why the clients' openness to innovation, its culture, and experiences with P3s are important to promote innovation. Lastly, risk as a factor of innovation also had strong alignment. This is not surprising as risk is a key tenet in the selection of P3 over a traditional delivery. Although the main arguments stated by practitioners are related to risk sharing and transfer as a way to offset more expensive finance, this research shows strong alignment between the literature and practitioners for risk as a factor of innovation. Proper risk allocation will allow the most able partner to hold a risk that they can handle and this will allow them to be more creative when handling the risk. Surprisingly, a weak alignment was found when it respects to the organizational structure. In a P3 the SPV is central as it is the legal company in charge of the project. Davies and Salter (2006) in their examination of SPVs said they have created a “moveable feast” given the subcontracting that is done. During the interviews it was mentioned by only two participants in one of the cases. This could had been because of different reasons; the participants are used to SPVs and do not see them as an important factor or that they are still in working relationships with the different members of the SPVs and did not wish to talk about that in the interview. Future research in which a researcher could act as a participant observer could shed additional light on the topic.

2.6 Conclusion

As described, factors of innovation greatly influence innovation. Their presence can promote the occurrence of innovation, and their absence can potentially stifle it. Presently, no study has synthesized and categorized the body of work that studies factors of innovation in infrastructure projects. This work identified 33 factors that act as drivers or inhibitors of innovation in infrastructure projects. These 33 factors were then arrayed into the network of organizations previously identified by Eaton et al. (2006). The categorization showed that the majority of factors fall into the project and organizational levels. When the factors identified in the case interviews were arranged with the factors uncovered in the literature, a majority of the factors were focused on the project level. This is not surprising, as the interviewees were project level personnel. More importantly, factors in the areas of procurement, risk, client, and project type were more prominently mentioned as factors of innovation in P3s; these strongly align with identical or similar factors cited in the literature. Interestingly, weak alignment was seen with the integration of project participants and the organizations structure or SPV. Both, integration of project participants and SPV members are key aspects of P3 projects and are frequently mentioned as important factors of why P3s are more innovative than traditional procurement.

This research has several contributions to the body of work. First, a synthesis and categorization of factors that promote innovation in infrastructure projects was generated. Second, a map of the factors that influence innovation in P3 projects was created based on case interviews. Finally, alignment between factors found in the literature and factors named by practitioners was particularly strong in the areas of procurement, risk and client; this suggests a potential bond in perspectives that can be emphasized in future research and practice. Also, future research will explore why there is weak alignment between the literature and case studies when it comes to the integration and organizational structure as factors of innovation.

3 Chapter 3: Development of a Framework for Assessing Innovation in Infrastructure Projects with Application to Alternative Technical Concepts[5]

3.1 Abstract

While innovation is generally well-defined in the academic community, its meaning to practitioners and in industry settings is less clear. This likely compounds the problem of illustrating and conveying whether innovation is present in infrastructure projects and more specifically within public-private partnerships (P3s). A principal justification for the utilization of P3s is that they deliver higher Value for Money (VfM) for citizens, and innovation is seen as a key driver of VfM – with an emphasis on what occurs at the project level. Yet, research to date that has identified and assessed innovation in infrastructure projects or P3s is rather opaque. In some respects, this is understandable since "measuring" innovation is a known challenge. However, studies that aim to do so should be clear and replicable to minimize limitations due to subjectivity or anecdotes. With this research we develop a replicable framework to: i) identify, ii) classify, and iii) assess innovation in infrastructure projects, utilizing prior work by Henderson and Clark (1990) and Slaughter (2000) as its basis. The framework is demonstrated by assessing 53 alternative technical concepts (ATCs) submitted in four infrastructure projects. Seven of these ATCs were classified as innovative – three were incremental, three were modular and one was architectural. Yet, a majority of the ATCs added value to the projects through optimization of design solutions or construction methods, which suggests that ATC processes may produce benefits greater than their costs. Consequently, the framework should assist governments and practitioners in gauging technical innovation and value provided by private participants in infrastructure projects.

3.2 Introduction

Innovation is an attractive topic of research in academia. Within the construction industry, innovation has been studied at the project level (Blayse and Manley, 2004; Gambatese and Hallowell, 2011a) and across the networks of industries (Hartmann, 2006; Taylor and Levitt,

[5] González, E. E., Garvin, M. J., and Ghadimi, B. (2017). "Development of a Framework for Assessing Innovation in Infrastructure Projects with Application to Alternative Technical Concepts." *Journal of Construction Engineering and Management*, (in preparation).

2007). While frameworks exist to identify the nature of innovation (Henderson and Clark, 1990; Slaughter, 1998), only a limited number of researchers have attempted to actually assess or measure innovation in infrastructure project environments (Tawiah and Russell, 2008; Gambatese and Hallowell, 2011b).

While innovation is generally well-defined in the academic community, its meaning to practitioners and in industry settings is less clear. This likely compounds the problem of illustrating and conveying whether innovation is present in infrastructure projects and more specifically within public-private partnerships (P3s). The principal justification for the utilization of P3s is that they deliver higher Value for Money (VfM) for citizens, and innovation is seen as a key driver of VfM – with an emphasis on what happens at the project level. Yet, research to date that has identified and assessed innovation in infrastructure projects or P3s is rather opaque. In some respects, this is understandable since "measuring" innovation is a known challenge (Henderson and Clark, 1990; Leiringer, 2006; Gambatese and Hallowell, 2011b). However, studies that aim to do so should be clear and replicable to minimize limitations due to subjectivity or anecdotes.

This research addresses this issue by creating a framework that: i) identifies, ii) classifies, and iii) assesses innovation in infrastructure projects. The applicability of the framework was tested by examining Alternative Technical Concepts (ATCs) within four infrastructure projects. The ATCs were submitted by proposers during infrastructure project procurements for the express purpose of improving the project through deviations from the original baseline established in the project's request for proposals (RFP). This circumstance provides a unique and "controlled" setting for the testing and application of the framework.

3.3 Literature Review

3.3.1 Prior work measuring innovation

Several studies have attempted to classify and measure innovation in construction projects and the methods utilized consist mainly of interviews and case studies. This is understandable, since such tools support answering how and why questions. For instance, Dulaimi et al. (2005) used questionnaires and interviews to identify the influence of project managers on the levels of innovation and performance in construction projects. Manley and McFallan (2006) performed a survey of 335 owners, contractors, consultants, and suppliers of road construction to explore the adoption of technology and practices. In addition, Hartmann (2006) argued that the performance of an innovation can be evaluated by looking at the potential of: i) *problem solving*, “the chance of an innovative idea to transform project requirements into constructional solutions” (p. 570); ii) *diffusion*, the potential of the innovative solution being accepted by other firms inside the project and externally; iii) *differentiation*, the potential that the innovation provides competitive advantage; and iv) *implementation*, the potential of the innovation to be “applied in practice.” He further classified these four potentials into two variables of innovation. The first was innovation attractiveness, which is composed of the potential for problem solving and the potential of diffusion. The second was innovation strength, composed of the potential of differentiation and the potential of implementation.

Other work has attempted to measure innovation in P3s. Leiringer (2006) explored four arguments favoring the occurrence of innovation in P3s: improved design freedom, collaborative working, risk transfer, and long-term commitment. He commented: “It is indeed difficult, if not impossible, to establish a common understanding of the degree of novelty, change and diffusion needed for the phenomenon to be an innovation” (p. 303). As part of his research he performed four case studies; he indicated three had “documented successful implementation of technological innovations” (p. 303) and one had no documented innovations. Still, Leiringer concluded that the common arguments for P3 innovation were questionable; yet, how this conclusion was reached is unclear.

Tawiah and Russell (2008) expanded a framework previously developed by Russell et al. (2006) that explored 22 factors of innovation to study four types of innovations: 1) Product, 2) Process, 3) Organizational/Contractual, and 4) Financial/Revenue. They utilized two case studies to demonstrate their framework; i) the design–build Oresund Tunnel project in Scandinavia and ii) the design-bid-build Dallas High Five interchange in Texas. They assessed the relative presence of their 22 factors within these projects, but they did not differentiate their significance. However, they provided “possible states of the factors”, an initial three level Likert-type scale of the factors to determine a project’s relative innovation potential. They commented: “We note that some of the factors are very difficult to express in quantitative terms; under such circumstances, an attempt has been made to express their possible states qualitatively in relation to their relevance in driving project innovation” (p. 180). They acknowledged that their approach needed further refinement and testing with additional case studies. Moreover, their approach results in the relative *innovation potential* rather than the *realized innovation*.

Gambatese and Hallowell (2011b) also performed a study to assess innovation utilizing case studies. They highlighted that industry participants mentioned the importance of measuring innovation, but the authors felt that firms in their study had low to moderate ability to measure and track innovation. The authors commented: "This perhaps is recognition of a lack of metrics, difficulty in measuring innovation, or a lack of tools available to assist in measuring innovation. The construction industry would benefit from the availability of a guideline or tool to assist firms in this process" (p. 565). They conducted interviews as part of the case studies, and interviewees reported innovations within their projects. Subsequently, given the authors' "experience", they decided how the reported innovations fit their definition of innovation: "during the interviews the participants were asked to identify what was innovative about their project. The researchers evaluated each of the identified innovations to determine which fit within the definition of innovation adopted for this study" (p. 558). While Gambatese and Hallowell (2011b) did provide the definition they used in their research, they did not provide a clear explanation of the process they followed to determine what fit and what did not. In addition, they assigned an innovation score to each innovative activity, not providing a clear explanation in this instance either. Their general approach appears reasonable, but it lacks detail – making it very difficult to verify their findings or perform subsequent research to extend or enhance their approach.

More recently, Antillon et al. (2016) and Himmel and Siemiatycki (2017) performed investigations in the US and Canadian P3 markets respectively, two markets not studied in depth. Antillon et al. (2016) explored contract timing and innovation in three projects in the US P3 market. They used interviews with project participants to identify innovation examples in the projects and classified these innovations using a framework adapted from several past studies including Henderson and Clark (1990), Gambatese and Hallowell (2011b), and Slaughter (1998). They linked Paulson's (1976) cost-influence curves to the levels of innovation achieved in P3 projects. The earlier a private participant was involved in the development of a P3 project, the higher the potential for innovations. Himmel and Siemiatycki (2017) used data from winning and losing proposals from 50 P3 projects procured by Infrastructure Ontario. To measure innovation, they used two variables from the project proposals. First, they used the variability between winning and losing proposal scores to identify the projects with bigger spreads. Their argument was that the spread was due to the use of innovation from the winning bidder. The second measure was the difference between the winning bidders estimated project cost and the original budget from the owner. Their argument in this case was that a bigger reduction in price between original budget and bid price was due to the incorporation of innovations from the bidder. Their findings indicated that the identified spreads were more a consequence of value engineering rather than innovation. They concluded that the innovations in P3s were more related to "clever or inventive way of doing things" rather than the use of new technologies or methods.

3.3.2 General classifications of innovation

The literature has characterized different types and levels of innovation. Several studies have synthesized and explored the literature (Saren, 1984; Garcia and Calantone, 2002; Rowley et al., 2011). For instance, Garcia and Calantone (2002) identified 28 different papers that categorize innovation in different fashions; one with eight categories, one with five categories, five with tetra categorization, two with triadic categorizations, and 19 with different dichotomous categorizations.

Marquis (1988) proposed a broadly accepted classification, between incremental and radical as the extremes of an innovation classification spectrum. Subsequently, Henderson and Clark (1990) argued this categorization was incomplete and proposed a framework that integrates modular and architectural innovations. Their framework consisted of a matrix with four different levels of innovation. As is predominantly found in the literature, the two extremes of innovation are incremental and radical. The former introducing minor changes and the latter "based on a different set of engineering and scientific principles" (p. 9), departing completely from the base concept. They explained that modular innovation entails changes in the core design of the concept while keeping the same linkages between the elements and components while architectural innovation entails changes in the linkages to the core concept, but not the core design. They covered architectural innovation in more depth and explained that the introduction of new linkages is harder to identify since the core concepts remain essentially unchanged.

3.3.3 Construction classifications of innovation

Slaughter (1998) added a fifth innovation, system innovation, to prior frameworks. Her scale of innovation for construction was composed of five models: i) incremental, ii) modular, iii) architectural, iv) system, and v) radical. Incremental is a small change in a specific element, and modular is a more significant change in a concept but with limited impact on other components.

Architectural innovations involve a small change that impacts the interaction with several components; system innovation involves multiple innovations with changes in several components, while a radical innovation involves a new approach that causes major changes in the industry.

Slaughter (2000) later changed her representation of the five models of innovation from a linear perspective to a two dimensional framework. Similar to Henderson and Clark (1990), her two dimensional representation depicted incremental and system innovations as lower and upper boundaries, while placing radical innovation beyond the boundaries since radical was deemed as something entirely new. The essence of the definitions she used previously were kept the same, but she adjusted the definitions of the change in concept and links that differ among the types of innovation. Here, she defined the five types of innovations (Figure 3.1) as: i) incremental innovation, "is a small improvement in current practice, and has minimal impacts on other components or systems" (p.3); ii) architectural innovation, is also a small improvement, but in this case "within a specific area or core concept, but requires significant modification in other components or systems in order to function" (p. 3); iii) modular innovation, "is a significant improvement (or even a new concept) within a specific region, but requires no changes in other components or systems" (p. 3); iv) system innovation, "is a set of complementary innovations which work together to provide new attributes or functions and together can significantly advance the state of knowledge or practice" (p. 3); and v) radical innovation, "is a completely new concept or approach which often renders previous solutions obsolete, including interdependent components or systems" (p. 3).

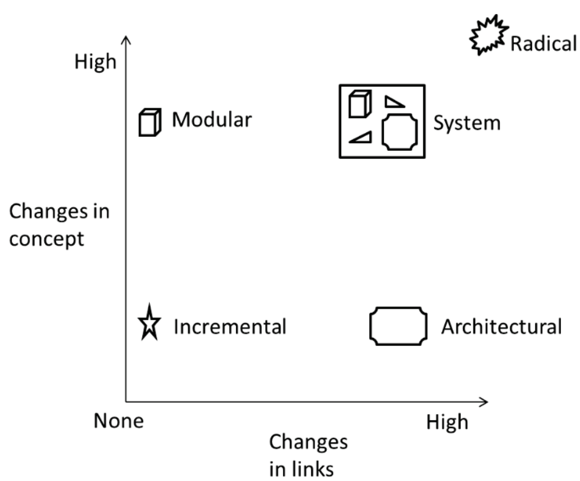

Figure 3.1: 'Categories of Innovations' (Slaughter, 2000)

Slaughter's work has been the foundation for numerous subsequent studies in construction. Many researchers have used her work as a means to assess innovation implementation in construction/infrastructure. For example, Park et al. (2004) used system dynamics to expand her work and specifically explored how project participants influence innovations and its implementation in the execution stage of projects. More recently, Murphy et al. (2015), used her work to design an innovation management model for the implementation of product innovations or technologies in buildings. Other researchers have used her work to develop completely different frameworks of innovation; for instance, Dikmen et al. (2005) created a conceptual framework to better understand the relationship between companies' objectives and strategies toward innovation, and how organizational and external factors influence these objectives and strategies. Still, Slaughter's characterization of five types of innovation in construction remains central in past and current innovation research.

3.3.4 Summary

Innovation is viewed as integral to the value proposition of P3s, but most importantly innovation is central in infrastructure development given the demands of society for more and better services and products, to address ever increasing complex problems and issues (Altshuler and Zegans, 1990). In response, private companies have a drive and motivation to be innovative (Goodrum and Haas, 2000) to lower cost, improve productivity, create competitive advantage, and increase market share or create new markets (Gambatese and Hallowell, 2011b). Indeed, innovation within infrastructure projects and P3s has attracted significant recent attention, but gaps in knowledge remain. While researchers have classified and assessed infrastructure project innovation, this work generally lacks the required transparency to replicate and corroborate findings and conclusions.

3.4 Point of Departure

Review of the literature shows the limitations of prior work, notably the lack of replicability and transparency of research that has assessed or measured innovation in infrastructure and construction. Hence, there is a need for a framework that allows a clear assessment of innovation as well as corroboration of findings by other scholars. Consequently, this motivates the following research question:

- **How can infrastructure project-based innovations be transparently and systematically identified and assessed?**

Certainly, innovation in infrastructure projects can occur in various areas such as managerial, financial, or organizational. This research, however, focuses on technical innovations submitted though established ATC processes.

3.5 Methodology

3.5.1 Framework development and application

The methodology for this research consisted of two phases. In the first phase, a framework to identify, classify, and assess innovation in infrastructure projects was designed; this framework was underpinned by prior innovation research. In the second phase, the framework was tested by examining ATCs within infrastructure projects. In the United States (US), the typical procurement process for large-scale infrastructure projects starts with the issue of a request for qualifications (RFQ) by the public owner. Interested proponents then submit a statement of qualifications (SOQ) addressing the requirements set forth in the RFQ. Usually, the owner then shortlists three to four respondents to have a manageable number of bidders while sustaining competitive tension. The shortlisted teams are then provided a request for proposals (RFP). The RFP documents establish a project's baseline conditions for technical, commercial, and legal matters. Frequently, a formal ATC process is utilized typically for the express purpose of allowing proposers to present creative or innovative changes to a project's baseline technical requirements established in the RFP. ATCs submitted by competing consortiums allow owners to consider (and approve or reject) concepts that differ from baseline conditions and could potentially be innovative. Hence, a project's ATC process provides a unique and "controlled" setting for testing and application of the framework. Previous researchers (Leiringer et al., 2006, Russell et al., 2006) indicated that their findings were limited given their results were dependent on interview data only and not on actual project documentation. The use of ATC documents minimized such shortcomings and provided a sound test of the framework.

The second phase demonstration utilized ATCs submitted and approved by the winning bidders in the four projects summarized in Table 3.1. These four projects were selected because they had well documented ATC submittals, and they provided a representative sample of the market. The projects are two managed lanes P3 projects and two fixed crossings, one a design-build and the other a P3. The managed lanes projects are the US 36 Express Lanes – Phase 2 project (US36) in Colorado and the I-4 Ultimate Improvement project (I4) in Florida. The two fixed crossings are part of the Ohio River Bridges (ORB) Project. The ORB Project consists of two major fixed crossing projects: i) the Downtown Crossing (DTC) procured as a design-build by the government of Kentucky and ii) the East End Crossing (EEC), procured as a P3 by the government of Indiana. Table 3.1 highlights language from the RFP, which indicates the purpose of the ATC process; three of four RFPs explicitly stated that the ATC process seeks innovation from the private sector, while the fourth (US 36) at least sought "equal or better" alternatives.

Table 3.1: Projects Studied

Project	Delivery Model	Purpose of the ATC Process (as stated in RFP)
Downtown Crossing	Design-build	"The [ATC] process allows for innovation, increased flexibility, time reductions, and cost savings to ultimately obtain the best value for the public."
East End Crossing	P3 with Availability Payment	"This process is intended to allow Proposers to incorporate innovation and creativity into the Proposals…"
I-4 Ultimate Improvements	P3 with Availability Payment	"This process is intended to allow Proposers to incorporate technical innovation and creativity into their Proposals…"
U.S. 36 ML/BRT Ph. 2	P3 Demand Risk	"[The owner] has encouraged the Proposers to recommend alternatives to the [owners] Phase 2 Construction Work Requirements and [the owners] Service Requirements… that are equal or better in quality or effect"

Project documentation, including the ATC submittals that the winning proponents included in their proposals and the acceptance letters from the public owners, was the primary source of data. A multi-step framework (explained in the following section) was employed to assess whether each ATC proposed by concessionaire teams in these projects qualified as an innovation.

3.5.2 Internal validation

In order to ensure the internal validity of the framework, inter-rater testing was done by two analysts; a supervisor monitored the process. The two analysts used the framework independently to assess the ATCs in all four projects. In order to assess the reliability of the framework and the agreement between raters, Cohen's kappa (Cohen, 1960) was used since it is appropriate for nominal data (Nguyen et al. 2017).

$$k = \frac{F_0 - F_c}{N - F_c}$$

Where: N - the total number of judgments made by each coder

Fo – the number of judgments on which the coders agree

Fc – the number of judgments for which agreement is expected by chance

When kappa is near or equal to 0.8, agreement is considered very strong, and therefore, sufficient (Landis and Koch, 1977), so the framework exhibits reliability.

3.6 Development of the Framework to Assess and Classify Project-based Innovation

The framework was designed with two distinct steps to assess project-based technical enhancements; the first step is a binary assessment of whether a change in a project qualifies as innovation or not while the second step classifies qualifying changes by type of innovation.

3.6.1 Binary assessment

Freeman (1974) mentioned that we owe the distinction between inventions and innovations to Schumpeter. Where "invention is an idea, a sketch or a model for a new or improved device, product, process or system…An innovation in the economic sense is accomplished only with the first commercial transaction involving the new product, process, system or device…" (p. 6). Schumpeter (1912/1934) said that inventions are economically irrelevant as long as they are not implemented and to do so a different set of skills is required than to invent them. Freeman (1974) explained innovation has two stages. First is the recognition of a need for a new product or process and second is employing the technical knowledge necessary to fulfill the identified need.

Prior work by Garvin and Jolley (2013) provided a basis to assess what qualifies as an innovation in project-based environments. They proposed the following definition: "Innovation is the actual use of nontrivial change and improvement in a process, product, or system that is novel to the institution developing that change" (p. 18), where i) actual use, ii) nontrivial, and iii) improvement were qualifying elements to determine if an ATC was an innovation or not. They explained: "Actual use" means the idea was implemented by the concessionaire, "nontrivial" refers to ideas that are not simply a reduction in scope or a result of prescribed project parameters, and “improvement” is based on positive, incremental change in one or more of the following metrics: time, cost (capital and NPV), revenue, scope, capacity, safety, level of service, and environmental impact. Gambatese and Hallowell (2011b) argued an additional innovation criterion is whether or not it diffuses, either by being used subsequently in a firm responsible for the innovation or by other firms in the industry; if not it is just problem solving. However, Hartmann (2006) argued that something that produces a solution to a specific problem, even if it does not diffuse, can be considered innovative.

Given this, the following definition was utilized:

> *“Innovation is the actual use of a nontrivial change and improvement in a process, product, or system that is novel” (Slaughter, 1998, p. 226) “to the company developing or using it” (Slaughter, 2000, p. 2); and has the “potential of solving problems” (Hartmann, 2006, p. 572) or has the potential to diffuse “beyond just the initial project” (Gambatese and Hallowell, 2011b, p. 556).*

The different elements of this definition were qualified for each individual case in an innovation assessment rubric composed of six elements: i) actual use; ii) nontrivial; iii) change; iv) improvement; v) process, product, or system; and vi) novel. Below each of these elements is further discussed.

3.6.1.1 Actual use

In order for an innovation to exist it has to actually be used, as Freeman (1974) explained the main difference between an invention and an innovation is that an innovation is only accomplished with its use. According to Roberts (1988), “Innovation = Invention + Exploitation” (p. 13), in this sense, the exploitation process includes the development and subsequent application of the ideas.

3.6.1.2 Nontrivial

A nontrivial technical enhancement precludes changes that could be considered “value engineering”, with a purpose of just reducing scope or cost, or changes which are not significant (Gambatese and Hallowell, 2011b). Products or processes prescribed within the project parameters will be considered trivial.

3.6.1.3 Change

A change entails something different from what has previously been done, something that deviates from the current state of practice or baseline state of knowledge. Russell et al. (2006) mentioned the deviation from the baseline will be achieved by using "new" techniques, concepts, materials, and approaches.

3.6.1.4 Improvement

Innovations result in a positive "change in basic project performance metrics" (Russell et al., 2006, p. 1523). This positive change can provide additional "economic, functional, or technological value" (Dikmen et al., 2005, p. 81). This is achieved by lowering construction costs, providing schedule savings, improving quality, increasing safety, or reducing environmental impacts. The beneficiaries of this added value can include owners who benefit from faster substantial completion dates, lower costs of construction, and higher quality. Consequently, private companies will reap competitive advantages and higher profits. Users and society in general may also benefit from this added value by having assets built with safer construction practices and that are environmentally friendly. Russell et al. (2006) mentioned how several of these metrics are ultimately expressed in terms of time, cost, and revenue; and subsequently in global project indicators of success like net present value (NPV), internal rate of return (IRR), and debt-service coverage ratios (DSCR).

3.6.1.5 Process, product, or system

In their exploration of innovation in construction, Tawiah and Russell (2008) described the following:

- Product innovations are provided by novel designs, new materials/components, and use of innovative technologies.
- Process and system innovations usually occur during construction and are provided by the trades, such as, logistics, advanced construction methods, and novel sequencing of construction activities.

3.6.1.6 Novel

An innovation does not have to be something entirely new; it might just be novel to the jurisdiction to be considered innovative (Freeman, 1974). Russell et al. (2006) argued that "complex and previously unencountered conditions create a necessity for novel solutions (concepts, methods, techniques), which might expand the boundaries of existing guidelines, codes, and standards" (p. 1524).

3.6.1.7 Summary

The elements just discussed were organized into a binary assessment rubric that includes the following "yes or no" questions:

- Actual use - Was it applied in the project?
- Nontrivial - Does it entail more than a scope or cost reduction in the project?
- Change - Does it deviate from current practice and standards?
- Improvement - Does it provide a positive change?
- Process, product, or system - Does it entail a new process, product or system (PPS)?
- Novel - Is it novel to the jurisdiction, client, or company?

3.6.2 Innovation Classification

If a project-based change qualifies as innovative, then the next step was to classify it according to type. Using the principles and frameworks of Henderson and Clark (1990) and Slaughter (2000), a two dimensional framework, depicted in Figure 3.2 classifies project-based innovation by type.

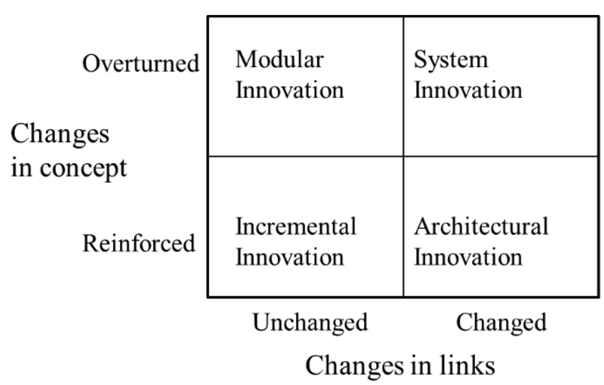

Figure 3.2: Proposed Framework to Classify Innovation

(Adapted from: Henderson and Clark, 1990 and Slaughter, 2000)

An *incremental innovation* is a small improvement that reinforces the concepts in current practice with unchanged or minimal impacts in the links with other components in a project. A *modular innovation* is a more significant improvement in practice with an overturning of core concepts but no changes in the links with other components of a project. An *architectural innovation* is one in which a small improvement in a core concept occurs, but prompts changes in the links with other elements or systems of a project. A *system innovation* is a combination of complementary innovations in which the core concepts are overturned and changes in the links with other elements of a project; such necessitate significant changes in current practice. Lastly, *radical innovation* is something new that drastically changes the industry, which Slaughter (1998) characterized as resembling a "shooting star." Following this characterization, radical innovations are outside the framework, since assessing this type of change cannot occur on any given project.

To determine the type of innovation, the framework poses the two questions below, which are answered using the flowchart in Figure 3.3 and its annotations shown in Table 3.2.

1. Does the innovation provide a significant improvement that overturns current practice and/or core concepts?
2. Does the innovation trigger changes in the interaction (links) between components or systems?

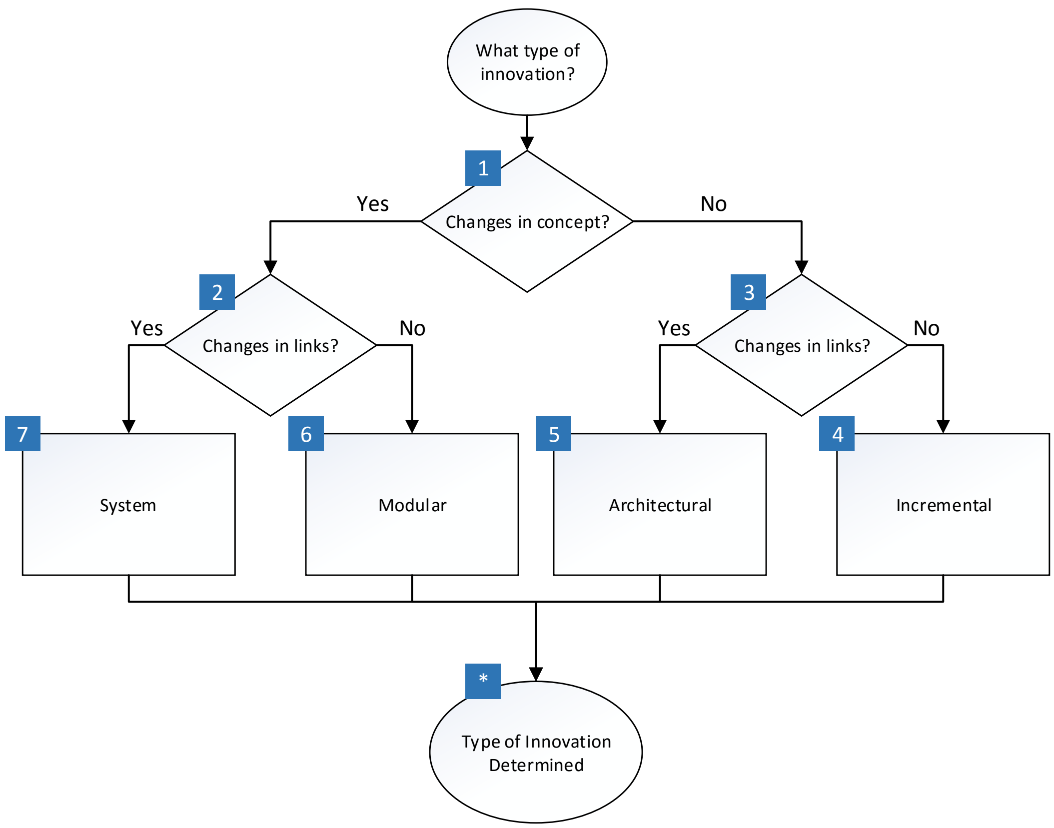

Figure 3.3: Flowchart for Innovation Type Classification (self-created)

Table 3.2: Flowchart Annotations

Note	Description
1	Every innovation starts at the base of the framework shown in Figure 3.2 as an incremental innovation. If the innovation moves vertically in the framework or remains in place, the change in concept needs to be addressed: **Does the innovation provide a significant improvement that overturns current practice and/or core concepts?** If a significant improvement is achieved the answer is yes and the innovation moves vertically to decide between a modular or system innovation. If the answer is no, because only a modest improvement in core concept is achieved, then the innovation remains in place and the next step determines whether it is an incremental or architectural classification.
2	The following question distinguishes between a modular or system innovation: **Does the innovation trigger changes in the interaction (links) between components or systems?** If the answer is no, then the innovation is classified as modular. If the answer is yes, then it is classified as a system innovation.
3	The following question distinguishes between incremental or architectural innovation: **Does the innovation trigger changes in the interaction (links) between components or systems?** If the answer is no, then the innovation is classified as incremental. If the answer is yes, then it is classified as a incremental innovation.
4	Examples of incremental innovations include: transition from waist harness protection system to a full body harness (Slaughter, 1998) or raised profile rebar that allows a "modest expected improvement in performance" (Slaughter, 2000, p. 3).
5	Examples of architectural innovations include: self-compacting concrete, "it is still concrete" but changes the process to create the ad mixture while eliminating vibration and consolidation (Slaughter, 1998, 2000).
6	Examples of modular innovations include: a machine that ties wires to rebar, changing the concept, but not any other methods or materials of concrete construction (Slaughter, 1998); another example is flexible piping replacing copper piping (Slaughter, 2000).
7	Examples of system innovations include: a new "zone module" prefabrication used in coal power plants that integrates four different modules with plumbing, electrical, etc., and a fifth module to raise and put in place the completed module (Slaughter, 1998); or

Note	Description
	a "new bridge design… coordinating the set of complementary innovations to achieve new levels of performance" (Slaughter, 2000, p. 4).
*	While radical innovations are not listed on the flowchart or shown in the framework Figure 3.2. They are something new that drastically changes the industry Examples include: structural steel when it was first introduced in the market (Slaughter, 1998) or fuel cells, which use chemical reactions instead of fossil fuels to produce energy (Slaughter, 2000).

3.7 Application of the Framework

3.7.1 Interrater testing results

Inter-rater testing of the framework was completed on the complete data set. Two raters independently analyzed all the ATCs on the four projects; results from the binary assessment were compared to determine the kappas obtained for each of element of the rubric. After review of the kappas, both raters discussed their findings and resolved most discrepancies. The results for the initial and final kappas obtained are presented in Table 3.3.

Table 3.3: Interrater Results for Binary Assessment

Element of the Rubric	Initial kappa	Final Kappa
Actual use	1.00	1.00
Nontrivial	0.41	1.00
Change	0.87	0.96
Improvement	0.87	0.87
PPS	0.71	0.87
Novel	0.77	1.00

Three of the elements of the binary assessment rubric did not meet the 0.8 kappa threshold for agreement between raters. These were the questions regarding nontriviality (kappa=0.41); process, product or system (PPS) (kappa=0.71); and novelty (kappa=0.77). After discussion, disagreement on the PPS and novelty responses were addressed, and subsequent ratings yielded kappas of 0.87 for PPS and 1.0 for novelty. The question regarding nontriviality needed more clarity, so it was revised. Once modified, subsequent ratings produced a kappa of 1. In the second step of the rubric, 100% agreement was reached on the type of innovation except for one of the identified innovations. This is discussed further in section 3.8.

3.7.2 Step-wise illustration

The application of the developed framework is first illustrated on two ATCs in the DTC project in Kentucky. Several of the ATCs submitted by the selected proponent of the DTC addressed a specific requirement within the RFP to submit an ATC for certain elements of the project. For example, the RFP identified the use of cast-in-place gravity retaining walls or mechanically stabilized earth as acceptable products, but instructed the submittal of an ATC if any precast retaining wall systems were to be used, even ones already approved by the Kentucky Transportation Cabinet (KYTC). The selected proponent submitted two ATCs addressing this topic, ATCs 19 and 29; ATC 19 proposed the use of a T-Wall precast retaining wall system, and ATC 29 proposed the use of precast retaining wall system. The binary assessment of each ATC is shown in Table 3.4.

Table 3.4: Demonstration of the Innovation Binary Assessment Rubric

Element	Binary Question	ATC 19	ATC 29
Actual use	Was it applied in the project?	Yes, the proposed ATC was presented and actually used in the project	Yes, the proposed ATC was presented and actually used in the project
Nontrivial	Does it entail more than a scope or cost reduction?	Yes, it allows improvement to traffic management besides cost reductions	Yes, it allows improvement to traffic management besides cost reductions
Change	Does it deviate from current practice and standards?	Yes, it provides a new option for retaining wall systems	No, Kentucky standards allow its use
Improvement	Improvement - Does it provide a positive change?	Yes, it provided improvements in construction time and traffic improvements	Yes, provided improvements in construction time and traffic improvements
PPS	Does it entail a new PPS?	Yes, it is product innovation	No, it has been used before by the owner
Novel	Is it novel to the jurisdiction, client, or company?	Yes, not approved by the state’s material office, not used previously by the owner	No, not novel to the state, approved by state’s material office

While ATC 29 provides improvements in construction time and traffic management, it is not a deviation in standard practice, does not provide a new PPS, and is not novel. However, ATC 19 is innovative. ATC 19 entailed the use of a T-Wall precast retaining wall system (T-Wall) instead of cast-in-place gravity retaining walls or mechanically stabilized earth. The T-Wall is a precast unit that has a rectangular face and a stem that extends towards the zone to be reinforced. The system is built by stacking separate units together and backfilling over the stem with selected backfill material. The use of the T-Wall system is proposed as a solution where the space is not sufficient to use mechanically stabilized earth systems and concrete trucks will affect traffic for cast-in-place retaining walls. The T-Wall is a new product, not previously used in the state, which improves construction time and limits traffic disruption. It is classified as an *incremental innovation* because it is a modest improvement in practice that allows faster construction of the retaining walls, avoids the disturbance of traffic that concrete mixer trucks would cause, and eliminates the curing time of cast-in-place retaining walls – but it does *not* change links to other elements.

3.7.3 Assessment of ATCs in four projects

The complete analysis of project documentation in the four projects identified 53 ATCs; a description and assessment of the complete set of ATCs identified are included in Appendix C. Table 3.5 provides a summary.

Table 3.5: Summary of Identified ATCs

Project	Identified ATCs	Innovative ATCs
DTC	13	2 (15.4%)
EEC	7	1 (14.3%)
I4	25	2 (8.0%)
US 36	8	2 (25.0%)
Total	**53**	**7** (13.2%)

After completing the binary assessment of the framework to determine if an ATC is innovative, only seven met all the criteria of the rubric and hence were deemed innovative. Incremental, architectural and modular types of innovation were identified; system and radical innovation were not. Table 3.6 summarizes the ATCs assessed as innovative; subsequent sections explain how they were classified into the different types of innovation.

Table 3.6: Innovative Alternative Technical Concepts

#	Project	Description	Changes in Concept	Change in Links
Incremental				
1	DTC	Use of a T-Wall precast retaining wall system instead of cast-in-place gravity retaining walls or mechanically stabilized earth	Reinforces the practice of precast retaining walls, introducing a new system to the jurisdiction	Unchanged, it is used as the other precast wall systems
2	US 36	Use of DR 11 HDPE pipes perpendicular to soil reinforcement to avoid the construction of several manholes and a trunk line in the median	Reinforces the practice of storm water design	Unchanged, no changes to the interaction to the other elements of the project
3	I4	Use of precast edge girders that incorporate a curb along the external edge of the girder that eliminates the need for overhang falsework in the bridge deck	Reinforces the use of precast concrete elements that increase site safety	Unchanged, it will be used as any other girder, except it allows it to be used as a scaffolding for the deck
Modular				
4	I4	Use of maturity meters to test concrete strength before 14 days and open roadway sooner to traffic	Overturns the concept of needing to have test cylinders to open a section of roadway early	Unchanged, no changes to the links of the other elements of the project and their interactions
5	US 36	Use of the Mechanistic-Empirical Pavement Design Guide (MEPDG)	Overturns the way the pavements are designed using a method that uses more site specific data	Unchanged, the pavement will be used the same way, no changes in links to other elements
6	DTC	Use of micropiles for bridge foundations with existing adjacent utilities	Overturns the design of the foundation and the placement method used to drive the micropiles into place	Unchanged, the links between the micropiles and other components and systems are the same as other foundations
Architectural				
7	EEC	Optimized tunnel cross section and utilities within it	Reinforces tunnel design practices	Changed the links with all the tunnel systems allowing smaller and more

#	Project	Description	Changes in Concept	Change in Links
				efficient complementary systems

3.7.3.1 Incremental

Three ATCs were classified as incremental innovations in the DTC, US36 and I4 projects. The use of the T-Wall in DTC was just described. In the US36 case, the selected proponent requested the use of DR 11 HDPE (ATC 10) pipes perpendicular to soil reinforcement to avoid the construction of several manholes and a trunk line in the median. The use of this new pipe for CDOT will allow avoiding the construction of new manholes in the median which according to the proposer provides design challenges given the configuration and are difficult to maintain. While the cost of construction of manholes and the new pipe cancel each other out, this provides substantial potential savings in maintenance costs. This is an incremental innovation that provides a modest improvement in practice that will provide potential savings in maintenance.

The innovation identified in the I4 project requested the use of precast edge beams with deck form curbs (ATC 7 R2), something not used previously in Florida and not specified in FDOT's structures manual and design standards. The ATC used a "FIB (Florida I Beam) pre-stressed beam or equivalent section with a modified top flange that incorporates a curb along the external edge of the exterior girder… a concrete 'curb' would be cast on the edge of the top flange that acts as the deck form and eliminates the need for overhang falsework" (I4, Proposal). According to the selected proponent, the utilization of this incremental innovation will save \$450K in crew time and an additional \$140K in construction, while increasing safety for employees and the traveling public by avoiding the use of falsework on site. This ATC is classified as incremental since it is a modest improvement in practice, but it does not impact links to other activities. It reinforces the practice of using precast concrete elements and makes the instalment of these units safer. This particular innovation could be confused as an architectural innovation, given the changes it provides in the need for scaffolding, but given its modest improvement and that it is localized specifically on the precast element makes it an incremental innovation for the practice.

3.7.3.2 Modular

The I4 project provides an example of a modular innovation. In this case, the winning proposer, submitted an ATC to use maturity meters (ATC 14) to test concrete compressive strength instead of waiting 14 days for testing representative cylinders before opening sections of pavement to traffic. The approved ATC allowed the use "ASTM C1074 (Standard Practice for Estimating Concrete Strength by the Maturity Method) in order to determine the compressive strength of the concrete pavement. Should the Maturity Method show the concrete to have sufficient compressive strength, that section of roadway may be opened to traffic earlier than the planned 14 calendar days" (I4, Proposal). While ASTM 1074 was adopted by ASTM in 1987, it is not adopted by FDOT; their standards require that "test cylinders, made in accordance with ASTM C31 and tested in accordance with ASTM C39, indicate a compressive strength of at least 2200 psi" (I4, Proposal). This ATC is a modular innovation since it represents a shift in the approach in the determination of compressive strength of concrete earlier but with no changes in the links with other elements. The use of this innovation reduced the schedule by ten substantial completion days, which, according to the winning proposer, translates to $1.1million in savings.

The second ATC classified as a modular innovation occurred in the US36 project; it is the use of the American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Pavement Design Guide (MEPDG) (ATC 19). The use of the AASHTO MEPDG, which is not used and allowed in CDOT specifications, is novel. AASHTO adopted the MEPDG in 2007, while CDOT and other state transportation agencies have studied it, Colorado has not adopted it; only seven states have to date. The use of the MEPDG allows a design that fits and adapts better to site-specific characteristics. The use of the MEPDG will provide potential construction cost savings by allowing the reduction in pavement thickness. As with the maturity meters previously discussed, the MEPDG provides a significant improvement in practice overturning the way pavements are designed and allow the use of data for a specific project, but with no changes in the links with other elements of the project. However, while this ATC provides innovation, the prescriptiveness of the owner could inhibit its full potential. The design using the MEPDG determined an 8 inch pavement, a substantial reduction compared to the 11 inch original design. Despite the selected proponent argument to use a 9.5 inch pavement to be conservative, the owner conditionally approved this ATC, requesting the placement of a 10 inch pavement. This shows that owners even allowing the deviations still are conservative.

Lastly, the third ATC classified as a modular innovation occurred in the DTC project. It requested the use of micropiles instead of other foundation types to avoid the relocation of existing utilities and avoid damage to existing structures due to the vibrations that are present while driving piles. In addition, micropiles need a smaller area than drilled shafts, providing a better solution to avoid the relocation of utilities. The RFP indicated that if the bidders wanted to use micropiles they needed to request their use through the ATC process, but currently there are no standards in Kentucky that allow the use of micropiles. The use of micropiles instead of driving piles or using drilled shafts provides a significant change in core concept in the way it has to be designed and placed on site; however, it will be used as any other foundation system, hence there are no changes in links to other components or systems.

3.7.3.3 Architectural

Of the seven identified innovative alternative technical concepts, one was architectural. It is related to the tunnel design in the EEC project. The selected proponent for the EEC project submitted two ATCs related to the tunnel design. The first one requested an optimization of the tunnel cross section and its systems (ATC 14). This was a partially accepted ATC, given several of the items within it were deemed compliant with the technical requirements of the project. This architectural innovation of optimizing the cross section of the tunnel allowed the concessionaire to: "reduce the required liner reinforcement and allow for a more suitable reinforcement size and spacing. Due to the tight constraints in which the reinforcement is to be installed above the formwork, the ATC will improve the construction safety of those placing the material. The increased reinforcement spacing will allow for proper concrete consolidation between the bars and provide a higher quality concrete liner" (EEC, ATC 14). This ATC also optimized the fire suppression system allowing the scope reduction of the ventilation system, which will lower operation and maintenance costs due to lower energy consumption. This ATC provides modest improvements to a core concept, but prompted and required changes in the links with other components of the project.

The second ATC related to the tunnel design was submitted because the optimization of the tunnel cross section was accepted. It requested a change in the position of the portals of the tunnels (ATC 5), shortening the tunnel in the south by 220 feet and in the north by 50 feet, for a total tunnel reduction of 270 feet. Additionally, this ATC requested a reduced pillar width in the south portal from 40 to 35 feet providing improved constructability. The incorporation of this ATC also reduces the size of the fire, ventilation, lighting, and drainage systems within the tunnel. This allowed a deduction on the availability payment of $1.1 million which translates to a net present value of approximately $21 million.

The classification of the identified innovations is shown below in Figure 3.4.

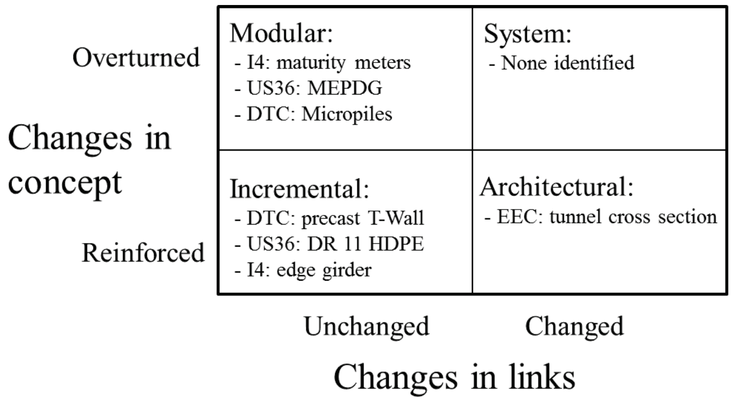

Figure 3.4: Classification of Identified Innovative ATCs (self-created)

3.7.3.4 Value added ATCs

The other 46 ATCs analyzed did not meet the innovation threshold for different reasons; however, they still provided added value to the projects. In several instances the ATCs complied with all elements of the rubric except the novelty aspect to the jurisdiction. This was the case with the use of weathering steel in the EEC project, the use of a roundabout in the EEC project, and the use of high definition CCTV in the I4 project. However, a majority of the identified ATCs highlight the use of value-adding approaches from the private concessionaire/contractor to optimize the preliminary design of the project to reduce the construction of bridges and overpasses by redesigning intersections and saving millions of dollars in construction.

The EEC project provides several instances in which the ATCs while not innovative provided substantial savings by optimizing the design. The use of a two multi-lane roundabouts instead of a crossover diverging diamond interchange (ATC 3) allowed savings from right of way acquisition, construction cost, and time; it will also have lower O&M costs and increase traffic safety. Together, these savings provided a potential reduction of $900K in monthly availability payments (MAP). Another example is the replacement of an 840 feet flyover ramp with a single point interchange (ATC 6) which provided an increase in safer operations and provides saving in estimated MAP of $225K.

Other examples of these types of optimizations are seen in the I4 project. A clear example is the Michigan-Kaley Interchange Realignment (ATC 19); the original design had the roadway going over a relic sinkhole via a flyover. By realigning the roadway and avoiding the relic sinkhole, the concessionaire estimated savings of $39 million and 36 days on substantial completion. ATC 26R1 is another case in which the private sector provided savings by optimizing the original design. This ATC allowed the reduction of 120 feet in the length of a bridge and allowed a road reconfiguration that avoided the encroachment of the roadway to a pond. This provided potential savings of $11 million and 23 days on substantial completion. In total, the 25 ATCs submitted by the selected proponent of the I4 project potentially saved the state of Florida $113 million from the original budgeted cost and provided $26 million of new construction not previously scoped in the RFP with the incorporation of new general purpose lanes and new connections.

3.8 Discussion

The framework proposed in this research is built on prior work by Slaughter (2000), Russell et. al. (2006), Hartmann (2006), Gambatese and Hallowell (2011b), and Garvin and Jolley (2013). Application of the framework illustrates its utility as a means to identify and classify technical innovation in infrastructure projects. Other researchers can employ, corroborate and critique the findings presented, which was a fundamental objective of this work. Moreover, the framework can clarify researcher perspectives and mitigate researcher bias (Leydens et al., 2004) since it requires the: (i) assessment of all elements and (ii) the classification of types of technical innovation, as defined. This was experienced in the conduct of this investigation when one of the raters involved in this work did a preliminary review of a sampling of the ATCs, unaided by the framework. This rater indicated that several of the ATCs appeared innovative. After employing the framework, though, the rater did not reach the same conclusions. These features of the framework differentiate it from prior research (Leiringer, 2006; Gambatese and Hallowell, 2011b; Antillon et. al. 2016) as a tool to assess technical innovation.

Indeed, the inter-rater testing done confirms the framework's internal validity and reliability; however, this does not mean that it can absolutely identify and classify technical innovation in infrastructure projects. In other words, the raters produced consistent results, but the results are not necessarily "correct". This issue can be addressed via convergent validity testing, i.e. employing another method or technique, to achieve comparable results. For instance, an expert panel could review the ATCs to identify and classify them. This is potential area for future research, which could not only provide convergent validity, but it would also deepen insights about perspectives of innovation in infrastructure projects. The potential that the results are incorrect, however, is tempered by the framework's application to ATCs. The ATC process is a mature method used during the procurement of infrastructure projects in the US; its express purpose is to provide respondents the opportunity to submit deviations from the established technical baseline. The process requires submission of documentation and approval by the procuring agency. This research utilized the publicly available documentation for approved ATCs in all four projects; hence, the data was similar in structure and content, facilitating objective appraisal.

Still, agreement among the raters, while very strong, was not absolute (as depicted in Table 3.3). Further, the raters were unable to agree on the type of innovation for an ATC identified as innovative in the I4 project – the use of a precast edge girder (Figure 3.5). One rater viewed this ATC as incremental innovation while the other considered it architectural; the disagreement was based on the links to other components and systems. One argued that the changes only existed in the girder itself whereas the other argued that changes in the girder necessitated changes in the way that the girder connected to the concrete barrier wall. After discussion with the supervisor, the innovation was classified as incremental since the connection between the concrete barrier wall and the concrete decking would have likely had a cold joint with or without the change to the edge girder. This situation highlights the known difficulties of assessing innovation (Henderson and Clark, 1990; Leiringer, 2006; Gambatese and Hallowell, 2011b). Regardless, the framework forced the research team to carefully consider the characteristics of the ATC to identify and classify it as a technical innovation. Additional information from either the public or the private sector would have helped in this assessment.

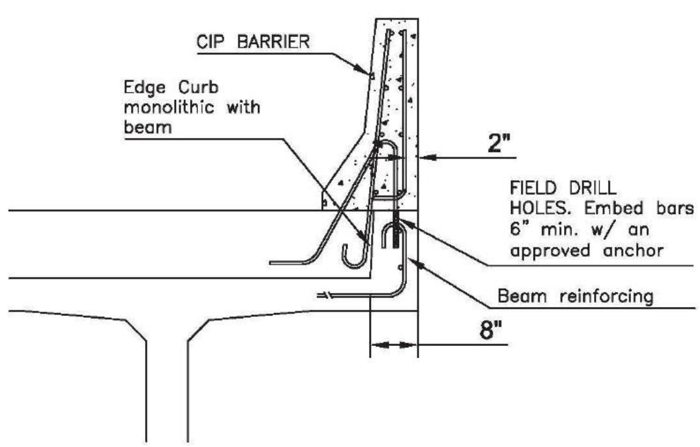

Figure 3.5: Edge Girder Detail (FDOT, 2014)

In addition, several ATCs in the P3 projects illustrated that the bundling of lifecycle phases generates deviations that focus on improving operations and maintenance. For instance, in the EEC project, an ATC eliminated the construction of a new bridge since an alternative access road was being provided by the winning proposer. This not only reduced the construction cost, but it removed the need to maintain the bridge. In the same project, the request to use weathering steel instead of painted structural steel avoided the expensive cost of repainting the structural elements of the bridge. In the I4 project, the winning proposer included an ATC that used power generators for the tolling system and ITS instead of using separate generators for both. This provided both upfront and maintenance cost savings. In the US 36 project, the RFP requested the removal of on-site material for a more permeable new material in the construction of a bicycle path. The winning proposer requested treating the on-site material since the use of the new permeable material would have created a "bathtub" effect with the clay on-site. This certainly avoided future operational problems.

Certainly, this research has additional limitations. The framework was only applied to the ATCs submitted and approved by the winning bidders in four projects; application to additional ATCs and projects would enhance its veracity. This is somewhat easier said than done, however. Requests were made to receive the ATCs from losing bidders in the four projects examined, but procuring agencies did not provide them, citing confidentiality concerns. Further, the documentation associated with ATCs is considerable, so assessing a larger set of projects would involve far more time and resources. Consequently, four projects and 53 ATCs were judged sufficient to test and demonstrate the framework. Moreover, the four projects are quite representative of large-scale infrastructure projects in the US highway market in terms of scope, contract value, and project delivery models. Finally, this work did not account for factors in each project's environment that may have influenced the number of ATCs submitted or approved. This was outside the scope of this investigation since the goal was not to look into causal factors or deem a project more or less innovative than another; however, such a study would be an interesting line of future investigation.

3.9 Conclusion

This research addresses the need for a replicable and verifiable framework to: i) identify, ii) classify, and iii) assess innovation in infrastructure projects. We build upon prior work in innovation and construction to propose an innovation definition and an innovation assessment rubric that can be used by other scholars to appraise innovation in infrastructure projects. The use of this framework will allow scholars to have clear and transparent conclusions that can be easily corroborated (or challenged) by other researchers.

To demonstrate the framework, a total of 53 ATCs were analyzed. Of these, only seven have been identified as innovative. Several of the ATCs originated from prescriptive language in the RFPs. For example, instructions to proposers for I4 stated: "Any concept that deviates from the Basic Project Configuration must be the subject of an ATC" (I4, RFP). This is an explanation for the higher number of ATCs that were submitted for this project. Although, a majority of the analyzed ATCs, 87% (46/53) were not classified as innovative, they do still provide value. This is clearly seen in the I4 project ATCs. The ATCs submitted to I4 demonstrate that the private sector can bring value by optimizing the designs and construction of public infrastructure.

The seven ATCs identified as innovative highlight the occurrence of innovation in P3 projects, albeit limited. Although no system or radical innovations were identified, other types of innovations were uncovered in these projects. Future research will explore the potential diffusion of these innovations and if other innovations are present as a consequence of performance based specifications and not necessarily outcomes of an ATC process.

The developed framework provides the infrastructure and construction community with a replicable approach to assess and classify technical enhancements in projects to determine whether they are innovative and if so what type of innovation. The framework is systematic and transparent, so it allows corroboration of findings and can be utilized by future researchers. Additionally, this investigation contributes to the body of work on innovation in P3s by providing new findings of a market that has not been studied in depth. Further, this research provides information to practitioners, that engaging the private sector creates more value so than innovation. The clear identification of innovations will allow the study of specific innovations and identify how they diffuse through the network of organizations. Further, examining future projects in same public agencies or by same private participants could pinpoint examples of diffusion.

4 Chapter 4: Influence of Project Characteristics on Technical Innovation and Value Creation in P3s: Evidence from US Highway Case Studies[6]

4.1 Abstract

Private sector innovation and creativity are touted as key benefits of public-private partnerships (P3s). Scholars and governments alike have devoted significant attention to P3s and innovation. However, research to date examining innovation in P3s has reached alternative conclusions; moreover, the US market in this context is largely unexplored. In order to assess innovation is occurring in United States (US) P3s and the influence that project characteristics have on it, six transportation P3 projects in the US were chosen as cases: i) East End Crossing in Indiana, ii) Elizabeth River Tunnels in Virginia, iii) 1-4 Ultimate Improvements in Florida, iv) 1-77 HOT Lanes in North Carolina, v) North Tarrant Express 3AB in Texas, and vi) SH-288 Toll Lanes in Texas. Four project characteristics were explored to better understand their influence on P3 innovation; i) the procurement approach, ii) project type, iii) payment mechanism, and iv) client. Consequently, innovation was uncovered in the cases, but minimally so. Further, the coupling of demand risk payment mechanism and project type influenced the generation of technical enhancements that provided added-value. Other notable value-added improvements proposed by private consortia were found in all six cases.

4.2 Introduction

Innovation is a claimed benefit of Public-Private Partnerships (P3s) and an important ingredient in the Value for Money (VfM) philosophy. While both government and private companies' documents in the United States (US) tend to expect innovative outcomes, they do not subsequently provide much evidence of such. For instance, "FDOT expects structuring the Project procurement as a PPP [P3] will…allow FDOT and the traveling public to benefit from lifecycle cost optimization and technical innovation from industry" (FDOT, 2007, p. 93). However, ensuing documentation of these benefits is extremely limited, although private

[6] González, E. E., and Garvin, M. J. (2017). "Influence of Project Characteristics on Technical Innovation and Value Creation in P3s: Evidence from US Highway Case Studies." *Journal of Construction Engineering and Management*, (in preparation).

companies do on occasion prepare briefs or presentations that highlight outcomes such as cost savings (Saenz de Ormijana and Rubio, 2015a).

Previous academic research exploring P3 innovation is also somewhat scarce, and the studies done are generally outside the US market. Further, past research has produced mixed results (Gonzalez and Garvin, 2016). For instance, researchers have essentially explored the relationship between the same set of factors and innovation outcomes, but their findings are contradictory; Leiringer (2006) argued no or limited innovation was uncovered, while Rangel and Galende (2010) indicated innovation was present. In addition, several studies investigating P3 innovation are vague in their methodological approach toward its assessment. Given the weight placed on innovation in P3s as both a benefit and a justification of implementation, more research on this topic is needed.

Prior research (Gonzalez and Garvin, 2017) identified factors influencing innovation in infrastructure projects. These factors guided a multiple case study design of P3 projects to investigate P3 innovation further in the US P3 highway market. A multi-step framework developed by Gonzalez et al. (2017) allowed the identification and classification of innovative technical enhancements in the case study projects while the case study design supported the appraisal of project characteristics on innovation. The cases explored enhance our understanding of how project characteristics influence technical innovation in P3 projects. Consequently, this research: i) generated additional evidence on this topic and ii) explored a market that to date has received limited attention in this area.

4.3 Innovation in Construction and P3s

4.3.1 General

Freeman (1974) indicated that we owe the distinction between inventions and innovations to Schumpeter. Where "invention is an idea, a sketch or a model for a new or improved device, product, process or system…An innovation in the economic sense is accomplished only with the first commercial transaction involving the new product, process, system or device". Schumpeter (1912/1934) indeed claimed that inventions are economically irrelevant as long as they are not implemented and to do so a different set of skills is required than to invent them. Freeman (1974) explained innovation has two stages. First is recognizing a need for a new product or process and second is employing the technical knowledge necessary to fulfill the identified need. Roberts

(1988) also argued technological innovation can alter the competitive status of companies and nations but its management is complex and requires the integration of people, processes, and plans.

4.3.2 Innovation in construction and infrastructure

In the context of construction, Nam and Tatum (1992) subsequently pointed out that under a conventional delivery approach where participants are segregated from one another, designers are reluctant to innovate, fearing that contractors will either refrain from bidding or will submit high bid prices. Winch (1998) argued this segregation between the actors involved in the design and constructions phases is one of the greatest barriers to innovation. Hence, the long term nature of P3 contracts should allow lifecycle integration through the bundling of activities. Roumboutsos and Saussier (2014) supported this perspective explaining that the long term nature of a P3 contract increases the potential for innovation given the higher incentives for investment. The private partner will have a drive to find innovations that will generate reductions in maintenance and operation. Uyarra et al. (2014) further argued that having longer contracts allows the reduction of uncertainty because it allows the private partner to accrue its return over a longer time horizon and invest in innovation. According to Mahoney et al. (2009) a central tenet behind P3s is the search for economic value creation and innovation. Expanding on this, Hoppe and Schmitz (2013) argued that the incentives for innovation are higher in P3s than in traditional deliveries, but more importantly they questioned which factors are driving or inhibiting innovation.

4.3.3 Innovation factors in infrastructure and P3s

The literature examining factors that act as barriers and enablers for the occurrence of innovation in infrastructure projects is rich. In particular, numerous authors (e.g., Tatum, 1984; Blayse and Manley, 2004; Bossink, 2004) have examined the factors, either enablers or inhibitors, of innovation in the construction industry, but this literature is fragmented. For instance, some research (Gambatese and Hallowell, 2011a) has explored leading indicators like: owner influence, innovation champions, collaboration, and integration; while other research (Gambatese and Hallowell, 2011b) has focused on motivating factors such as: cost, productivity, and market share; while others (Tatum, 1984) have studied both. In addition, some authors have studied such factors in the context of P3s (Eaton et al., 2006; Russell et al., 2006); however, the relative significance of innovation factors within P3s has received limited attention.

Consequently, Gonzalez and Garvin (2017) completed an extensive review of the literature to identify factors that may impede or stimulate innovation in infrastructure project settings. These factors were placed into categories ranging from client characteristics to procurement processes. Further assessment of the literature distinguished categories most often linked with P3 outcomes such as innovation. Five categories were identified as particularly influential in P3 project settings: procurement processes, specifically the use of performance based specifications instead of prescriptive ones; the influence of lifecycle on design; client characteristics, particularly the client's openness, culture, and experience; risk profile, with traffic risk taking a prominent role; and project type, especially the complexity and scale of a project.

As mentioned previously, a commonly held view is that the integration of designers and contractors promotes innovation; the literature also indicates that integration of lifecycle activities enhances innovation potential. Raisbeck (2009) argued that the transfer of design risk is an important source of innovation in P3s because different facets of the asset life cycle are incorporated into the design and savings are possible through the incorporation of maintenance and operation cost reductions with a more efficient design. Others reinforce the influence of the lifecycle on design as a driver of innovation, allowing the incorporation of construction, maintenance, and operation cost reductions with a more efficient design, e.g., "interdisciplinary coordination within the design team" (Tatum, 1984), design involvement of contractors allowing construction input during design (Goodrum and Haas, 2000; Ozorhon et al., 2016). Ball et al. (2000) described innovation as a key feature of the Private Finance Initiative (PFI) and as one of the key advantages of the approach over traditional procurement methods. They explained that advocates and promoters of the PFI indicated that although private finance is more expensive, this should be offset by private sector innovations in design and operational management. Interestingly, Kline and Rosenberg (1986), argued that innovations have been brought forward even when the "science is inadequate, or even totally lacking". They highlighted how contrary to common wisdom, the first step to an innovation is not research, but design, "usually either inventions or analytic design" (p. 302). Where they describe analytic design as: "a study of new combinations of existing products and components, rearrangements of processes, and designs of new equipment within the existing state of the art" (p. 302).

Second, a driver of innovation in P3s is the use of performance or output specifications in procurement. Ball et al. (2000) found that an output specification approach was crucial for promoting innovation. Allowing the private partner to have the ability to use its creativity, and propose a solution to the government will be a key enabler of innovation. Having output specifications is essential for design flexibility and increases the potential for innovation, while in the other hand, prescriptive specifications are seen as barriers to innovation (Tatum, 1984; Eaton et al., 2006; Uyarra et al., 2014). Russell et al. (2006) argued that having too stringent requirements also could act as a barrier to innovation, they say the following: "stringent requirements and constraints can limit competition or increase the risks and penalties associated with novel technologies and therefore inhibit innovation" (p. 1526).

Lastly, the project type and scale is seen as a driver of innovation (Russell et al., 2006). Russell et al. (2006) argued a higher potential of innovation in heavy civil projects than in vertical construction projects because of project size, scope, and complexity. A similar argument could be said for the payment mechanism in a P3 project that is demand risk vs. an availability payment (AP) P3 project; Jolley and Garvin (2014) stated: "There is very little, if any, incentive for concessionaires to propose changes to a conceptual design that increases the potential for demand if they do not receive any benefit from increased toll revenue—in AP PPPs [P3s]" (p. 11). Other authors (Blayse and Manley, 2004; Miller et al., 2009) point to the nature of construction projects as a factor of innovation. For example; usually, infrastructure is expected to have long service lives, this puts pressure in the industry to use "tried and tested" solutions instead of innovative approaches (Blayse and Manley, 2004). Uyarra et al. (2014) explained how a project contract not been "big enough" can act as a barrier to innovation, they explained how larger firms are sensitive to the scale of the projects and having a "too small or too short public contracts may act as a strong disincentive to innovation."

Other authors have also identified aspects of P3s that act as barriers to innovation. One is the continuation of traditional roles; Nam and Tatum (1992) mentioned that among the barriers that prevent integration is the inertia of traditional roles; for example, the reluctance of designers to receive input from construction personnel or governmental personnel treating a P3 as a traditional procurement (Eaton et al., 2006). Additionally, by not wanting to adapt to new processes and products, and having a "strong reliance on past experience" (Miller et al., 2009) innovation could be inhibited. A second inhibitor of innovation is the difference in culture between public and private partners. Barlow and Koberle-Gaiser (2008) mentioned the difference in culture between public and private parties hinders innovation, since interviewees in their study saw a "public sector mentality" that did not allow them to "think outside the box." But this can happen as well among the different member companies that comprise special purpose vehicle (SPVs) or joint ventures (JVs) that pursue projects. Blayse and Manley (2004) and Liu et al. (2016) indicated that the innovation culture of the companies involved as an important driver of innovation; Pellicer et al. (2014) and Ozorhon et al. (2016) also emphasized the impact of organizational culture.

Lastly, the organizational structure or the legal entity created by the equity holders of a project for the development and exploitation of the asset, or the SPV, is seen as a factor of innovation. Davies and Salter (2006) in their examination of SPVs said they have created a "moveable feast" given the subcontracting that is done in the different stages of the life cycle. They argued there is less evidence for a new model of innovation; the government has just shifted the separation of design, construction, and operation from them, to the private sector without higher integration. They indicated that P3 SPVs tend to fragment as a risk allocation and transfer strategy. Hobday (1998) indicated that all else equal (*ceteris paribus*) increasing the amount of companies involved in the delivery of a product makes coordination more complex. As mentioned by Jones and Saad (2003), an inappropriate organizational structure is a barrier to innovation. Given the arguments about SPVs by Hobday (1998) and Davies and Salter (2006), SPVs could be acting as an inappropriate organizational structure for the promotion of innovation.

4.3.4 Prior work examining innovation in P3 projects

Given the literature scrutinizing innovation in construction/infrastructure and more specifically P3s, some archival literature has explored innovation outcomes in P3 projects (Leiringer, 2006; Eaton et al., 2006; Russell et al., 2006; Barlow and Koberle-Gaiser, 2008; Rangel and Galende, 2010; Antillon et al., 2016; Himmel and Siemiatycki, 2017); these seven papers: i) performed empirical studies of innovation in P3 projects and ii) studied projects that were at least under construction or in operation. Consequently, they are indicative of the current baseline understanding of innovation in P3 projects and present findings of innovations that were actually implemented in P3 projects. Each was examined to uncover the article's: (1) motivation, (2) approach for defining and assessing innovation, and (3) findings and conclusions.

4.3.4.1 Research motivation

Leiringer (2006) built upon construction and mainstream innovation theory indicating that several publications that promote P3 innovation were based in "anecdotal evidence and wishful thinking" (p. 303). Exploring some of the claims for the use of P3s, he focused on four arguments that are prominent in the P3 literature for promoting innovation: improved design freedom, collaborative working, risk transfer, and long-term commitment. He highlighted government reports that mention that private sector innovation in P3s aims to achieve VfM. Eaton et al. (2006) based their research on "social and contextual factors that influence the creative and innovative [behavior] of individuals in construction organizations within the limited and constrained context of the PFI" (p. 64). Russell et al. (2006) described how the P3 model is considered a mode of infrastructure acquisition that taps the innovative capacity of the private sector. Part of the motivation for their study was to examine whether the common argument that the higher cost of financing and procurement are outweighed by private sector innovation.

Barlow and Koberle-Gaiser (2008) indicated that governments have argued that PFI stimulated innovation from the private sector. To explore this, they used a framework that combines concepts of 'complex products and systems' (CoPS) and 'large technical systems' (LTSs). Rangel and Galende (2010) cited literature that argues that innovation can enable the private sector to provide more cost-efficient services and based their research on the Organization for Economic Co-operation and Development (OECD) Frascati manual for analysis of R&D activities and the Oslo manual for analyzing other innovative activities. Antillon et al. (2016) based their research on the 'promise' that P3s provide cost-saving innovations during the DB phase of the projects. In order to explore this argument, they employed "the lens of innovation theory" (p.1) using Henderson and Clark's (1990) work as a foundation. Finally, Himmel and Siemiatycki (2017) explained that the lack of empirical evidence in the literature supporting populist arguments from practitioners that innovation is provided in P3 projects motivated their research.

4.3.4.2 Approach for defining and assessing innovation

Leiringer (2006) utilized the OECD definition of innovation: "Technological product and process (TPP) innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes" (p. 303). There is no clarity in the approach taken to assess innovation in this paper, besides the participatory observations performed and the data collected from the projects by the author. Eaton et al. (2006)

defined innovation as "the successful implementation of creative ideas; for something to be classified as creative it has to be novel to only the unit of adoption be it the individual, project team or organization" (p. 66). They utilized survey data to assess the drivers and inhibitors found on P3 projects. Russell et al. (2006) defined innovation "as the use of advanced technologies, methodologies, and creative concepts that result in a positive incremental change in basic project performance metrics. Metric concept includes time, cost, revenue, quality, scope and capacity, safety and environmental impact" (p. 1523). They assessed the innovations as product, process, organizational or financial. Barlow and Koberle-Gaiser (2008) defined innovation as design innovation, in the sense of physical adaptability, the "ability of a building to economically accommodate future changing requirements" (p. 1392). They used a framework that combines concepts of 'complex products and systems' (CoPS) and 'large technical systems' (LTSs). Rangel and Galende (2010) defined innovation according to the OECD Oslo Manual; "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (p. 50). They also used survey data to assess the occurrence of innovation.

Antillon et al. (2016) defined innovation as the "implementation of a new or significantly improved technological change, in product or process design, that strategically benefits or improves the long-term lifecycle performance of a project" (p. 3). Once identified as an innovation, they used the level of change and the impact on components of the project in order to classify the impact of the innovation. Although Himmel and Siemiatycki (2017) discussed the definitions of innovation used in other works in the innovation literature, the definition they used in their analysis was the one used by Infrastructure Ontario: "evolutionary novelties that raise the quality of the built structure, improve user efficiency and lower cost" (p. 8). They measured innovation in the projects using two indicators: i) variability on evaluation scores between bidders, where a bigger variability will indicate innovation; and ii) the difference between the winning bids cost and the original budgeted cost by Infrastructure Ontario, where a bigger difference highlighted higher innovation in the project.

4.3.4.3 Findings and conclusions

Leiringer (2006) found that P3 construction contracts were written in a "stringent" fashion, so their structure inhibited innovation. He also observed that the literature states that innovation and risk go hand-in-hand, and innovation brings uncertainty. He concluded that the common arguments that promote innovation in P3s – improved design freedom, collaborative working, risk transfer, and long-term commitment – are questionable. Eaton et al. (2006) found that construction companies want to innovate given the pressure they receive from clients to reduce costs and accelerate construction. Their results indicated innovation was largely unrealized. They found that the amount of impediments surpassed the stimulants, thus stifling innovation. Russell et al. (2006) identified 22 factors that might act as drivers or inhibitors of innovation in P3s. Their evidence was more anecdotal and not significantly founded on documentation; hence, they were unable to make strong conclusions about the presence of innovation. Barlow and Koberle-Gaiser (2008) uncovered two potential factors that affected innovation in PFI projects; first, the use of the public sector comparator (PSC) created pressure to drive cost down and hence reduced innovation, and second, the difference in culture between public and private parties hindered innovation, since interviewees in their study saw a "public sector mentality" that did not allow them to "think outside the box."

Rangel and Galende (2010) proposed a model to study four characteristics in P3 contracts that could promote innovation: i) type of risk assumed by the private party, ii) transfer of design responsibility, iii) provision of penalties against private party, and iv) competition between bidders. Their results showed significant relationships between research and development (R&D), an influential factor for the promotion of innovation, and three of the characteristics: type of risk assumed by the private party, provision of penalties against private party, and competition between bidders. They suggest that further studies are required to determine if these or other characteristics affect commercial or organizational innovation. Antillon et al. (2016) uncovered innovation occurring in P3 projects and concluded that contract timing has an influence on the amount and level of innovations that can occur in P3s. Himmel and Siemiatycki (2017) found cost-saving solutions are favored by the private sector given the innovation incentives present; the innovations that occur were mainly incremental in nature, and they sought to find the "most efficient design for the project" (p. 14) and focus on new construction methods or technologies.

4.3.5 Summary

Prior research has pointed to several factors that may drive or inhibit innovation. Stimulants of innovation in P3s include: integration of design, construction, and O&M (Tatum, 1984; Eaton et al., 2006; Uyarra et al., 2014); having the correct set of incentives during the procurement

(Hoppe and Schmitz, 2013); procurements that use performance or output specifications instead of prescriptive specifications (Tatum, 1984, Goodrum and Haas, 2000; Ozorhon et al., 2016); and the project type and payment mechanism (Russell et al., 2006; Jolley and Garvin, 2014). Other factors act as barriers to innovation: the continuation of traditional roles (Nam and Tatum, 1992; Eaton et al., 2006; Miller et al., 2009) and the organizational structure used (Davies and Salter, 2006). Interestingly, Raisbeck (2009) argued that the transfer of design risk is an important source of innovation, but Leiringer (2006) concluded that the argument for improved design freedom is questionable.

While definitions of innovation were provided in the paper set specifically studying innovation in P3s, the approaches taken to assess innovation in P3 projects varied in their transparency and clarity; in other words, replication of their findings would prove challenging. While Antillon et al. provided a general framework; other studies (such as Leiringer, Barlow and Koberle-Gaiser, and Rangel and Galende) were less clear about how they assessed the occurrence of innovation.

Further, four of the seven studies (Leiringer, Eaton et al., Russell et al., and Barlow and Koberle-Gaiser) did not uncover or uncovered limited innovation while the remaining three (Rangel and Galende, Antillon et al., and Himmel and Siemiatycki) found innovation. Numerous authors have argued that innovation is a key value driver for P3s; yet, the research examined here provides mixed results and the US market is not studied in depth.

4.4 Point of Departure

Innovation is viewed as integral to the value proposition of P3s. The archival literature that has explored innovation outcomes in P3 project settings has produced mixed results regarding the occurrence of innovation, and these studies have posited various factors that have potentially influenced such outcomes. Moreover, the number of studies examining innovation in P3s is quite limited; this is surprising given the emphasis innovation receives in the overall VfM equation. Further, research focused on the US market is minimal. Accordingly, further investigation of this issue is essential to both advance the state of knowledge and to provide evidence for interested stakeholders, i.e. the general public and legislators, of whether the technical innovation that P3 advocates and theorists are promising is occurring and which project characteristics are influential. The mixed evidence, the need to better understand the influence of project characteristics on technical innovation, and the limited exploration of the US P3 market motivate the following questions:

- **What types of technical innovation are found in US P3 projects?**
- **How are project characteristics influencing technical innovation in P3 projects?**

4.5 Methodology

A multi-case study approach was adopted to determine the types of innovation found and to assess the influence of key project characteristics on P3 project innovation. According to Yin (1994) and Taylor et al. (2011), special attention is needed in the selection of the units of analysis and the cases to ensure they are relevant to the questions being studied. The technical enhancements proposed in P3 projects are the unit of analysis for this study. This research focused on identifying technical innovations submitted though established alternative technical concept (ATC) processes or as technical enhancements allowed in the project's baseline specifications. Technical enhancements are either: (1) improvements included in a respondent's proposal which are allowed by a project's RFP (since they likely comply with the RFP's specifications or conform with current standards and practices) or (2) ATCs submitted by bidders as part of a formal process to request deviations from an RFP's or prevailing standards and specifications. Several ATC documents state that the purpose of the ATC process is to promote private sector creativity and innovation.

4.5.1 Case study selection

Yin (1994) explained how case studies must be carefully selected so the set "(a) predicts similar results (a literal replication) or (b) produce contrasting results but for predictable reasons (a theoretical replication)" (p. 46). Consequently, a deliberate process was followed to select the cases for this research. The case selection process began by defining P3s since a universal definition remains elusive. Garvin and Bosso (2008) proposed that "a P3 is a long-term contractual arrangement between the public and private sectors where mutual benefits are sought and where ultimately (a) the private sector provides management and operating services and/or (b) puts private [equity] at risk" (p. 163). Using this definition, then the contemporary US P3 highway project universe is 28, considering projects from 1993 to the present that have reached financial close. Projects implemented in the 1990's that are atypical of the current US P3 market and leases of brownfield assets where significant design & construction stages are limited were discarded. Similarly, projects that were not currently under construction were also discarded since activities or circumstances that might influence innovation are likely not easily recalled by human subjects or are undocumented.

From the remaining projects, innovation factors identified in the literature guided the selection of cases. While numerous factors were identified, the following were selected for their explanatory potential: i) *procurement approach*: competitive vs. non-competitive; ii) *public sector client*: leading vs. lagging[7]; iii) *project type*: fixed crossings vs. managed lanes; and iv) *payment risk*: demand (tolls) vs. availability payments (AP). Table 4.1 presents the cases selected based on the four factors identified along with additional relevant information. The project set contains the two predominant P3 project types in the US, managed lanes and fixed crossings as well as projects ranging in scale from $655 million to over $2 billion in contract value. The data set also contains alternative procurement approaches and payment risk mechanisms used in the US P3 market. Consequently, these cases are representative of recent US P3 projects.

Table 4.1: Selected Case Study Projects

Factors / Projects	Financial close	Jurisdiction	Client	Project Type	Scale (Contract Value $100K)	Procurement Approach	Payment Risk
I-77 HL Charlotte (I77)	May 2015	North Carolina	Lagging	Managed Lanes	655	Competitive, but only one bidder submitted a proposal for the project	Demand Risk
N. Tarr. Exp. 3A&B (NTE)	September 2013	Texas	Leading	Managed Lanes	1,350	Predevelopment agreement	Demand Risk
SH 288 Toll Lanes (SH288)	May 2016	Texas	Leading	Managed Lanes	800	Competitive	Demand Risk
I-4 Ultimate Imp. (I4)	September 2014	Florida	Leading	Managed Lanes	2,323	Competitive	Availability Payment
East End Crossing (EEC)	March 2013	Indiana	Leading/ Lagging	Fixed Crossing	763	Competitive	Availability Payment
Elizabeth River Tunnels (ERT)	April 2012	Virginia	Leading	Fixed Crossing	2,100	Predevelopment agreement	Demand Risk

[7] A leading state is one in which at least three projects have reached financial close in the previous two decades (2001-2010 and 2011-present). A lagging state is one in which less than three projects have reached financial close.

4.5.2 Replication logics

Replication is an essential element of case studies. The cases chosen have similarities and variances across the dimensions selected. Jurisdiction and client vary across four of the six cases, so this dimension addresses a rival explanation, i.e. jurisdictional or client issues impact outcomes; if outcomes are consistent regardless of jurisdiction and client, then this enhances the ability to generalize.

Two replication sets exist among the cases:

1. Managed lanes projects: I77, NTE, SH288, and I4 are the same *project type* with one difference in *procurement approach* (NTE was non-competitive) and one difference in *payment mechanism* (I-4 is AP);
2. Fixed crossing projects: EEC and ERT are the same *project type*, with variance in *procurement approach* (competitive vs. non-competitive) and *payment mechanism* (demand risk vs. AP).

The similarity among the first set, the managed lanes projects, supports literal replication, so one would expect to find similar outcomes in these cases; however, the slight differences also enables some explanatory potential. The differences in the second set, the fixed crossings, offers greater explanatory potential, although the similarity in project type may mitigate this to some extent.

4.5.3 Data collection & analysis

Data was drawn from project documentation that included the request for qualifications (RFQs), request for proposals (RFPs), ATC submittals, technical standards, and the winning bidders' proposal for the six projects. Semi-structured interviews of 23 public and private sector participants with direct knowledge of the case study projects supplemented the project documentation; the interviewees had on average 26 years of experience in the industry. Participants from the private organizations held positions such as bid directors, project SPV CEOs, and project development/sponsor technical directors. Public participants were personnel directly involved in proposal evaluations and negotiations as well as review and approval of ATCs. The technical enhancements identified were proposed by concessionaire teams; these were assessed to determine project-level value creation and innovation as well as how project characteristics influenced innovation. The enhancements were either submitted in compliance with the project's specifications or submitted and accepted through each project's defined ATC process.

A multi-step rubric developed by Gonzalez et al. (2017) was employed to assess whether each technical enhancement generated value and qualified as an innovation; the rubric was based on prior work by Slaughter (2000), Russell et. al. (2006), Hartmann (2006) and Gambatese and Hallowell (2011b). The foundation of the multi-step rubric is the definition of innovation adopted:

> *"Innovation is the actual use of a nontrivial change and improvement in a process, product, or system that is novel" (Slaughter, 1998, p. 226) "to the company developing or using it" (Slaughter, 2000, p. 2); and has the "potential of solving problems" (Hartmann, 2006, p. 572) or has the potential to diffuse "beyond just the initial project" (Gambatese and Hallowell, 2011b, p. 556).*

The rubric first employed a binary assessment of the following elements:

- Actual use - Was it applied in the project?
- Nontrivial - Does it entail more than a scope or cost reduction in the project?
- Change - Does it deviate from current practice and standards?
- Improvement - Does it provide a positive change?
- Process, product, or system - Does it entail a new process, product or system?
- Novel - Is it novel to the jurisdiction, client, or company?

This was done to differentiate between enhancements that solely generate value versus those that generate value *and* qualify as innovative. Technical enhancements can provide added "economic, functional, or technological value" (Dikmen et al., 2005, p. 81). This is achieved by lowering construction costs, providing schedule savings, improving quality, increasing safety, or reducing environmental impacts. The beneficiaries of this added value include the owners who benefit from faster substantial completion dates, lower costs of construction, and higher quality. Consequently, users and society in general benefit from this as well as the productivity of the region is increased by having new connections that allow faster delivery of goods and the allocation of savings towards the construction of new infrastructure. This in turn provides companies with competitive advantages and higher profits. Users and society in general also benefit from this added value by having assets built with safer construction practices and that are environmentally friendly.

An enhancement deemed innovative was then evaluated to determine its degree of change in both core concepts and system linkages as shown in Figure 4.1. This framework is adapted from prior work by Henderson and Clark (1990), Slaughter (1998), and Slaughter (2000). For example, an enhancement that reinforces core concepts and does not alter system linkages was classified as an incremental innovation whereas one that transforms core concepts and system linkages was classified as a system innovation. A modular innovation is a more significant improvement with a modification of core concepts but no changes in the links between other components of the project. An architectural innovation is one in which a small improvement in a core concept occurs, but prompts changes in the links between other elements or systems of the project. Interviewees were first generally queried about their views of the project characteristics that had influenced innovation in each case; probing questions further inquired about aspects such as the procurement stage, interactions between public and private partners, and technical enhancements submitted; these perspectives were substantiated with project documentation.

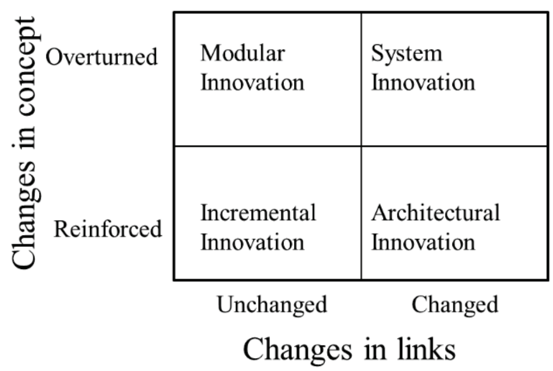

Figure 4.1: Framework to Classify Innovation

(adapted from: Henderson and Clark, 1990 and Slaughter, 2000)

4.5.4 Within case and across case analysis

All the project documentation previously mentioned was collected for each case. Review of these documents allowed better understanding of the projects. The RFPs gave insights into ATC processes followed. Review of the winning bidders' proposals identified some of the technical enhancements that were proposed by some bidders and found compliant with the RFP for competitive procurements or negotiated to comply with public agency expectations for non-competitive procurements; the remainder were submitted through the procurement's prescribed ATC process. The ATC submittals and the project technical standards provided deeper insights into the deviations submitted. Interviews with public and private sector participants with direct knowledge of the projects reinforced and expanded the information found in the project documentation. Interviewees were queried about the technical enhancements and ATCs and their views of the project characteristics and how they influenced both value and innovation. For example, one of the questions was the following: "What factors or aspects of the project's characteristics impeded or promoted creative solutions or innovation in {project}?" Further questions probed their answers. Together, project documentation and interview data was then analyzed to identify technical enhancements and assess if they met the threshold of innovation and to identify the project characteristics that had influenced value creation and innovation. Once all the cases were analyzed across case analysis was performed to identify strong and weak coupling of characteristics that influenced value creation and innovation.

4.5.5 Validity and reliability

This study took multiple steps to enhance validity and reliability. Taylor et al. (2011) emphasize three types of validity in case study research: i) construct validity, ii) internal validity, and iii) external validity. First, construct validity entails "establishing correct operational measures" (p. 306); for this, a clear research protocol was followed, which subsequent studies can replicate in the future. Proper operational measures were established such as using multiple sources of evidence: interviews with different private and public participants, descriptions of project-specific innovations, procurement and contract documents, and alternative technical concepts submitted. The careful specification of data collection and subsequent analysis procedures controlled for reliability. Second, internal validity and potential generalizability was reached by "establishing credible causal relationships" (p. 306). This was achieved by having a multiple case study design with literal and theoretical replications: four very similar managed lanes projects and two fixed crossings with specific differences. The chain of evidence related to technical innovation was constructed by establishing a unit of analysis appropriate for the research questions, designing a data collection and analysis approach to examine the unit of analysis, and within and across case assessment to gain insights about the influence of project characteristics on value creation and innovation. Consequently, this allowed the formulation of several propositions. Moreover, rival explanations were considered to strengthen the findings. Lastly, the external validity, which entails "establishing the domain where results may be generalized" (p. 306) was achieved by connecting research outcomes with existing literature.

4.6 Case Studies

The analysis of project documentation and interview data for the six cases uncovered 60 technical enhancements, which are listed in Appendix D. Each case is discussed in the sections that follow. Interviews responses are indicated by quotations and attributed to the interviewee using I1, I2, I3, etc. If multiple references are listed, the quote is attributed to the first and corroborated by those following.

4.6.1 I-77 HOT Lanes (I77)

The I77 project is the first and to date the only P3 project performed by NCDOT. It consists of the construction of 26 miles of managed lanes in an open median with few major intersections in the Charlotte, NC metropolitan area. Although the I77 project was competitively procured with four consortiums shortlisted, only one bidder submitted a proposal and NCDOT decided to proceed to close with the sole bidder. I77 took approximately 37 months in procurement, from launch of the draft RFP to financial close. I77 was the only project that used a formula instead of a scoring system for technical and financial criteria. The formula weighted the financial aspects of a proposal over the technical aspects of it.

$$\text{Adjusted Proposal (\$)} = [[\text{PFA or (CP)}] + \text{Risk Adjusted DRAM Cap}] - \text{TQC}$$

Where: PFA – the net present value of the public funds amount

CP – the net present value of a concession payment

Risk Adjusted DRAM Cap – Developer Ratio Adjustment Mechanism (DRAM) Aggregate Cap Amount ($), multiplied by 0.15

TQC – Technical Score Quality Credit, consisting of technical score multiplied by $375,000

A technical score ranges between zero and 200 points, so the maximum TQC deduction possible in the Adjusted Proposal value was $75 million. It is composed of: 25 points for ‘General Project Management’, 125 points for the ‘Design-Build Technical Solutions’, and 50 points for the ‘Operations and Maintenance Technical Solutions’ (I77, RFP). The DRAM is a type of a fiscal support mechanism that will provide the concessionaire with up to $12 million per year (for a maximum of $75 million) if there are shortfalls in revenues that allow the debt service coverage ratio to go below one (‘1.0’). The formula was not actually employed since only one bidder submitted a proposal. In this project, no concession payment was made by the concessionaires to the state, but NCDOT provided a public subsidy of $88.21 million (I77, Financial Plan).

The sole bidder included three ATCs in their proposal. One ATC optimized the intersection of I77 with I85. As seen below in Figure 4.2, the original concept had the HOT north and south bound lanes, shown in yellow, separated.

Figure 4.2: Intersection Optimization in I77 Project

(NCDOT, 2015)

The ATC widened an existing structure to accommodate both north and south bound lanes, which eliminated the need for a third level flyover and shifted north bound HOT lane away from a residential community to lower noise levels. A second ATC requested a variance in bridge width to allow the expansion of an existing bridge over a lake towards the median instead of towards the lake, which minimized the environmental impacts on the lake. The third ATC kept existing sound walls in a section of the project instead of demolishing them as specified in the original scope; the bidder was able to achieve this by reducing the shoulder width in that section. The proposal also highlighted several technical enhancements that the bidder called "other innovations", like temporary detour roads to alleviate traffic during construction, other intersection optimizations, and lane realignments. None of the ATCs or technical enhancements qualified as innovative.

The nature of the project, which had an open median with limited connections to other major highways, was viewed as an inhibitor of innovation by one of the interviewees: "busy interstate with existing bridges over the interstate" (I17). The same interviewee mentioned having a "unit on innovative contracting that helps with the cultural inertia" was important to overcome some resistance of the owners' personnel. The scope of the project, building managed lanes in an open corridor with existing connections to the few major intersections within the project's boundaries curtailed the amount of ATCs and technical enhancements developed by the only bidder. However, despite these limitations, the ATCs and technical enhancements in this project provided added value. The state and tax payers benefitted from reduced construction cost. Users and the travelling public benefitted from safer highways by having safer weaving distances in the connections between the HOT lanes and the general purpose lanes. Lastly, society in general benefitted from more environmentally friendly construction that reused existing structures and lowered environmental impacts.

4.6.2 North Tarrant Expressway 3A&B (NTE)

The NTE segments 3A&B project was a predevelopment agreement. The concessionaire had won a prior competitive procurement in 2009 for the NTE segments 1&2A, composed of 13 miles in Dallas, TX so they also were given the right for first refusal for an additional 12 miles in the NTE 3A&B project. Just over 29 months after the concessionaire won segments 1&2A, they negotiated and agreed on a facility implementation plan (predevelopment agreement) for segments 3A&B with TxDOT and financial close was reached approximately 26 months after.

Six technical enhancements were uncovered in the NTE project, and one was identified as innovative. The use of a conveyer belt system to carry materials over traffic from the stockpile to the placement site was classified as incremental.

> *"Traditionally we would have loaded it in trucks and hauled it to the other side. What they ended up doing was running a conveyer belt through one of the forms for the bridge beds, so they ran a conveyer belt through that form, put it on the conveyer belt on one side, and used the conveyer belt to convey it over the traffic to the other side where they were actually placing it. That saved us a ton of money, a ton of cost in trucking…and it also kept all those trucks out of the lanes where we had motorists… So that was an innovation in safety and project cost."* (I16).

This construction technique was innovative for TxDOT; it was a technique they had not used before and they indicated that they will use again. This is an incremental innovation because it reinforces the process in which materials are moved but allowed an improvement in practice that lowered hauling cost and increased safety in the project; however, aside from the change of mode for moving the material, no other changes were required in the interaction with the other components or systems of the project. The material that was conveyed, in this case crushed concrete, remained the same and was used in the same way as it was originally intended.

The other technical enhancements included the optimization and rearrangement of intersections and general purpose lanes, and the redesign of bridges. However, one of the technical enhancements included in this project provided added-value by allowing an extension of the project terminus to connect with I30 (Figure 4.3).

The NTE project was previously envisioned by TxDOT as the rehabilitation of existing general purpose lanes and the new construction of managed lanes in approximately 10 miles of I35 ending at the intersection with SH 121. A private participant indicated that the early involvement of the private sector in the project before a final EIS was approved allowed the entire project to become an "enhanced ATC" (I23) process that permitted the discussion of creative ideas. After performing traffic and revenue studies and analyzing connectivity and congestion issues within the project, the concessionaire suggested the extension of the project terminus by 1.2 miles to connect the managed lanes to I30. This provided new connections and increased revenue to the asset (I6, I23). The added revenue paid for the new construction and reduced the public contribution by $150 million (Saenz de Ormijana and Rubio, 2015b). In this case, the payment mechanism and early involvement of the private sector before the EIS was approved allowed the inclusion of this technical enhancement. This will provide benefits to the users of the region who will have enhanced connections. It also benefitted taxpayers, as the government contribution was reduced, and now those funds are available for other projects. The demand risk nature of the project, its non-competitive procurement, and the fact that the environmental impact statement (EIS) remained open when the private partner got involved in the project, coupled with the location of the project next to a busy interstate highway, allowed the extension of the project terminus to connect with I30.

Figure 4.3: Extension of NTE Project

(NTE Mobility Partners, 2017)

4.6.3 SH-288 Toll Lanes (SH288)

The SH288 project consists of the maintenance of existing general purpose lanes and the construction of new managed lanes in 10.3 miles of SH 288 in Houston, Texas. SH288 was competitively procured, and this process took approximately 27 months; according to a public representative, this allowed the inclusion of additional scope into the project. It took a year between the selection of a preferred bidder and the achievement of commercial close. “The delay was due to the complexity of such a huge deal” (InfraPPP, 2016). Prior to this project, TxDOT had previously closed four other P3 projects; SH 130: 5&6 in 2008, NTE 1&2 in 2009, I-635 managed Lanes in 2010, and NTE 3A&B in 2013.

The SH288 project weighted the financial proposal over the technical proposal, 20 points for the technical aspects and 80 for financial. An analysis of the winning consortium proposal identified several “innovative concepts” the bidder included. These technical enhancements are relatively similar to the ones in I77 and NTE; the enhancements included the realignment of ramps and general purpose lanes and the redesign of portions of the highway to increase speed and two interrelated ATCs. The first one, which performed major redesign and modifications to the I610 intersection, will be discussed further below. The second ATC was contingent on the first one and closed weaving sections between general purpose and managed lanes given the new connections provided in the redesign of the I610 interchange. The original scope of the project had the managed lanes going over the intersection with I610 in a fifth level flyover with no connections to I610 (I10, I15) as seen on the top image of Figure 4.4. The concessionaire saw an opportunity to connect the managed lanes to a busy interstate highway (I610) to increase traffic. The reconfiguration of the I610 interchange allowed the relocation of toll lanes at grade, eliminated the need for the fifth level interchange and improved connections and movements between I610 and the existing general purpose lanes and new managed lanes in SH288 as seen on the bottom image of Figure 4.4.

> *“The result was an interchange that was more connected, better driver experience, because they don't have to drive through a fifth level giant ramp over this whole interchange, reduction of environmental impacts if you don't have this huge structure, and a huge impact to the traffic and revenue study [we] were able to project a lot more revenue and in the end we were able to give a concession payment to TxDOT of $25 million at financial close” (I11).*

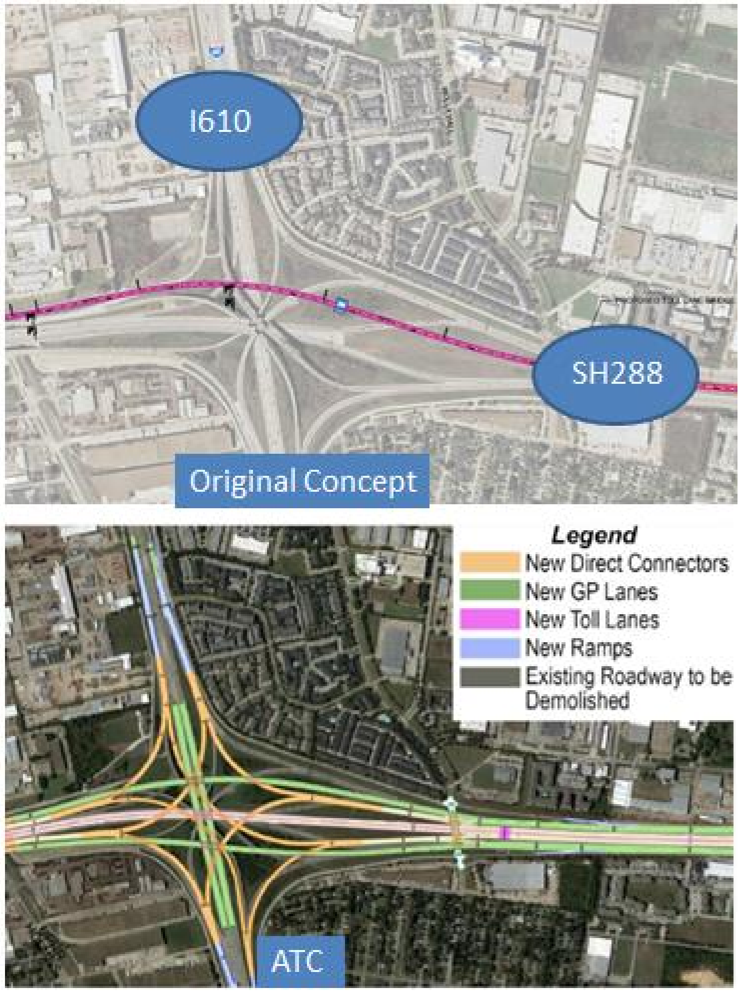

Figure 4.4: ATC in I610 Intersection

(TXDOT, 2013 and TXDOT, 2016)

None of the ATCs or technical enhancements qualified as innovative. However, the private bidder did provide value to the public owner and taxpayers through the ATC for the I610 interchange; this ATC provided an optimized design and a better driving experience to the users by not having to drive over a fifth level flyover. Further, the incorporation of the ATC paid for its construction, is expected to increase the profit to the private entity, and it provided a substantial upfront payment to the owner. The coupling of the demand risk nature and the project type – where the roadway crossed a major corridor (I610) – prompted the submission of this value-added ATC.

4.6.4 I-4 Ultimate Improvements (I4)

The I4 project consists of the construction of four managed lanes and the rehabilitation of general purpose lanes of 21 miles of highway through downtown Orlando, Florida. The I4 project took approximately 11 months in procurement. Prior to this project, FDOT had successfully procured two P3 projects; the I-595 Express Lanes and the Port of Miami Tunnel. In this project, four consortiums submitted proposals.

Two of the 25 ATCs submitted for this project met the innovation threshold. The first one, requested the use of precast edge beams with deck form curbs, something not used previously in Florida and not specified in FDOT's structures manual and design standards. The ATC used a "FIB (Florida I Beam) pre-stressed beam or equivalent section with a modified top flange that incorporates a curb along the external edge of the exterior girder… a concrete 'curb' would be cast on the edge of the top flange that acts as the deck form and eliminates the need for overhang falsework" (I4, Proposal). According to the ATC document submitted by the concessionaire, the utilization of this incremental innovation will save $450K in crew time and an additional $140K in construction, while increasing safety for employees and the traveling public by avoiding the use of falsework on site. This technical enhancement was classified as incremental given its small improvement in practice and no impacts on the links to other components or systems.

The second innovation arose from an ATC that requested the use maturity meters to test concrete compressive strength instead of waiting 14 days for testing representative cylinders before opening sections of pavement to traffic. The approved ATC allowed the use "ASTM C1074 (Standard Practice for Estimating Concrete Strength by the Maturity Method) in order to determine the compressive strength of the concrete pavement. Should the Maturity Method show the concrete to have sufficient compressive strength, that section of roadway may be opened to traffic earlier than the planned 14 calendar days" (I4, Proposal). While ASTM 1074 was adopted by ASTM in 1987, it has not been adopted by FDOT; their standards require that "test cylinders, made in accordance with ASTM C31 and tested in accordance with ASTM C39, indicate a compressive strength of at least 2200 psi" (I4, Proposal). This ATC is a modular innovation since it represents a definitive shift in the approach to determine the compressive strength of concrete earlier, but it does not change the links with other elements. The use of this innovation reduced the schedule by ten substantial completion days, which, according to the winning proposer, translates to $1.1 million in savings.

The I4 project had 60 points for technical aspects and 40 for financial in its bidder evaluation criteria. Further, 15 of the 60 technical points were allocated for the inclusion of 'project technical enhancements' (PTEs); FDOT requested bidders include PTEs that enhanced or provided additional value to the project. The PTEs had to be submitted as ATCs and could include features that: (i) improved the level of service by increasing capacity, (ii) provided new movements, or (ii) even increased the aesthetic aspects of the corridors since the owner desired a 'signature corridor' (I2, I22). This in part explains why this project had so many ATCs submitted and approved by the winning proposer that increased traffic in the corridor. Out of the 25 ATCs submitted for this project, nine were PTEs, which increased the project cost by an estimated $26 million and added 16 days to the project schedule. Such ATCs are unusual in an availability payment project because they increase CAPEX and O&M costs without the counter benefit of increased revenue. A private interviewee explained how their team considered PTEs:

> *"On I4, the project technical enhancements [were] because there was value on the point scoring; you did have to weight though that you were adding so much new work back in, unless you went over the upset limit[8]...what you had to weight was, a proposal point is worth so much in value, did the cost of my enhancement, was it more than what the value of the point I was going to get; and that was a big thing we looked at. What is the cost of the enhancement and where do I think the client will score in value. If I had to spend a million dollars to get a million dollars in points then it was null. If I only had to spend a hundred thousand dollars to get a million dollars in points I will. We always look at that risk reward…can't give it away for free"* (I22).

Additionally, the RFP instructed proposers that: "Any concept that deviates from the Basic Project Configuration must be the subject of an ATC." Basically, proposers had to submit an ATC for any change of over 5-feet from the original design in the vertical or horizontal alignment. A public interviewee mentioned this '5-feet rule' was included based on the owners experience in a previous project: "We are all products of our experiences, and what we had experienced in another project, a team had done something pretty drastic and if we had known about it we would of not allowed it to happen" (I2). An additional seven of the 25 ATCs were a

[8] The upset limit was the maximum availability payment that the owner was willing to pay in any given year. The RFP stated: "Availability Payments in the Financial Price Proposal Form should not exceed the Availability Payment Upset Limit in total or in any period identified" (I4, RFP).

consequence of the ‘5-feet rule’. These ATCs entailed intersection realignments that provided substantial savings on the project. A member of the winning team mentioned that if the ‘5-feet rule’ had not existed, they would have included several of these ATCs as “project optimizations” (I22).

Also, five additional points out the 60 technical points were allocated for the inclusion of a direct connector from the managed lanes to SR 408 (Figure 4.5). By including a direct connector, the bidders not only got five overall points out of the 60 technical points, but they also got to lower the net present value of the availability payments used in the financial price scoring by a set value of $11.6 million. The preferred bidder not only provided the additional direct connection from the managed lanes to SR 408, but it also provided an ATC in addition to the PTE that optimized the intersection and reduced the estimated project cost by $28 million by incorporating road realignments and eliminating the need for two 1,400 foot two lane viaducts.

Figure 4.5: Direct Connector to SR 408

(FDOT, 2014)

Another ATC in the I4 project was the Michigan-Kaley Interchange Realignment (ATC 19); the original design had the roadway going over a relic sinkhole via a flyover. By realigning the roadway and avoiding the relic sinkhole, the concessionaire estimated savings of $39 million and 36 days on substantial completion. An interviewee commented that they achieved this improvement by requesting deviations to some ramp widths and exit velocities to avoid the relic sinkhole; by changing the geometry "versus trying to drive deep piles and put that section on a bridge, we moved it over. We managed to realign the roadway, adjust different ramps and things in another interchange so that we could squeeze by the relic sinkhole, again, just a better engineering solution" (I22).

These PTEs and ATCs related to design optimizations of intersections, while not innovative, provided added value by delivering savings to owners and providing better and safer driving experiences to users.

The combination of the evaluation criteria used in a competitive procurement and the project type, a constrained corridor with a fixed geometry and expensive right of way, prompted interesting design optimizations to better use the resources of the state by providing enhanced value in the project that allowed estimated savings of $87 million after deducting the added $26 million from the PTEs in new construction. In addition, the desire to minimize lane closures during construction and increase safety in a very congested corridor triggered the identified incremental and modular innovations.

4.6.5 East End Crossing (EEC)

The EEC project is part of the Ohio River Bridges (ORB) Project. The ORB Project consists of two major fixed crossing projects: i) the Downtown Crossing (DTC) procured as a design-build by the government of Kentucky and ii) the East End Crossing (EEC), procured as an AP P3 by the government of Indiana. Interestingly, both projects began as a single project performed under a memorandum of agreement between the two state governments and remained as a single project until conclusion of the environmental permitting process. The EEC project consists of the construction of a new 2,500 foot cable-stayed bridge and its approach sections, which includes a 3.3 mile two-lane extension of US 42 that requires the construction of a 1,680 foot tunnel on the Kentucky approach and the 4.1 mile two-lane extension of Lee Hamilton Highway on the Indiana approach. InDOT has some experience with P3s; it had previously closed the lease of the Indiana Toll Road back in 2006 and subsequently the DBFOM of I-69 Section 5 in 2014.

The EEC project took the least time in its procurement, taking approximately 7 months to reach financial close. According to a public interviewee for the project, having such a compressed procurement time affected the amount of innovation generated. Four consortiums were shortlisted and submitted proposals for this project. An industry member is quoted saying the following:

> *"After starting the procurement, IFA/INDOT consistently stayed on schedule. They focused on solutions for every challenge that arose, establishing an environment that encouraged technical innovation. Shortlisted competitors were really listened to, and appropriate commercial modifications were made, which helped to establish a very competitive bidding environment"* director of P3 Development for Kiewit, as told to InfraAmericas (InDOT, 2013).

The EEC project evaluation criteria weighted the financial proposal over the technical proposal, 75 points for financial aspects and 25 points for technical. The winning proposer included seven ATCs in their proposal; these ATCs lowered the net present value of the availability payments by an estimated $76 million. The ATCs achieved this by lowering construction costs and reducing right of way acquisitions. These ATCs included the replacement of a crossover diverging diamond and traffic signals with a roundabout, elimination of an 840 foot flyover for a single point interchange, and reduction in the thickness of the shoulder pavement. Interestingly, only one of the ATCs addressed an element of the fixed crossing while two other ATCs addressed elements of the approach tunnel. The ATC pertinent to the bridge requested the use of weathering steel as a way to lower maintenance costs and enhance the aesthetic features of the bridge. The RFP specifically stated: "*No ATCs for bridge types will be considered*" (EEC, RFP). A private sector interviewee commented on the focus of ATCs in the project:

> *"The bridge is obviously a big signature element of this project; this area is a crossing of the Ohio River, from an aesthetic point of view had a lot of input from everyone in the area. When it comes to a tunnel, ultimately is a hole in the ground, but there are still aesthetics even involved in that...the tunnel portals to make them aesthetically pleasing"* (I19).

This is understandable given 'signature structure' standing of the bridge and that the reference design had been selected by the Governor in 2008. This is highlighted in the RFP for the project:

> *"The reference bridge design was selected by the Governors of Indiana and Kentucky in 2008 after a year-long Bridge Type Selection Process. The final design of the new*

bridge must be consistent with the environmental commitments set forth in the SEIS with respect to maximum tower heights and aesthetics and other design and construction requirements" (EEC, RFP).

Alternatively, one of the two ATCs related to the tunnel design met the innovation threshold. The first one requested an optimization of the tunnel cross section and its systems. This was a partially accepted ATC, given several of the items within it were deemed compliant with the technical requirements of the project. This architectural innovation of optimizing the cross section of the tunnel allowed the concessionaire to: "reduce the required liner reinforcement and allow for a more suitable reinforcement size and spacing. Due to the tight constraints in which the reinforcement is to be installed above the formwork, the ATC will improve the construction safety of those placing the material. The increased reinforcement spacing will allow for proper concrete consolidation between the bars and provide a higher quality concrete liner" (EEC, ATC 14). This ATC also optimized the fire suppression system allowing the scope reduction of the ventilation system, which will lower operation and maintenance costs due to lower energy consumption. This ATC provides a modest improvement reinforcing practice in tunnel design and construction, but the change in the design and construction of the tunnel prompted and required changes in the links with other components of the project, specifically the design optimization of the fire suppression, ventilation, and electrical systems.

The other ATC related to the tunnel which did not meet the innovation threshold was prompted because of the previously discussed architectural innovation. It requested a change in the position of the portals of the tunnels, shortening the tunnel in the south by 220 feet and in the north by 50 feet, for a total tunnel reduction of 270 feet. Additionally, this ATC requested a reduced pillar width in the south portal from 40 to 35 feet providing improved constructability. Together this generated significant savings: "the winning proponent, their profile was compliant for about 2/3 of the length of the tunnel, but outside the envelope for about 1/4 of the tunnel length so they bear all that risk in that zone but they saved quite a lot of money in rock excavation and a much better balanced project from an earthwork stand point" (I5). The incorporation of this ATC also reduced the size of the fire, ventilation, lighting, and drainage systems within the tunnel. This allowed a deduction on the availability payment of $1.1 million which translates to a net present value of approximately $21 million.

Here, the project type was a driver of innovation since the tunnel sections opened opportunities for the private bidder to deviate from the original design through the ATC process. Whereas the bridge section, the main fixed crossing, was bounded by more prescriptive specifications that did not allow the private bidder to change much, only the incorporation of weathering steel instead of painted structural steel. In addition, the typical AP payment mechanism further focused the bidder on ATCs that optimized cost and schedule instead of revenue generating deviations.

4.6.6 Elizabeth River Tunnels (ERT)

The ERT project started as an unsolicited proposal. Subsequently, VDOT solicited conceptual competing proposals but only one team submitted; after 20 months of review and negotiations, they decided to proceed with an interim agreement (predevelopment agreement) with the only bidder and reached financial close on the project approximately 27 months after. VDOT had and has a proven track record of closing P3 deals and was one of the only jurisdictions with a dedicated P3 Unit, although it recently consolidated this unit into an office inside VDOT. VDOT was generally viewed as a pioneer in the P3 market with the Dulles Greenway in 1993; subsequently, the Pocahontas Parkway in 2006, and the I-495 Capital Beltway Express in 2007. After the ERT project it has closed two additional projects, with the most recent being the I-66 Managed Lanes this year.

The ERT project is a portfolio of four facilities. It consists of the extension of the Martin Luther King (MLK) Freeway, the improvement and rehabilitation of the existing Downtown and Midtown Tunnels connecting the cities of Portsmouth and Norfolk, and the design & construction of a new immersed concrete tunnel parallel to the existing Midtown Tunnel. ERT project was a demand risk project. In particular, the design and construction of the new tube parallel to the existing Midtown Tunnel was a feature of the project that stimulated the incorporation of four innovations.

The original design of the project had the new tunnel located very close to the existing tunnel; in order to mitigate the risk of the existing tunnel collapsing into the trench of the new tunnel, the private consortium suggested a curved alignment to avoid excavating next to the existing tunnel to avoid damaging the structure.

> *"The initial VDOT proposal had envisioned building a new tunnel parallel and very close to the existing tunnel which will require, once placing an immersed tunnel you*

will need to make a very deep excavation…sediments under water don't stand up well, you have to lay the slopes back at a very flat angle of about 3:1 and the closer you get the new excavation to the old tunnel the more of the old tunnel you take soil off and you risk uncovering it. Basically you then subject the existing tunnel to an un-trussed horizontal load that makes the old tunnel want to slide into your new hole" (I21, I3, I14).

The new alignment, not previously considered by VDOT, introduced "a very broad S curve underwater in the tunnel to get the new tunnel further away from the existing tunnel" (I21, I3). The tunnel was built in 11 sections in a dry-dock facility in Maryland. The tunnel sections were built with temporary bulkheads so they could float. They were then towed to the jobsite and prepared for immersion.

A dredge barge with a crane was used to excavate the trench where the tunnel was placed, approximately 1.5 million cubic yards of sediments were removed (ERT, 2017). Once the excavation was finished, approximately 2 feet of gravel was placed and leveled at the required slope where the tunnel rests. The 11 tunnel sections were placed one per month using "a special 'catamaran' barge with placing girders spanning the opening between the barge halls. The barge was capable of receiving, supporting, ballasting, and lowering the negatively buoyant" (ERT, 2017) sections of the tunnel. To achieve the negative buoyancy required, temporary water tanks were placed in the tunnel sections and filled with 4 million gallons of water (Forster, 2014). Given the curved alignment and to ensure the vertical and horizontal alignment of the sections, removable survey towers attached to the sections combined with GPS technology were used. Each section of the tunnel was outfitted with thick rubber seals that once in place and the water was pumped out created a water tight seal between sections. After placing the sections, the excavation was backfilled to prevent horizontal displacement and covered. Finally, an armor stone cover was provided to prevent damage to the tunnel from anchors or scour.

The use of an immersed concrete tunnel is certainly innovative:

"All tunnels down here, all the immersed tunnel here are steel binocular tunnels, they are basically big steel tubes underwater and there is an air duct above and air duct below and the road is in the middle…it required getting everybody comfortable with a different structure type and a different layout of the structure" (I21, I3).

In this case, the use of an immersed concrete tunnel is composed of complementary innovations that overturn core concepts in means and methods to build, transport, and place the tunnel sections; and provides changes in the links and interaction between the elements, making this a system innovation.

The decision to change the alignment and to utilize immersed concrete sections as well as the motivation to reduce the amount of dredging for the new tunnel prompted the selection of the cross section (Figure 4.5) of the new tunnel.

> *"In the early discussion or design period it became evident that we could dig a shallower trench if we went to a flat box structure as opposed to a circular structure, which is shallower. It made a huge difference to the amount of material we had to dredge from the bottom of the river and that then allowed us to change the tunnel type from steel to concrete"* (I21).

The selection of this shallower box type cross section influenced the selection of the jet-fan ventilation system:

> *"Here going with a shallower structure which reduced the dredge we went with jet-fans, so there were no ducts. Fans mounted in the roadway itself, the roadway prism so to speak, that blow air only in one direction, so it is a longitudinal ventilation system. That allowed for a more efficient ventilation system that allowed it to handle a much larger fire so it saves money"* (I21).

The tunnel cross section enhancement highlights a modest change in a core concept, a tunnel cross section, but it influenced other elements of the system – in this case the selection of the ventilation system and this is why the cross section design is classified as an architectural innovation.

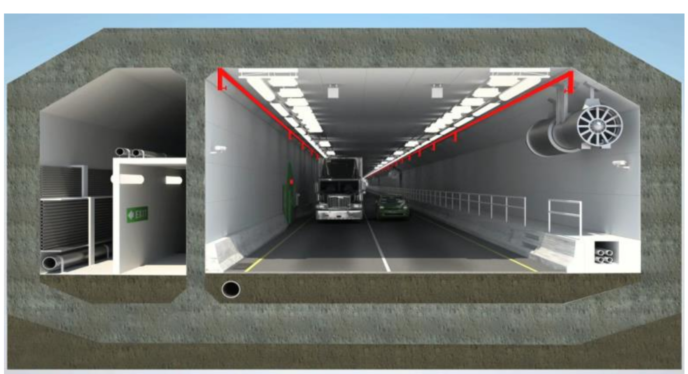

Figure 4.6: Cross section of ERT Tunnel Showing Jet-fan and Deluge System (ERT, 2017)

The ERT ventilation system is the third innovation. The use of a jet-fan ventilation system, which moves the air longitudinally with traffic instead of the traditional transverse ventilation system, brings a new technology not previously used by VDOT. The jet-fan provides a significant improvement over the traditional transverse ventilation system providing a more efficient circulation of air. This overturns a core concept, but no changes in the links with other elements of the project, making it a modular innovation.

Lastly, the use of a deluge fire suppression system is the fourth innovation in this project. The "sprinkler system or deluge system for the tunnels which is very unusual in the States…a deluge system which is like a sprinkler system on steroids, deluge meaning it's like you are standing in a hurricane" (I21). In this case this is a modular innovation because it provides a significant change in a core concept not previously used in Virginia without changes in links with other elements. However, this innovation could have impacted the design of the ventilation system, but VDOT decided to be more conservative and keep both systems as if the other was not present; a concessionaire's representative commented:

> *"If you are going to pay all the money and rely on that system, those systems can be very effective at limiting the fire size and so why wouldn't you take advantage of that and downsize the ventilation system from say a 100 MW to 20 or 40 MW so you could have some savings and the state's position was they had never had a longitudinal ventilation system or a deluge system. So these are two systems they had no operating experience with. So, from their perspective they weren't comfortable with counting on both systems operating, they were more comfortable assuming one was going to operate and maybe the other wasn't. So it is a little bit of belt and suspenders, perfectly understandable"* (I21).

The non-competitive, negotiated procurement and the early involvement of the private partner, coupled the project type and the concessionaire's desire to mitigate the risk of damaging the existing tunnel, prompted the four innovations found in this case.

4.7 Across Case Analysis

Only eight of the 60 technical enhancements complied with all elements of the innovation assessment framework and hence were classified as innovation. Table 4.2 provides a summary and details of the identified technical enhancements in all of the cases.

Table 4.2: Summary of Identified Technical Enhancements

Project	Technical Enhancements Identified	Proposed as Compliant	Proposed as ATCs	Innovative Technical Enhancements
I77	11	8	3	0/11
NTE	6	6	0	1/6
SH288	5	3	2	0/5
I4	25	0	25	2/25
EEC	7	0	7	1/7
ERT	6	6	0	4/6
Total	60	23	37	8/60

All types of innovation were identified, except radical innovation. Table 4.3 summarizes the technical enhancements assessed as innovative.

Table 4.3: Innovative Technical Enhancements

#	Project	Description	Changes in Concept	Change in Links
Incremental				
1	I4	Use of precast edge girders that incorporate a curb along the external edge of the girder that eliminates the need for overhang falsework in the bridge deck	Reinforces the use of precast concrete elements that increase site safety	Unchanged, it will be used as any other girder, except it allows it to be used as a scaffolding for the deck
2	NTE	Conveyer system for reuse of pavement instead of trucks	Reinforces the process in which materials are moved	Unchanged interaction with the other components or systems of the project
Modular				
3	ERT	Use of a deluge fire suppression system, not previously used in Virginia	Overturns the current practice with a system not used in the state	Unchanged links with other elements given owners prescriptiveness and conservativeness
4	ERT	Use of jet-fans for ventilation system instead of transverse ventilation system	Overturns the current practice	Unchanged links with other

#	Project	Description	Changes in Concept	Change in Links
			with a significantly improved system currently used at the time	elements given owners prescriptiveness and conservativeness
5	I4	Use of maturity meters to test concrete strength before 14 days and open roadway sooner to traffic	Overturns the concept of needing to have test cylinders to open a section of roadway early	Unchanged, no changes to the links of the other elements of the project and their interactions
Architectural				
6	ERT	Tunnel cross section (box type) instead of circular	Reinforces the tunnel design practice by using a shape not previously used in the state tunnels	Changed the links with the ventilation system
7	EEC	Optimized tunnel cross section and utilities within it	Reinforced, it reinforces the practice of tunnel design	Changed the links with all the tunnel systems allowing smaller and more efficient systems
System				
8	ERT	Immersed concrete tunnel instead of steel tube encased in concrete tunnel	Multiple innovations that overturn the current practice	Changed several links in components and systems of the project

Eight of the 60 identified technical enhancements and ATCs met the innovation threshold; however, a majority of the other 52 provided added value to the projects either by increasing safety, improving the level of service, providing savings in construction costs, lowering the maintenance costs, or shortening the project duration. In several instances, the technical enhancements complied with all elements of the rubric except the novelty aspect to the jurisdiction. This was the case with the use of weathering steel in the bridges in the MLK Freeway in ERT and in EEC, the use of a roundabout in the EEC project, and the use of reclaimed aggregates and high definition CCTV in the I4 project.

4.7.1 Managed lanes

In the four managed lanes cases, a majority of the ATCs and elements described as "innovative" in the interviews or the proposal documents were found to be value-adding solutions from the private concessionaires to optimize the owners' preliminary project designs by decreasing the construction of bridges and overpasses through the redesign of intersections, which saved millions of dollars in construction. However, the coupling of project type and demand risk factors encouraged creative solutions to enhance highway connectivity that increased traffic in the NTE and SH288 projects. The demand risk nature of the SH288 project coupled with the presence of an intersection with a busy interstate highway drove the submission of an ATC that was expected to generate enough revenue to cover the additional project costs and to provide an upfront payment to the state. This corroborates prior findings by Jolley and Garvin (2014), who encountered that concessionaires had limited incentives to promote revenue generating ATCs if they did not benefitted from this additional revenue. While ATCs are also part of other project delivery methods like design-build, the ATCs that provide increased connectivity are unique to P3s. A private sector interviewee commented: "On a straight design-build we wouldn't propose adding another ramp, unless there was value, unless we get some sort of credit for it. If we are not going to get credit for additional cost, why would we do it" (I22). This is why these types of revenue generating ATCs are incorporated in demand risk P3 projects.

The early involvement of the private sector in the NTE project, when the EIS had not been finalized also allowed the incorporation of a major change in the project – moving the terminus of the project to increase traffic in the managed lanes and hence increase revenue. This extends findings by Antillon et al. (2016) who found that the contract timing or the early involvement of the private partner in the project will promote more innovation; in this case, the revenue potential triggered the highway's extension. Such enhancements were not observed in I77 due to the open nature of its corridor and it few intersections where additional connectivity was needed. Despite this, the I77 enhancements provided moderate value through design optimization of intersections and flyovers.

4.7.2 Fixed crossings

In the two fixed crossing cases, EEC had no major changes incorporated into the bridge given its signature structure status, but significant changes were incorporated into the tunnel on US 42 that allowed substantial savings in the project and the early completion of the project due to the shorter length of the tunnel by 270 feet. In this tunnel, one architectural innovation was identified. The ATCs submitted in this project provided value to the project by increasing safety and lowering the total availability payments by an estimated $76 million. In ERT, it also had an architectural innovation given the use of a new cross section. The use of a ‘box’ cross section instead of the typical circular cross section also influenced the development of the two modular innovations identified in the project. The project type, particularly the tunnel systems in both of these two cases, influenced the incorporation of innovations from the private sector. This corroborates prior findings by Russell et al. (2006), who discussed that the project type is an important factor of innovation.

ERT also benefitted from its non-competitive procurement and the early involvement of the bidder. By not having a fully closed EIS and the bidder involved early in the process, modifications were possible in ERT (as was also found in NTE); the alignment of the new immersed concrete tunnel would have proven unlikely had the EIS been finished. The change in the alignment of the tunnel in the ERT project initiated the four innovations previously discussed, one of them being the only system innovation uncovered in this investigation.

4.7.3 Across all cases

The procurement process is central to achieving innovation in a project. In the cases, neither ERT nor NTE were competitively procured. Public representatives for these two non-competitive cases indicated that not having competition affected the procurement because "it took longer and negotiations were harder" (I16, I14). Hence, non-competitive procurements are likely more difficult, although it can potentially increase innovation as Antillon et al. (2016) found and our findings support. The other four cases were competitively procured. However, three cases – EEC, I77 and SH288 – used best value scoring where far less weight was given to technical aspects versus financial; only the I4 case gave a higher portion of points to technical aspects; this difference in the evaluation criteria, as well as the specific points allocated to PTEs, in I4 generated the type of value-added technical enhancements typically seen in demand risk projects such as improved connectivity. This finding corroborates findings by Hoppe and Schmitz (2013) who argued that incentives in the procurement phase can promote innovation. However, just having one project that highlighted this outcome is not sufficient to generalize, further research is required to better understand how the evaluation criteria can impact innovation and value creation.

In summary, the case factors procurement approach and project type most strongly influenced both innovation and value creation in the cases – particularly in ERT, EEC, NTE, and I4. The payment mechanism factor also had an effect; however, the I4 case illustrates that procurement evaluation criteria may incentivize comparable outcomes. Given this, the couplings of: (1) the demand risk payment mechanism and project type (scope) and (2) demand risk and early private partner involvement have the strongest relationship with added-value and innovation in P3 projects. Additional case evidence would strengthen these observations. Also, it seems that non-competitively procured projects provided more innovation and value than competitively procured ones. This could have been because the non-competitive projects also had their statutory environmental studies still open when the private partner got involved. This allowed the modifications that provided innovation and value on these projects and not necessarily their non-competitive nature. This expands prior research by Raisbeck (2009) on the influence of design freedom on innovation; moreover, it provides evidence of the influence of design freedom in P3s, which Leiringer (2006) did not uncover. Our findings show that the ATC process in the US or early private partner involvement provides the private sector with the design flexibility needed to promote innovation and value creation. Interestingly, public participants for both the NTE and ERT projects mentioned the lack of competition affected the projects because "the negotiations were harder because [we] didn't have that competitive incentive for the developers to come to the table quickly with a good alternative and a good cost" (I16). Further studies are needed to better understand what was given up for the increased innovation and value found on these two projects.

Consequently, the findings support the derivation of several propositions for further investigation:

- Proposition A: Demand risk and project scope that involves connectivity opportunities with major intersections will promote technical enhancements that are innovative or add value in P3 projects;
- Proposition B: Engaging a private partner before a P3 project's scope is fully defined provides more opportunities for technical innovation and value creation; and
- Proposition C: Procurement processes in P3 projects that weight technical evaluation criteria over financial aspects can: (i) prompt technical enhancements that are

innovative or add value and (ii) incentivize technical enhancements that respondents would not otherwise propose.

4.8 Conclusions

This research analyzed project documentation and interview data to identify technical enhancements in six US highway P3 projects. Consequently, 60 technical enhancements were identified. After employing the multi-step assessment framework, eight technical enhancements met the innovation threshold and were classified. All levels of innovation were uncovered, except radical innovation. This is not surprising as a radical innovation is described by Slaughter (2000) as something completely new that makes prior technology, processes, or products obsolete.

The remaining 52 technical enhancements, although not innovative, did provide value to the projects by providing increased safety, improved mobility, increased environmental sustainability, lower maintenance cost, and savings in construction cost and time. Among practitioners, value-added enhancements and innovation are essentially equated or seen as similar. Based on this analysis, a number of these enhancements are indeed creating value, mainly by optimizing the design solutions – essentially the private sector's engagement in the procurement process brought additional "value engineering" in each case. Further, significant innovation or value engineering is more likely when the private concessionaire is engaged earlier in project development process – the single system innovation example, the immersed concrete tunnel, was found in the ERT case and the extension of a project's footprint, which reduced the public contribution by $150 million, was found in the NTE case. However, careful attention has to be given by public servants considering to structure pre-development agreements in their projects. Further research is needed to better understand the dynamics that occur in non-competitive procurement.

The early involvement of the private sector in non-competitive procurement of assets in the ERT and NTE cases drove important value-added technical enhancements and innovations. The project location and type also influenced the occurrence of innovative solutions. The use of a demand risk payment mechanism or evaluation criteria that incentivizes increased traffic like in the I4, also encouraged additional value added solutions from the private sector.

This research contributes to the body of knowledge by employing a framework for assessing and classifying innovation in a systematic, transparent, and replicable way that allows the corroboration of findings and can be utilized by future researchers. Additionally, this investigation contributes to the body of work on innovation in P3s by providing new findings of a market that has not been studied in depth and discussing the factors that prompt value and innovation in P3s. Further, this research provides information to practitioners, that engaging the private sector creates more value so than innovation. Perhaps, the P3 community will be better served by emphasizing value-added over innovation.

5 Chapter 5: Summary, Contributions, and Future Research

5.1 Summary of Findings

As explained in the introductory chapter, this research addressed the gaps in the literature through a phased and integrated research approach as shown in Figure 5.1. The first phase of the research involved three efforts: Phase 1A that synthesized infrastructure project innovation factors; Phase 1B which developed a framework to identify and classify infrastructure project innovation, and Phase 1C that tested the framework developed in Phase 1B using ATCs from four infrastructure projects. Phase 2 of the research utilized case studies to further investigate innovation in P3 projects.

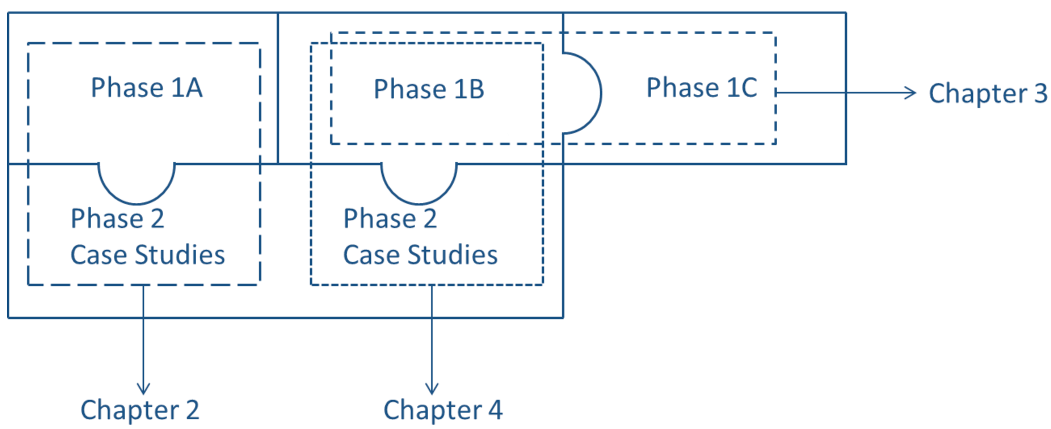

Figure 5.1: Reinforcing Studies in this Dissertation (self-created)

In Phase 1A, the rich body of work exploring the factors of innovation in construction (Tatum, 1984; Gann and Salter, 2000; Bossink, 2004; Ozorhon et al., 2014, etc.) was synthesized and further categorized following the network of organizations structure of Eaton et al. (2006) in Chapter 2. This allowed the identification of the 33 factors synthesized from the body of work; 14 are at the project level, ten at the organizational level, seven at the external level, and two at the job level. In Phase 2, interviews conducted with project participants in six contemporary P3 projects allowed the identification of 110 factors that they viewed as influencing innovation in P3 projects. Employing coding and content analysis techniques, these factors were further categorized into six main factors: procurement, public client, private company, risk, project type, and external. Areas of alignment between academic and practitioner perspectives indicate a potential union with respect to innovation factors that can act as enablers or inhibitors in P3s. Procurement, client, and risk have the strongest alignment between the literature and practitioners.

In Phase 1B, an innovation assessment framework was developed from prior work (Henderson and Clark, 1990; Slaughter, 1998; Slaughter, 2000; Hartmann, 2006; Gambatese and Hallowell, 2011b; Garvin and Jolley, 2013) to transparently identify and classify innovation at the project-level. The framework consisted of a multi-step rubric where first a binary assessment is done to determine if a technical enhancement complies with the elements of the innovation definition adopted. Once an innovation is identified, a framework modified from Henderson and Clark (1990) and Slaughter (2000) is used to identify the type of innovation given its changes in core concepts or linkages with other components or systems. The innovation assessment framework was demonstrated and tested (Phase 1C) in four infrastructure projects, one delivered via design-build and three delivered as P3s. Together Phase 1B and 1C provided Chapter 3.

Having identified the main factors influencing innovation in the P3 environment in Chapter 2 and developed the innovation assessment framework in Chapter 3, I conducted a case study to gauge what types of innovation were found in six projects representative of the contemporary US P3 market and how project characteristics were influencing innovation and value in these projects (Phase 1B & Phase 2). Analysis of the case study data uncovered that the main factors influencing value and innovation in P3 projects are traffic risk (demand risk), the structure of the procurement (competitive vs non-competitive), and the project type. The couplings of: (1) demand risk and non-competitive procurement and (2) demand risk and project type appeared to be the strongest facilitators of innovation and added-value. All types of innovation were identified, except radical innovation. While innovation was uncovered, the majority of the technical enhancements provide more value than innovation. The owner, the users, and society in general benefit from this added-value through savings in project funds that can be used for other projects, increased safety, and lower environmental impacts.

5.2 Contributions and Implications for Practice

This dissertation and has several contributions and implications for practice. As a whole, it advances the state of knowledge with respect to infrastructure project-based innovations within P3 arrangements. Each manuscript has significant individual contributions:

5.2.1 Factors Influencing Innovation in Public-Private Partnership Projects.

The work synthesizing infrastructure/construction project innovation factors and identifying factors influencing innovation in P3s contributes in several ways. First, it integrates a rich but fragmented body of literature focused on drivers/inhibitors of innovation in construction and infrastructure projects (Blayse and Manley, 2004; Bossink, 2004; etc.). Second, it also enriches the work that has explored innovation factors in P3 projects (Eaton et al., 2006; Russell et al., 2006) by identifying the relative significance of different factors that influence innovation in P3 arrangements – based on practitioner input. Moreover, it found strong alignment between academic and practitioner perspectives of innovation drivers in the areas of procurement, client characteristics and risk. For instance, the procurement phase and a client's openness and P3 experience appear central to facilitate innovation in these transactions. In addition, practitioners will benefit from insights provided about the influence of proper structuring and management of procurement elements such as ATCs and procurement time, particularly sufficient time early in the process to discuss and review technical enhancements, on innovation and value creation.

5.2.2 Development of a Framework for Assessing Innovation in Infrastructure Projects with Application to Alternative Technical Concepts.

The framework developed and applied in this chapter builds on prior work (Henderson and Clark, 1990, Slaughter 1998, and Slaughter 2000; Hartmann, 2006; Gambatese and Hallowell, 2011b; Garvin and Jolley, 2013) to establish a transparent and replicable framework to assess technical enhancements in infrastructure projects as innovative or not and to classify qualifying enhancements by innovation type; prior work (e.g. Gambatese and Hallowell, 2011a; Leiringer, 2006) lacks the clarity found in the presented framework. The framework can clarify researcher perspectives and mitigate researcher bias (Leydens et al., 2004) since it requires the: (i) assessment of all elements and (ii) the classification of types of technical innovation, as defined. These features of the framework differentiate it from prior research (Leiringer, 2006; Gambatese and Hallowell, 2011b; Antillon et. al. 2016) as a tool to assess technical innovation. The application of the framework on ATCs highlights the known difficulties of assessing innovation (Henderson and Clark, 1990; Leiringer, 2006; Gambatese and Hallowell, 2011b). Regardless, the framework forces researchers to carefully consider the characteristics of the ATC to identify and classify it as a technical innovation. Moreover, an important derivative of the framework is its ability to identify enhancements that add value in projects. Indeed, an important finding from the application of the framework is the value generated through ATCs in terms of cost and schedule savings, increased safety, and lower environmental impacts. Further, several ATCs in the P3 projects illustrated that the bundling of lifecycle phases generates deviations that focus on improving operations and maintenance, something that would be unlikely in design-build projects. Perhaps, policy-makers and practitioners would be better served *if they emphasized value creation more than innovation as a consequence of private participation in large-scale infrastructure projects and P3s*.

5.2.3 Influence of Project Characteristics on Technical Innovation and Value Creation in P3s: Evidence from US Highway Case Studies.

The multi-case study utilized outputs from Chapter 2 (key innovation factors) and Chapter 3 (innovation assessment framework) to investigate whether innovation is occurring in P3s and how certain project characteristics influence innovation outcomes. It expands prior work focused on this area (Leiringer, 2006; Eaton et al., 2006; Russell et al., 2006; Barlow and Koberle-Gaiser, 2008; Rangel and Galende, 2010; Antillon et al. 2016; Himmel and Siemiatycki, 2017), and it is one of the few studies that has examined the US market. This research corroborates prior findings by Russell et al. (2006), who discussed that the project type is an important factor of innovation. In this research we uncovered how the project type, more specifically the project scope can promote value-added technical enhancements. Further, the study provided evidence of how incentives (Hoppe and Schmitz, 2013) during procurement, more specifically in the evaluation criteria, can promote value-added technical enhancements. Limited innovation was uncovered in the six cases, but like Chapter 3 it did uncover the occurrence of innovation and value through the incorporation of technical enhancements in P3 projects. The ATC process seems to provide the required design freedom (Raisbeck, 2009) to promote technical innovation and value; something that Leiringer (2006) argued was not happening in P3s. In particular, the findings corroborate and expand recent work by Antillon et al. (2016); early involvement of the private sector in project planning and design promotes higher levels innovation and added value.

However, the advantages of such early involvement, particularly if services are procured non-competitively, need to be weighed against broader societal and public interest concerns such as accountability and legitimacy before opting for earlier engagement of private participants. Perhaps, the competitive dialogue approach used in Europe warrants further investigation as a method to balance early engagement with issues related to public interest. Additionally, the case evidence indicated more generally that: (i) procurement approach, project type and payment mechanism are factors in the P3 environment driving or inhibiting innovation and (ii) engaging a private partner before a P3 project's scope is fully defined provides more opportunities for technical innovation and value creation.

5.3 Future Research

My investigations here have opened up several avenues of future research. Foremost, I plan to continue examining innovation and value creation in infrastructure project settings, but I can extend its nature and scope in several ways:

- **Measurement and quantification of technical enhancement benefits and costs**: the research demonstrated that the technical enhancements had both social and economic value as well as costs; in some cases, estimates of cost or schedule savings were made. Clearly, the benefits (and costs) of these enhancements go beyond this. Research to improve the measurement and quantification of such benefits would better inform project stakeholders of the worth of such benefits, which would also allow improved assessment against their costs.
- **Consideration of other innovations**: certainly, technical enhancements are important in infrastructure projects and systems; however, the research that I have done here provides a foundation to examine other forms of innovation. Given the infrastructure funding challenges worldwide, innovations in project and program financing have the potential to address such challenges (at least partially). A logical extension of my work is to examine factors influencing financial innovation in infrastructure projects and P3s. Similarly, I can look into organizational settings in both the public and private sectors. Literature suggests that dedicated P3 units and lifecycle integration are drivers of P3 benefits such as innovation. Future work can examine the significance of public agency structures and competencies on innovation as well as SPV relationships and collaboration on

innovation; the latter might require participant observation to shed light on the topic, given the reticence of private entities (at least in the US) to share information.

- **Early involvement of the private sector**: the case studies indicated that earlier involvement of the private sector enhanced innovation and value-added outcomes. I can also explore this further in the future by examining P3s delivered via unsolicited proposals or pre-development agreements. Of course, sole source procurement or selection can raise legitimacy as well as best value concerns, so procurement approaches in international settings such as the competitive dialogue offer another model for consideration and research.
- **QCA research**: The case research completed suggests that project characteristics/factors combine to generate innovation and value in infrastructure projects. Utilizing Qualitative Comparative Analysis (QCA), a broader set of cases, conditions (factors) and outcomes (innovation/value) could be examined to determine, which conditions combine to create outcomes of interest. QCA can provide similar insights as case research, but it is less resource intensive.

Longer term, I can examine the diffusion of innovations (Hartmann, 2006): vertical diffusion (Sheffer and Levitt, 2012) and in the network of organizations (Eaton et al., 2006; Taylor and Levitt, 2007). This type of work will require a longitudinal structure (forward looking via cases over time or backward looking via archival analysis) since diffusion is not easily measured at a point in time (as explained in this effort). However, the enablers and barriers to diffusion are quite important for overall social and economic progress, so studies of this sort could have very broad impacts.

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Appendices

Appendix A:

The 33 factors uncovered in the literature that enable or stifle innovation are listed below alphabetically, with their definition on the right hand side of the table.

#	**Factors (alphabetically)**	**Description**
1	Certainty/uncertainty	Clarity or fuzziness on aspects of the project
2	Champion	Person in leadership position that promotes the innovations
3	Client	Person or entity that sponsors the project
4	Collaboration	Effective working together towards a goal
5	Communication	The effective exchange of information between participants
6	Company support and motivation	Upper management support of employees to be creative and the companies motivation and drive to be innovative
7	Competition	The source and number of participants in the procurement
8	Complexity	Project complexity can "be defined as 'consisting of many varied interrelated parts' and can be operationalized in terms of differentiation and interdependency." (Baccarini, 1996)
9	Continuance of traditional roles	Stakeholders treating new processes and products as they did previously, not adapting to new ways
10	Contracts	Serves as the central governance mechanism of a project
11	Contract timing	The point in time at which the private sector gets involved in the project
12	Culture	Difference in culture between public and private (contracted parties) and between private partners (SPV, joint ventures, etc.)
13	Employee experience and motivation	Employees with suitable backgrounds, experience, and motivated to provide creative work
14	End user	The citizens and entities that benefit from the asset or service

#	Factors (alphabetically)	Description
15	Exogenous	Events that were considered exogenous before the project, e.g. project finance
16	Incentives/penalties	The existence or promotion of incentives to motivate the use of innovations
17	Influence of lifecycle on design	Incorporation of construction, maintenance, and operation cost reductions with a more efficient design
18	Integration/lack of integration	Effective long term assimilation of the different participants of the SPV. The construction industry is fragmented in three ways: 1) vertically, horizontally, and 3) longitudinally (Fergusson, 1993)
19	Knowledge management/lessons learned	The use of tools to compile previous experiences in other projects and use it in new projects
20	Long term nature of contracts	Increases the opportunity of innovation occurring given the higher incentives for investment (Roumboutsos and Saussier, 2014)
21	Market	Trends in the market and a client that promotes innovations
22	Opportunity to reuse innovation	Versatility of the innovation to be used in other projects
23	Organizational structure	Legal entity created by the equity holders of the project for the development and exploitation of the asset
24	Partnering	"…a long-term commitment between two or more organizations for the purpose of achieving specific business objectives by maximizing the effectiveness of each participant's resources." (CII, 2016)
25	Procurement	The means used by governments to buy their products and acquire assets and services
26	Project type and scale	The nature and magnitude of the project
27	Regulations and standards	The body of government documents that establish the regulative governance

#	Factors (alphabetically)	Description
28	Research and development	Investment in investigation of new products and processes
29	Risk	Exposure to the probability of adverse events in the project
30	Socioeconomic and environment	Social and environmental factors that motivate the company to create goodwill in the community
31	Specifications	Guidelines for the design and construction of the project asset or services
32	Supply chain	The effect of suppliers and specialized subcontractors
33	Technology	The availability and need of new technologies to approach construction or the provision of services

Below each of the 33 factors uncovered in the literature are explained. They are ordered by the number of papers discussing the factor.

Company support and motivation

As a counterpart to the client, the companies involved have a drive and motivation to be innovative (Goodrum and Haas, 2000) to lower cost, increase productivity, create competitive advantage, and increase market share or new markets (Gambatese and Hallowell, 2011b). In order to do this, upper management has to be committed (Liu et al., 2016) to the innovation process and supportive (Goodrum and Haas, 2000; Gambatese and Hallowell, 2011a) of employees. They show their commitment and support by: being open to new ideas (Eaton et al., 2006), having employee recognition programs (Eaton et al., 2006; Gambatese and Hallowell, 2011a), establishing conflict resolution strategies (Liu et al., 2016), and providing the necessary resources (Miller et al., 2009). Companies also promote innovation by being responsive to internal and external changes (Liu et al., 2016), establishing clear and appropriate goals (Eaton et al., 2006), and having "explicit coordination of the innovation process" (Bossink, 2004).

Champion

A shift in the position of the government has occurred where it is not acting as simply a buyer, but it is more involved in the process as mentioned by Nam and Tatum (1997). An important role needed inside governmental agencies and private companies to promote innovation, is the role of the innovation champion (Tatum, 1984; Nam and Tatum, 1997; Winch, 1998; Goodrum and Hass, 2000; Blayse and Manley, 2004; Bossink, 2004; Miller et al., 2009; Gambatese and Hallowell, 2011a; Pellicer et al., 2014; Ozorhon et al., 2016). This champion needs empowerment (Bossink, 2004) and must be an effective leader (Ozorhon et al., 2016). According to Nam and Tatum (1997), the innovation champion needs two characteristics, technical competence and authority. The technical competence enables the champion to overcome the uncertainty of innovation and the authority allows them to overcome the resistance to innovation.

Client

The client could be the most important stakeholder to promote innovation, given its unique position to demand innovation (Bossink, 2004; Pellicer, et al., 2014; Ozorhon et al., 2016) in their requirements, its leadership (Liu et al., 2016), its influence (Gambatese and Hallowell, 2011a) and involvement (Bossink, 2004; Liu et al., 2016) in the project lifecycle. Although the government as a client could be more risk averse, it still demands innovation from construction companies to "improve quality, reduce costs and speed up construction processes" (Eaton et al., 2006). The client could also inhibit innovation by having low capabilities (Miller et al., 2009; Uyarra et al., 2014), lack of interest (Miller et al., 2009), and not having the knowledge to evaluate proposals and alternatives provided by the competing companies institutions (Bossink, 2004).

Employee experience and motivation

The employees need the support and commitment from their companies to be innovative. The employees must be challenged with interesting tasks (Eaton et al., 2006) and feel free to question (Goodrum and Haas, 2000) anything related to the project. The team needs diversity of experience (Goodrum and Haas, 2000; Eaton et al., 2006; Russell et al., 2006), and it must have enough freedom, autonomy (Eaton el al., 2006), and training (Bossink, 2004; Eaton et al., 2006; Ozorhon et al., 2016) to be creative.

Collaboration

Leiringer's (2006) work questions the collaboration in P3s given the "stringent fashion" in which contracts are written; similarly, others (Bossink, 2004; Eaton et al., 2006; Miller et al., 2009; Uyarra et al., 2014) discuss poor collaboration as an impediment to innovation. Aghion and Tirole (1994) exploring innovation in an incomplete contract framework, explain how partners are hesitant to share knowledge in research joint ventures if they cannot protect their intellectual profit, because by increasing the potential of success of the joint venture, they could be strengthening their future competitors. For Roberts (1988), the formal and informal collaboration of "critical role-players" is required for effective innovation to occur, while, Liu et al. (2016) mention how having partners that have experience in collaboration is a critical success factor of innovation. Eaton in the other hand sees a "lack of openness and trust" as a barrier to innovation.

Integration/lack of integration

Russell et al. (2006) list responsibility integration and procurement that promotes greater integration of life cycle phases as a potential for greater innovation. Others see integration as an important driver of innovation as well, "integration of design and build" (Tatum, 1984; Bossink, 2004) and "project team integration" (Gambatese and Hallowell, 2011a), while the "segmentation of project disciplines" (Eaton et al., 2006) is seen as an inhibitor of innovation.

Fergusson (1993) argues that the construction industry is fragmented in three ways: 1) vertically, different stages of the life cycle; horizontally, disciplines or trades; and 3) longitudinally, through time with different companies working on different projects. Later, Fergusson and Teicholz (1996) found that vertical and longitudinal integration allowed higher quality. Building on Fergusson's work, Sheffer and Levitt (2012) look at two types of innovations; 1) modular, which match current industry standards and processes; and 2) integral, which challenge current standards and require new interfaces and processes. They found "clear support for the widely-held view that team integration is beneficial to project outcomes." They mention horizontal integration eliminates longitudinal fragmentation and that horizontal and vertical integration can help align the interests of the different firms. Theoretically, horizontal and vertical integration is found in P3 arrangements, which ought to spur innovation.

Dubois and Gadde (2002) characterize the construction industry as being composed of activities that are tightly and loosely connected. When these connections are loose, there is no communication between activities, resulting in a lack of learning and innovation. They argue that long term relationships beyond single projects are necessary to foster innovation, creating tighter couplings that may enhance opportunities for innovation. However, according to findings from Guevara and Garvin (2015), repeat relationships are not necessarily happening in the US and Canadian markets. They mapped the markets for the last 20 years to explore the participation and integration of private firms and found that most of the interactions are not recurrent and companies that work together on one project often compete against each other in subsequent projects.

Knowledge management/lessons learned

The use of tools to compile previous experiences in other projects and use it in new projects is an important factor of innovation. Information gathering, the “creation of knowledge networks” (Bossink, 2004), and “sharing of ideas in the industry” (Eaton et al., 2006) are seen as important drivers of innovation because they allow the industry to learn from previous success and failures. The codification of this knowledge is seen also as an important driver to promote learning across the industry (Blayse and Manley, 2004; Miller et al., 2009; Gambatese and Hallowell, 2011a; Ozorhon et al., 2016).

Procurement

Procurement processes are the means used by governments to buy their products and acquire their assets. Akintoye and Main (2012), argued that innovation through procurement is needed now more than ever given the push for enhanced VfM, more complex projects, stronger competition among potential vendors/bidders, and pressure from legislative demands. They mentioned integrated procurement methods such as P3s have been associated with delivering innovation through process improvement since these methods engender trust, cooperation, and teamwork, which enable focusing on project objectives. For Edler and Georghiou (2007) the demand for innovation, in the sense of a client that requests innovative solutions in their procurement of goods and services, is a key driver of innovation that is not fully utilized. They argue public procurement policies could aid in this regard, they define demand-side innovation policies the following way: “all public measures to induce innovations and/or speed up diffusion of innovations through increasing the demand for innovations, defining new functional requirement for products and services or better articulating demand.”

For de Valence (2010), traditional procurement processes create transparent transactions on which the private sector is going to compete, but this acts as an inhibitor to innovation because the tender process is directly tied to a price on a specific product. If a bidder submits an alternative solution, it will be non-conforming with the original invitation to bid. While in a non-traditional procurement, like P3, the government can encourage more innovative solutions. The ability to evaluate different alternatives inside the procurement process is seen as a factor of innovation by several authors (Tatum, 1984; Russell et al., 2006; Miller et al., 2009). Additionally, Uyarra et al. (2014) mention the following barriers to innovation in procurement: “a lack of interaction with procuring organisations, the use of rigid as opposed to outcome-based specifications, low competences of procurers, a poor management of risk, poor feedback, a low appreciation of unsolicited ideas and previous private sector delivery history, and cumber-some pre-qualification procedures and conditions”.

Incentives/penalties

The existence or lack thereof of incentives or penalty regimes in the contract agreement can serve as a driver or an inhibitor of innovation (Goodrum and Haas, 2000; Eaton et al., 2006; Pellicer et al., 2014; Ozorhon et al., 2016). Also subsidies during the procurement could act as drivers of innovations by promoting the use of "innovative applications and materials" (Bossink, 2004). But the use of these incentives during the procurement could generate a rent-seeking mentality from the private sector acting as an inhibitor to innovation (Hoppe and Schmitz, 2013).

Risk

The risks of the project are formally allocated within the contract. Proper risk allocation for the promotion of innovation is salient in several papers: Eaton et al. (2006) places "conservatism and avoidance of risk" as an impediment for innovation; Leiringer (2006) mentions that "innovation and risk go hand-in-hand"; and Russell et al. (2006) mention the "reasonableness of risk assignment" as a driver/inhibitor of innovation. But proper risk allocation is not potentially an inhibitor to innovation; risk itself could be inhibiting the occurrence of higher order innovations. Roumboutsos and Saussier (2014) argue the innovations will mainly be incremental, given they have lower risk, and the private is driven to lower the exposure to risk.

Technology

The lack of technology to address new requirements that challenge the existing practice in the constructions industry (Tatum 1984; Pellicer et al., 2014), as the introduction of new technology (Tatum, 1984; Ozorhon et al., 2016) are drivers of innovation. But the cost of these new technologies could be too high, making companies hesitant to adopt them and introduce them in the construction field (Miller et al., 2009) potentially inhibiting innovation.

Regulations and standards

The procurement process, as the acquisition of services or goods, is at the center of the provision of infrastructure. It is codified within the current regulations and standards followed in practice and approved by law. Miozzo and Dewick (2002) looking at the relationship between corporate governance and innovation highlight the important role that governments could have in innovation by promoting collaboration and supporting alternative procurement relations. Innovation stimulating regulations are seen as a driver of innovation (Goodrum and Haas, 2000; Blayse and Manley, 2004; Bossink, 2004; Ozorhon et al., 2016). Gann and Salter (2000) mention that government regulations and policies influence the direction of technological change; this influence could be promoted through procurement mechanisms that incentivize innovation, e.g. providing bonus points for innovative solutions in a procurement, or by having procurements that demand innovations (Edler and Georghiou, 2007). But if the regulations and standards are too rigid they could act as an inhibitor of innovation (Tatum, 1984; Eaton et al., 2006).

Communication

Leiringer (2006) suggests that greater communication between the public and private partners is necessary to reach mutual understandings of their needs and ambitions. Communication is seen as an important driver of innovation (Goodrum and Haas, 2000; Eaton et al., 2006; Gambatese and Hallowell, 2011a). Bossink (2004) sees lateral communication structures (LCS) as an important driver of innovation, he argues that the LCS "facilitated the exchange information needed to develop and implement new business processes and materials and applications in the projects." Eaton et al. (2006) argue that poor or a lack of communication is an impediment to innovation; while Tatum (1984) found "rigid barriers to engineering and construction communication" as a barrier to innovation.

Culture

Barlow and Koberle-Gaiser (2008) mention the difference in culture between public and private parties hinders innovation, since interviewees in their study saw a "public sector mentality" that did not allow them to "think outside the box." But this can happen as well between the different member companies that comprise SPVs or joint ventures (JVs) that pursue projects. Blayse and Manley (2004) and Liu et al. (2016) indicate that the innovation culture of the companies involved as an important driver of innovation; while Pellicer et al. (2014) and Ozorhon et al. (2016) indicate that organizational culture is important to innovation.

Exogenous

Gann and Salter (2000) mention the management of innovation is complex given the discontinuous nature of project-based production because of the broken loops of learning and feedback. They mention that projects are affected by events that were considered exogenous before the project. As an example they mention the timing and structure of project finance or environmental concerns, which introduce new institutional players that could affect the use of technologies. Additionally, other exogenous factors are mentioned in the literature; patient money (Goodrum and Haas, 2000), internal political problems (Eaton et al., 2006), "pervasive public attitude towards construction – not in my back yard" (Miller et al., 2009), external support (Liu et al., 2016), and lack of financial resources (Ozorhon et al., 2016). Interestingly, Uyarra et al. (2014) mention the inadequate management of IPR (intellectual property rights) as a barrier to innovation, something that is relevant in ATC procurement processes.

Research and development

Contractors and construction companies are not necessarily the stakeholders that are performing the majority of the research and development (R&D) in the industry. Manley and McFallan (2006) found that the majority of the R&D in the construction industry is performed by manufacturers. This reluctance of investment in R&D from construction companies is seen as a barrier to innovation (Miller et al. 2009). But R&D can serve as a driver of innovation, even in an informal fashion (Bossink, 2004), hence the importance of the management of knowledge that is acquired during previous projects.

Competition

Competition can "encourage experimentation, diversify sources, lower prices, expand services, and enable foreign access" (Steil et al., 2002), something that Russell et al. (2006) argue could drive innovation. They mention competition in price based approaches can act as an inhibitor to innovation, but mention that technical competitions have provided "significant innovations" because they focus on the design and the solution. The literature shows the; competition atmosphere (Goodrum and Haas, 2000), source of competition (Russell et al., 2006), number of competitors (Russell et al., 2006), and competition level (Ozorhon et al., 2016) as factors of innovation. Russell et al. (2006) argue that while the increase in competition will entail lower costs to the owner, the construction companies will require greater efficiencies, something that could promote innovations. The increase in participants could prompt bidders to lose interest in the process given the low chances of winning the project. To encourage competition and innovation, they argue owners will need to make a project procurement that is a "function of other factors (e.g., type, scale, repeatability of project type, risk assignment, economic climate)" (Russell et al., 2006), all of which are also factors of innovation I have uncovered in this investigation.

Influence of lifecycle on design

Raisbeck (2009) argues that the transfer of design risk is an important source of innovation in P3s. This is one of the arguments of the benefits of P3s because different facets of the asset life cycle are incorporated into the design and savings are possible through the incorporation of maintenance and operation cost reductions with a more efficient design. Others see the influence of lifecycle on design as a driver of innovation, allowing the incorporation of construction, maintenance, and operation cost reductions with a more efficient design, e.g., "interdisciplinary coordination within the design team" (Tatum, 1984), design involvement of contractors allowing construction input during design (Goodrum and Haas, 2000; Ozorhon et al., 2016). Ball et al. (2000) describe innovation as a key feature of the Private Finance Initiative (PFI) and as one of the key advantages of the approach over traditional procurement methods. They explain that advocates and promoters of the PFI indicated that although private finance is more expensive, this should be offset by private sector innovations in design and operational management. Interestingly, Kline and Rosenberg (1986), argue that innovations have been brought forward even when the "science is inadequate, or even totally lacking". They highlight how contrary to common wisdom, the first step to an innovation is not research, but design, "usually either inventions or analytic design." Where they describe analytic design as: "a study of new combinations of existing products and components, rearrangements of processes, and designs of new equipment within the existing state of the art." This is something particularly interesting given the lack of investment in R&D in the construction industry as mentioned previously (Seaden and Manseau, 2001).

Partnering

Barlow (2000) looking at offshore oilfields mentioned that partnering resulted in technical and process innovation when compared with traditionally procured projects. He sees partnering as a tool for stimulating innovation and learning benefits at the organizational level. Barlow believes that partnering with a clear risk/reward sharing and development of trust will allow successful partnering. Other authors see partnering as a driver of innovation; industry relationships (Blayse and Manley, 2004), "strategic alliances and long term relationships" (Bossink, 2004), and professionalism and credibility of partners (Liu et al., 2016).

Project type and scale

The project type and scale is seen as a factor of innovation (Russell et al., 2006). Russell et al. (2006) argue a higher potential of innovation in heavy civil projects than in vertical construction projects because of project size, scope, and complexity. A similar argument could be said for the payment mechanism in a P3 project that is demand risk vs. an availability payment (AP) P3 project; Jolley and Garvin (2014) say the following: "There is very little, if any, incentive for concessionaires to propose changes to a conceptual design that increases the potential for demand if they do not receive any benefit from increased toll revenue—in AP PPPs [P3s]". Other authors (Blayse and Manley, 2004; Miller et al., 2009) point to the nature of construction projects as a factor of innovation. For example; usually, infrastructure is expected to have long service lives, this puts pressure in the industry to use "tried and tested" solutions instead of innovative approaches (Blayse and Manley, 2004). Uyarra et al. (2014) explain how a project contract not been "big enough" can act as a barrier to innovation, they explain how larger firms are sensitive to the scale of the projects and having a "too small or too short public contracts may act as a strong disincentive to innovation."

Specifications

Ball et al. (2000) found that an output specification approach was crucial for promoting innovation. Allowing the private partner to have the ability to use its creativity, and propose a solution to the government will be a key enabler of innovation. Having output specifications is essential for design flexibility and increases the potential for innovation, while in the other hand, prescriptive specifications are seen as barriers to innovation (Tatum, 1984; Eaton et al., 2006; Uyarra et al., 2014). Russell et al. (2006) argue that having too stringent requirements also could act as a barrier to innovation, they say the following: "stringent requirements and constraints can limit competition or increase the risks and penalties associated with novel technologies and therefore inhibit innovation."

Certainty/uncertainty

Altshuler and Zegans (1990) explain that public agencies tend to utilize resources inefficiently, wanting to minimize the risk of embarrassing incidents while trying to innovate. They argue that while business managers search for new ideas, public managers take refuge in the familiar. This is further clarified by Teisman and Klijn (2004) who highlighted that governments can tolerate losses as long as they are tolerated by the electorate. This highlights the difference between the private sector that has its share of market leaders willing to take risks for a higher return and the public sector in general, which is risk averse and in a majority of instances want to be sure innovations will not fail. Hartmann (2006) says that "because innovation is inherently uncertain, it is unlikely that all variables are known in advance." But the private sector also needs certainty in the environment it is doing business, Russell et al. (2006) list four factors that could act as drivers or inhibitors of innovation out of the 22 they uncovered for this topic: i) certainty of economic environment, ii) certainty of political environment, iii) certainty of regulatory environment, and iv) certainty of stakeholder environment.

Opportunity to reuse innovation

Several authors mention the ability of using an innovation from a current project in subsequent projects as a driver (Tatum, 1984; Goodrum and Haas, 2000; Russell et al., 2006; Liu et al., 2016). Others (Blayse and Manley, 2004; Liu et al., 2016) mention the necessity of reusing past innovations as a strategic importance. Given the low levels of R&D in the construction industry, been able to adapt and reuse innovations created internally and externally is of great importance.

Complexity

Denhardt (2003) explains how in the past government procurement started by specifying exactly what was expected and the contractor had to provide what was in the specifications even if it was not what was needed. Now, government procurement can start with specifying objectives and government goes through the process together with the contractor instead of just waiting for the product at the end. This has made contracts more complex because governments are now requesting solutions and knowledge rather than requesting just a product. In this regard, Russell et al. (2006) argue how the evidence shows a higher potential of innovation in heavy civil projects than in vertical construction projects, because of project size, scope, and complexity. "Project complexity implies a high level of technical sophistication in the design and related construction processes; it also implies stringent technical and performance requirements." (Russell et al., 2006) They explain how the project complexity – uniqueness can act as an inhibitor because of a lack of previous experience, but this same situation could act as a driver because the lack of standards, codes, and previous experience could promote the creation of novel solutions.

Continuance of traditional roles

Nam and Tatum (1992) mention that among the barriers that prevent integration is the perceived traditional roles, for example, reluctance of designers to receive input from construction personnel, or governmental personnel treating a P3 as a traditional procurement (Eaton et al., 2006). Additionally, by not wanting to adapt to new processes and products, and having a "strong reliance on past experience" (Miller et al., 2009) innovation could be inhibited.

Market

Innovation occurs within firms or organizations when potential exists to capture value or payoff from the innovation. According to Kline and Rosenberg (1986), the drive to innovate is motivated by the desire to create competitive advantages over other companies; this competitive advantage will enable them to create a market, enter a new market, and/or increase profits. Roberts (1988) says the following: "Technological innovation can provide the potential for altering the competitive status of firms and nations. It can contribute to increased corporate sales and profits, as well as individual and national security and wellbeing." For Bossink (2004) the "market pull" is an important driver of innovation, this could occur naturally, pushed by the market (Miller et al., 2009), or requiring governmental guarantees to motivate companies to offer the innovative solutions (Bossink, 2004).

Organizational structure

The legal entity created by the equity holders of a project for the development and exploitation of the asset, or the special purpose vehicle (SPV), is seen as a factor of innovation. Davies and Salter (2006) in their examination of SPVs say they have created a "moveable feast" given the subcontracting that is done in the different stages of the life cycle. They argue there is less evidence for a new model of innovation; the government has just shifted the separation of design, construction, and operation from them, to the private sector without higher integration. They indicate that P3 SPVs tend to fragment as a risk allocation and transfer strategy. Hobday (1998) indicated that all else equal (*ceteris paribus*) increasing the amount of companies involved in the delivery of a product makes coordination more complex. As mentioned by Jones and Saad (2003), an inappropriate organizational structure is a barrier to innovation. Given the arguments about SPVs by Hobday (1998) and Davies and Salter (2006), SPVs could be acting as an inappropriate organizational structure for the promotion of innovation.

Socioeconomic and environment

Ozorhon et al. (2016) mention "corporate social responsibility" (CSR) and "environment and sustainability" (E&S) as drivers of innovation; they argue that CSR improves the corporate image and helps in providing a higher client satisfaction. They mention there is a connection between a CSR strategy and innovative performance. In the other hand, they argue that by wanting to comply with the E&S requirements and lower environmental impacts, companies are driven to innovate. Russell et al. (2006) argue that the "requirement for broader socioeconomic benefits, often incorporated into contracts and concession agreements" can be drivers of innovation in process innovations due to local construction processes that could provide efficiencies. But they could act as inhibitors in product innovations given the exclusion of specialized foreign parties with knowledge in products that are not available locally.

Contracts

The contract document in a P3 transaction serves as the central governance mechanism to enforce the negotiated terms and specifications during the procurement. Uyarra et al. (2014) mention the contract size as another inhibitor to innovation; a small contract size will act as an inhibitor given the investment in procurement versus contract size. Something not necessarily prevalent in P3s given the contract size, but the high transaction costs and the potential use of an alternative technical concept (ATC) process in which the private is incurring in additional costs could act as inhibitors to innovation. Tatum (1984) found that an "adversarial contractual relationship" could act as a barrier to innovation, as did Eaton et al. (2006) for the "format of the project contract". Something especially relevant, since Leiringer (2006) argues that P3 contracts are written in a "stringent fashion", something that could be inhibiting innovation in P3s.

End user

The citizens and entities that will benefit from the asset or service, sometimes have the least input on the final configuration of the asset or service, although they are represented by the client, which in the case of highway infrastructure, will be elected officials and government agency representatives. A "clear identification of users' needs" (Liu et al., 2016) is identified as an important factor for innovation, as is the ability to get feedback from them (Miller et al., 2009).

Contract timing

Contract timing refers to the point in time at which the private sector gets involved in the project. Antillon et al. (2016) found that the early involvement of the private sector in P3 projects is a driver of innovation. Ozorhon et al. (2016) also saw the early involvement as a driver of innovation in construction as it allows trust to grow between partners and for them to share information early on in the project.

Long term nature of contracts

The long term nature of P3 contracts should allow lifecycle integration and bundling of activities. Roumboutsos and Saussier (2014) explain how the long term perspective of a P3 contract increases the opportunity of innovation occurring given the higher incentives for investment. The private partner will have a drive to find innovations that will generate reductions in maintenance and operation. Uyarra et al. (2014) argue that having longer contracts allows the reduction of uncertainty because it allows the private to project a return for a long term and encourages investment in innovation.

Supply chain

The supply chain is seen as an important factor for innovation (Eaton et al., 2006). Suppliers and specialized sub-contractors are the ones that usually introduce new processes and products to contractors (Bossink, 2004).

Appendix B

Identified Papers Discussing Factors of Innovation in Construction/Infrastructure

#	Authors	Year	Title	Journal	Citations
1	Aghion, P. and Tirole, J.	1994	The Management of Innovation.	*The Quarterly Journal of Economics*	1417
2	Gann, D. M. and Salter, A. J.	2000	Innovation in Project-Based, Service-Enhanced Firms: the Construction of Complex Products and Systems.	*Research Policy*	1206
3	Hobday, M.	1998	Product Complexity, Innovation and Industrial Organisation.	*Research Policy*	1109
4	Edler, J., and Georghiou, L.	2007	Public Procurement and Innovation—Resurrecting the Demand Side	*Research policy*	704
5	Dubois, A., and Gadde, L. E.	2002	The construction industry as a loosely coupled system: implications for productivity and innovation.	*Construction Management and Economics*	697
6	Winch, G.	1998	Zephyrs of creative destruction: understanding the management of innovation in construction.	*Building Research & Information*	467
7	Blayse, A. M., and Manley, K.	2004	Key influences on construction innovation.	*Construction innovation*	417
8	Barlow, J.	2000	Innovation and learning in complex offshore construction projects.	*Research Policy*	301
9	Nam, C. H. and Tatum, C. B.	1997	Leaders and Champions for Construction Innovation.	*Construction Management and Economics*	276
10	Roberts, E. B	1988	Managing Invention and Innovation.	*Research Technology Management*	239
11	Miozzo, M., and Dewick, P.	2002	Building competitive advantage: innovation and corporate governance in European construction.	*Research Policy*	203
12	Bossink, B. A.	2004	Managing drivers of innovation in construction networks.	*Journal of construction engineering and management*	183
13	Ling, F. Y. Y.	2003	Managing the implementation of construction innovations.	*Construction Management and Economics*	150
14	Taylor, J. E., and Levitt, R.	2007	Innovation alignment and project network dynamics: an integrative model for change.	*Project Management Journal*	131
15	Leiringer, R.	2006	Technological Innovation in PPPs: Incentives, Opportunities and Actions.	*Construction Management and Economics*	120

#	Authors	Year	Title	Journal	Citations
16	Hartmann, A.	2006	The context of innovation management in construction firms.	*Construction management and economics*	105
17	Nam, C. H. and Tatum, C. B.	1992	Noncontractual Methods of Integration on Construction Projects.	*Journal of Construction Engineering and Management*	101
18	Gambatese, J. A., and Hallowell, M.	2011a	Enabling and measuring innovation in the construction industry.	*Construction Management and Economics*	86
19	Barlow, J. and Köberle-Gaiser, M.	2008	The Private Finance Initiative, Project Form and Design Innovation: The UK's Hospitals Programme.	*Research Policy*	82
20	Uyarra, E., Edler, J., Garcia-Estevez, J., Georghiou, L., and Yeow, J.	2014	Barriers to innovation through public procurement: A supplier perspective.	*Technovation*	74
21	Eaton, D., Akbiyikli, R., and Dickinson, M.	2006	An Evaluation of the Stimulants and Impediments to Innovation within PFI/PPP Projects.	*Construction Innovation*	69
22	Altshuler, A. and Zegans, M.	1990	Innovation and Creativity: Comparisons Between Public Management and Private Enterprise.	*Cities*	67
23	Manley, K., and McFallan, S.	2006	Exploring the drivers of firm-level innovation in the construction industry.	*Construction Management and Economics*	59
24	Gambatese, J. A., and Hallowell, M.	2011b	Factors that influence the development and diffusion of technical innovations in the construction industry	*Construction Management and Economics*	56
25	Park, M., Nepal, M. P., and Dulaimi, M. F.	2004	Dynamic modeling for construction innovation.	*Journal of Management in Engineering*	49
26	Hoppe, E., and Schmitz, P.	2013	"Public-private partnerships versus traditional procurement: Innovation incentives and information gathering."	*RAND Journal of Economics*	48
27	Dikmen, I., Birgonul, M. T., and Artuk, S. U.	2005	Integrated framework to investigate value innovations.	*Journal of Management in Engineering*	45
28	Tatum, C. B.	1984	What Prompts Construction Innovation?	*Journal of Construction Engineering and Management*	40
29	Ozorhon, B., Abbott, C., and Aouad, G.	2014	Integration and leadership as enablers of innovation in construction: Case study	*Journal of Management in Engineering*	34

#	Authors	Year	Title	Journal	Citations
30	Lloyd-walker, B. M., Mills, A. J., and Walker, D. H.	2014	Enabling construction innovation: the role of a no-blame culture as a collaboration behavioural driver in project alliances.	*Construction Management and Economics*	33
31	Ball, R., Heafey, M., and King, D.	2000	Managing and Concluding the PFI Process for a New High School: Room for Improvement?	*Public Management: An International Journal of Research and Theory*	31
32	Murphy, M., Heaney, G., and Perera, S.	2011	A methodology for evaluating construction innovation constraints through project stakeholder competencies and FMEA.	*Construction Innovation*	27
33	Russell, A. D., Tawiah, P., and De Zoysa, S.	2006	Project Innovation – a Function of Procurement Mode?	*Canadian Journal of Civil Engineering*	26
34	Pellicer, E., Yepes, V., Correa, C. L., and Alarcón, L. F.	2014	Model for systematic innovation in construction companies.	*Journal of Construction Engineering and Management*	25
35	Kulatunga, K., Kulatunga, U., Amaratunga, D., and Haigh, R.	2011	Client's championing characteristics that promote construction innovation.	*Construction Innovation*	22
36	Yitmen, I.	2011	Intellectual capital: A competitive asset for driving innovation in engineering design firms.	*Engineering Management Journal*	21
37	Tawiah, P. A., and Russell, A. D.	2008	Assessing infrastructure project innovation potential as a function of procurement mode.	*Journal of Management in Engineering*	20
38	Roumboutsos, A., and Saussier, S.	2014	"Public-private partnerships and investments in innovation: the influence of the contractual arrangement."	*Construction Management and Economics*	16
39	Chan, I. Y., Liu, A. M., and Fellows, R.	2014	Role of leadership in fostering an innovation climate in construction firms.	*Journal of Management in Engineering*	15
40	Xue, X., Zhang, R., Yang, R., and Dai, J.	2014	Innovation in construction: a critical review and future research.	*International Journal of Innovation Science*	14
41	de Valence, G.	2010	Innovation, Procurement and Construction Industry Development.	*Construction Economics and Building*	13
42	Yepes, V., Pellicer, E., Alarcón, L. F., and Correa, C. L.	2016	Creative innovation in Spanish construction firms.	*Journal of Professional Issues in Engineering Education and Practice*	11

#	Authors	Year	Title	Journal	Citations
43	Serpell, A., and Alvarez, R.	2014	A systematic approach for evaluating innovation management in construction companies.	*Procedia Engineering*	6
44	Brockmann, C., Brezinski, H., and Erbe, A.	2016	Innovation in Construction Megaprojects.	*Journal of Construction Engineering and Management*	3
45	Havenvid, M. I., Hulthén, K., Linné, Å., and Sundquist, V.	2016	Renewal in construction projects: tracing effects of client requirements.	*Construction Management and Economics*	2
46	Liu, H., Skibniewski, M. J., and Wang, M.	2016	Identification and hierarchical structure of critical success factors for innovation in construction projects: Chinese perspective	*Journal of Civil Engineering and Management*	1
47	Ozorhon, B., Oral, K., and Demirkesen, S.	2016	Investigating the Components of Innovation in Construction Projects.	*Journal of Management in Engineering*	1
48	Kimmel, S. C., Toohey, N. M., and Delborne, J. A.	2016	Roadblocks to responsible innovation: Exploring technology assessment and adoption in US public highway construction.	*Technology in Society*	1
49	Antillon, E. I., Molenaar, K. R., and Javernick-Will, A.	2016	Evaluating the Effect of Contract Timing on Lifecycle-Design Innovation in Public–Private Partnerships: Comparative Case Study of Highway Projects.	*Journal of Construction Engineering and Management*	0
50	Demirdöğen, G., and Işık, Z.	2016	Effect of Internal Capabilities on Success of Construction Company Innovation and Technology Transfer.	*Tehnicki vjesnik/Technical Gazette*	0
51	Liu, A. M., and Chan, I. Y.	2017	Understanding the Interplay of Organizational Climate and Leadership in Construction Innovation.	*Journal of Management in Engineering*	0
52	Ozorhon, B., and Oral, K.	2017	Drivers of Innovation in Construction Projects.	*Journal of Construction Engineering and Management*	0
Books					
53	Kline, S. J. and Rosenberg, N.	1986	An Overview of Innovation	*The Positive Sum Strategy: Harnessing Technology for Economic Growth,*	5669
54	Steil, B., Victor, D. G., and Nelson, R. R.	2002	Introduction and Overview,	*Technological Innovation and Economic Performance*	154

#	Authors	Year	Title	Journal	Citations
55	Jones, M. and Saad, M.	2003	*Managing Innovation in Construction*	1st Ed., Thomas Telford, London, England.	84
56	Denhardt, K. G.	2003	The Procurement Partnership Model: Moving to a Team-Based Approach,	*The Procurement Revolution*	11
57	Davies, A and Salter, A	2006	The Great Experiment: Public-Private Partnerships and Innovation in Design, Production, and Operation of Capital Goods in the UK,	*Flexibility and Stability in the Innovating Economy,* 1st Ed., Oxford University Press,	7
58	Akintoye, A and Main, J.	2012	Innovation through Collaborative Procurement Strategy and Practices	*Construction Innovation and Process Improvement*	1
Conference					
59	Teisman, G. and Klijn, E. H.	2004	"PPPs: Torn Between Two Lovers."	*European Business Forum*	17
60	Goodrum, P. and Haas, C.	2000	Variables Affecting Innovations in the U.S. Construction Industry.	*Construction Congress VI*:	12
61	Raisbeck, P	2009	"Considering Design and PPP Innovation: A Review of Design Factors in PPP Research."	*Proc., 25th Annual ARCOM Conference*, Association of Researchers in Construction Management	4
Reports					
62	Miller, G., Furneaux, C. W., Davis, P., Love, P., and O'Donnell, A.	2009	*Built environment procurement practice: impediments to innovation and opportunities for changes*.	Curtin University of Technology, Australia.	27
63	Sheffer, D. A., and Levitt, R. E.	2012	"Fragmentation inhibits innovation: overcoming professional and trade lock-in."	*CRGP Working paper# 0069*	4

#	# of Papers Cited	Journal	Web of Science (2015)	SJR Scopus (2015)
1	11	*Construction Management and Economics*	No	0.967
2	7	*Journal of Construction Engineering and Management*	1.152	1.219

#	# of Papers Cited	Journal	Web of Science (2015)	SJR Scopus (2015)
3	7	*Journal of Management in Engineering*	1.84	1.06
4	6	*Research Policy*	3.47	3.536
5	4	*Construction innovation*	No	0.508
6	1	*The Quarterly Journal of Economics*	5.538	20.761
7	1	*RAND Journal of Economics*	1.582	3.654
8	1	*Technovation*	2.243	1.794
9	1	*Building Research & Information*	2.196	1.433
10	1	*Cities*	2.051	1.422
11	1	*Project Management Journal*	1.765	0.979
12	1	*Journal of Civil Engineering and Management*	1.53	0.907
13	1	*Journal of Professional Issues in Engineering Education and Practice*	0.538	0.678
14	1	*Research Technology Management*	No	0.522
15	1	*Canadian Journal of Civil Engineering*	0.586	0.386
16	1	*Tehnicki vjesnik/Technical Gazette*	0.464	0.333
17	1	*Construction Economics and Building*	No	0.319
18	1	*Engineering Management Journal*	0.468	0.307
19	1	*Procedia Engineering*	No	0.238
20	1	*International Journal of Innovation Science*	No	0.173
21	1	*Technology in Society*	0.185*	No
22	1	*Public Management: An International Journal of Research and Theory*	No	No

*2000

Appendix C

Identified Alternative Technical Concepts

All of the these identified ATCs form part of the proposal submitted by the winning proposers and were actually used in the projects, hence all comply with element 'A' of the rubric employed in this research to identify and assess innovation.

A. Actual use - Was it applied in the project?
B. Nontrivial - Does it entail more than a scope or cost reduction in the project?
C. Change - Does it deviate from current practice and standards?
D. Improvement - Does it provide a positive change?
E. Process, product, or system - Does it entail a new process, product, or system (PPS)?
F. Novel - Is it novel to the jurisdiction, client, or company?

#	Description	A	B	C	D	E	F	Meets Threshold
				DTC				
1	ITC 3 Concept 1: Uses post tensioning to convert a bridge structure in 9th Street from two spans to a single span. Eliminates splicing of the beams and eliminates the construction of additional interior piers.	Y	Y	N	Y	N	N	The RFP required the submittal of an ITC if post tensioning was going to be used in bridge superstructures. The use of post tensioning provides improvements in construction costs; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
2	ITC 3 Concept 2: Use of solid sections for straddle bents in the Ramp 5 Flyover using cast-in-place or post tensioned elements instead of steel.	Y	Y	N	Y	N	N	The use of concrete lowers the maintenance and inspection costs of the straddle bents. It also allows the use of only two columns instead of two. This provides improvements in construction and O&M costs and allows a better use of the alignment by eliminating the two additional columns; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
3	ITC 3 R1: Proposed the authorization of several potential approaches to build the columns in the Ramp 7 Flyover Bridge. cast-in-place, precast, pre-stressed, or post tensioned systems of one, two, or three columns instead of four.	Y	N	N	Y	N	N	Allows faster construction in a congested section of the project providing potential schedule and cost improvement to the project; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
4	ITC 4 & 4 R1: Requested the used of multiple ground improvement methods not specified in the original RFP, but previously used in the state: stone columns/rammed aggregate piers (approved with conditions), cementitious soil improvement (approved with conditions) , auger cast piles (approved with conditions), timber piles (not approved), monotube piles (not approved), wick drains (approved with conditions).	Y	Y	N	Y	N	N	The methods approved in the ITC will provide substantial schedule and cost savings in the project by eliminating the need for excavation of material at the site and consolidation time before construction; but these are not a deviation in standard practice, do not provide a new PPS, and are not novel.
5	ITC 5: Proposed to use precast pre-stressed concrete box beams instead of precast pre-stressed tub girders given a lower construction cost and increased availability in the state.	Y	N	N	Y	N	N	Provides potential savings in construction cost; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
6	ITC 6 R1: Proposed the consideration of lateral resistance provided to drilled shaft foundations by overburden soil above the bedrock in the design of the foundation.	Y	N	N	Y	N	N	After considering the appropriate scour level, the consideration of the lateral resistance of the soil will allow savings in construction costs; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
7	ITC 10: Proposed the use of multiple lightweight fill material in areas prone to settlement: EPS foam block (approved with conditions), lightweight concrete/foam concrete (approved with conditions), lightweight aggregate/expanded shale (approved with conditions), fly ash (not approved), and tire derived aggregate (not approved).	Y	Y	N	Y	N	N	Provides potential improvements in accelerated construction and avoids settlements in certain sensitive areas; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel. The conditions for approval are substantial and prescriptive, in the case of the EPS foam block, 22 conditions accompany the approval.

#	Description	A	B	C	D	E	F	Meets Threshold
8	ITC 11: Requested the use of micropiles for bridge foundations with existing adjacent utilities.	Y	Y	Y	Y	Y	Y	The RFP indicated that the use of micropiles required the submittal of an ITC. The use of micropiles has the potential of avoiding impacts to existing utilities and the need to do expensive relocations.
9	ITC 12: Requested the approval to use Indiana and Illinois DOTs approved temporary concrete barriers instead of the Kentucky approved.	Y	N	N	N	N	Y	The Indiana and Illinois barriers are shorter than the Kentucky barriers allowing easier transport and placement; but this is not a deviation in standard practice and does not provide a new PPS.
10	ITC 14: Proposed the use of minimal piping and free falling runoff as alternate bridge drainage instead of having a fully closed pipe drainage system.	Y	N	N	N	N	N	The use of a fully closed pipe drainage system according to the ITC document is "highly susceptible to clogging", this is avoided by the alternative of using a free fall of runoff and splash basins; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
11	ITC 19: Proposed to use a T-Wall precast retaining wall system instead of cast-in-place gravity retaining walls or mechanically stabilized earth.	Y	Y	Y	Y	Y	Y	The use of the T-wall system is proposed as a solution where the space is not sufficient to use mechanically stabilized earth systems and concrete trucks will affect traffic for cast-in-place retaining walls. The use of this system is a new product, not previously used in the state, which provides improvements in construction time and traffic.
12	ITC 29: Proposes the use of precast concrete gravity retaining wall systems approved by the state, but that required the submittal of an ITC requesting its use.	Y	Y	N	Y	N	N	The use of the approved precast retaining wall systems proposed as a solution where the space is not sufficient to use mechanically stabilized earth systems and concrete trucks will affect traffic for cast-in-place retaining walls will provide benefits in construction time and traffic; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
13	ITC 33 R2: Request to perform the design of overlay pavement	Y	N	N	N	N	N	Approved with highly prescriptive conditions that established milling depths and materials to use. This is not a deviation in standard practice, does not provide a new PPS, and is not novel.
EEC								
#	Description	A	B	C	D	E	F	Meets Threshold
14	ATC 3: Replace a crossover diverging diamond and traffic signals with two multi-lane roundabouts.	Y	Y	Y	Y	Y	N	The use of the roundabout in lieu of the original design provided a solution that saved in: right of way acquisition, construction cost, and time; it will also have lower O&M costs and increase traffic safety. Additionally, it provides a potential reduction of $900K in monthly availability payments (MAP); but the use of roundabouts is novel to the region of the project but not to InDOT or the state of Indiana.
15	ATC 4: Provide an alternative access road instead of the realignment of existing road and construction of new bridge.	Y	Y	N	Y	N	N	The use of an alternate access point allowed the avoidance of realigning an existing road and the construction of a new bridge structure improving traffic in the community, and lowering environmental impacts while providing a potential MAP saving of $70K; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
16	ATC 5: Shorten tunnel length by 220 feet on the south and 50 feet on the north, additionally reduced pillar width from 40 to 35 feet on south portal and widen to 40 feet subsequently inside the tunnel.	Y	N	N	Y	N	N	Shorten tunnel length by 270 feet, avoided shale layer to reduce temporary support, shortened project duration as tunnel was on critical path, avoided the disposition of 500K CY of material. The MAP will be lowered by an estimated $1.1MM; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
17	ATC 6: Elimination of a 840 feet flyover ramp and replacement with a single point interchange.	Y	N	N	Y	N	N	The elimination of the flyover ramp provided an increase in safer operations and provides saving in estimated MAP of $225K; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
18	ATC 9: Use of uncoated weathering steel instead of painted structural steel.	Y	Y	Y	Y	Y	N	The use of weathering steel which creates protective rust instead of structural steel which requires costly maintenance and upkeep of the paint provides savings in construction and O&M, this translates to an estimated $738K saving in MAP; but it is novel to InDOT.
19	ATC 14: Optimized tunnel cross section and utilities within it.	Y	Y	Y	Y	Y	Y	The optimization of the tunnel cross section allowed the reduction of the width of the walkway, minimized the liner thickness, and improved the efficiency of the ventilation and fire suppression systems; all of this provided a potential discount of $620K in MAP.
20	ATC 15: Request for concessionaire to design shoulder pavement to its choice (accepted with conditions).	Y	N	N	N	N	N	The reduction of shoulder thickness is just a cost reduction; it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
					I4			
#	Description	A	B	C	D	E	F	Meets Threshold
21	ATC 4 R2: Build 11 feet wide lanes on urban arterials instead of 12 feet as prescribed in specifications.	Y	N	N	Y	N	N	A reduction in scope that will allow faster construction and construction savings estimated at $2.4 MM. This is allowed in AASHTO Greenbook and is not a deviation in standard practice, does not provide a new PPS, and is not novel.
22	ATC 6 R1: This ATC proposes to use recycled concrete aggregate (RCA) from the I4 project as aggregate for the base.	Y	Y	N	Y	N	N	Provides a potential $5.2 MM in savings by using RCA instead of new material. This cost reduction provides an improvement in construction cost. However, although a materials bulletin did not allow its use in projects with Federal aid, a new FDOT specification allowed its use, predicated in research performed at the University of Florida. It is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
23	ATC 7 R2: This ATC proposed the use of precast edge girders that incorporate a curb along the external edge of the girder that eliminates the need for overhang falsework in the bridge deck.	Y	Y	Y	Y	Y	Y	FDOT specifications considered typical girders and did not consider the deck form curb. The use of this modified precast beam was previously used by the proponent in projects in North Carolina, but not used before in Florida and is expected to provide $450K in schedule savings and $140K in construction. It also provides increased safety by reducing the need for forming the overhang.
24	ATC 14: Use maturity meters to test concrete compressive strength instead of waiting 14 days for testing representative cylinders.	Y	Y	Y	Y	Y	Y	While ASTM 1074 was adopted by ASTM in 1987, it is not adopted by FDOT; their standards require that test cylinders be performed or that 14 have passed in order to open a segment to traffic. This complies with all elements of the rubric.
25	ATC 15*: Wymore-Riddle overpass reconfiguration.	Y	N	N	Y	N	N	The rearrangement of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
26	ATC 19*: Michigan-Kaley interchange realignment.	Y	N	N	Y	N	N	The rearrangement of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
27	ATC 20 R2*: I-4/SR 408 direct connection proposal.	Y	Y	N	Y	N	N	Providing a direct connection alleviates traffic; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
28	ATC 21: Use reclaimed limerock aggregate for new aggregate base.	Y	N	N	Y	N	N	Provides an improvement in estimated costs of $3.7MM by utilizing reclaimed limerock from the existence base instead of new material, but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
29	ATC 24*: Redesign Formosa Curve to comply with stopping sight distance.	Y	N	N	N	N	N	Provides a typical section instead of a wide section to comply with stopping sight distance due to the elimination of a toll gantry in the final RFP. This is not a deviation in standard practice, does not provide a new PPS, and is not novel.
30	ATC 26 R1*: Provide an optimization to the fly-under ramp at Orange Blossom Trail (OBT).	Y	N	N	Y	N	N	The optimization of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
31	ATC 27*: Kirkman Road pedestrian bridge.	Y	Y	N	Y	N	N	The construction of a new pedestrian bridge not previously considered in the RFP increases safety; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
32	ATC 28: recently installed pipes to remain.	Y	N	N	Y	N	N	The reduction of scope of allowing the recently installed pipes to remain instead of installing new ones provides cost savings; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
33	ATC 29 R2*: This ATC provided additional auxiliary lane – EB I-4 Princeton to Fairbanks to improve capacity.	Y	Y	N	Y	N	N	This ATC added $1.23 MM of additional scope in the project improving the level of service. However, the construction of new general purpose lanes does not deviate from current practice, provide a new PPS, or is novel.
34	ATC 30 R1*: This ATC provided additional auxiliary lane – WB I-4 Maitland to Lee to improve capacity and reduce weaving distance between ramps.	Y	Y	N	Y	N	N	This ATC added $1.28 MM of additional scope in the project improving the level of service and increasing the weaving distance between two ramps; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
35	ATC 31*: Elimination of median rail corridor.	Y	N	N	Y	N	N	Eliminates the rail corridor depicted in the design plans but eliminated from the RFP, it provides an estimated $8.7MM in savings, but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
36	ATC 32: Use of high definition CCTV instead of analog as required in the RFP.	Y	Y	Y	Y	Y	N	Provides an improved technology over the required in the RFP and not currently used by FDOT; however it is used by other agencies in Florida.
37	ATC 34*: This ATC provided additional auxiliary lane – WB I-4 OBT to Conroy to improve capacity.	Y	Y	N	Y	N	N	This ATC added $2.18 MM of additional scope in the project improving the level of service which includes the widening of an overpass bridge; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
38	ATC 36: This ATC proposes to increase the floor plan of the toll equipment buildings to allow space to house the ITS equipment in a separate room, instead of building two separate structures.	Y	N	N	N	N	N	This ATC provides a trivial reduction in scope. That does not deviate in standard practice, does not provide a new PPS, and is not novel.
39	ATC 38 R1*: This ATC provides additional auxiliary lane – EB I-4 Colonial To Princeton to improve capacity and improves an exit that used to overflow with traffic previously.	Y	Y	N	Y	N	N	This ATC added $1.91 MM of additional scope in the project improving the level of service and includes improvements to an exit to alleviate traffic overflow; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
40	ATC 39 R1*: Division-Kaley intersection improvements.	Y	N	N	Y	N	N	The improvements of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
41	ATC 41 R1 Option 2*: Maitland Summit Boulevard grade separation and geometric realignment to convert to a tight urban diamond interchange.	Y	Y	N	Y	N	N	This ATC added $9 MM of additional scope in the project improving the level of service and reducing traffic overflow; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
42	ATC 42*: Garland Avenue alignment modification.	Y	N	N	Y	N	N	The refinement of the original design provided a potential saving of $3.8MM; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
43	ATC 43*: Lee Road Lane revision.	Y	N	N	Y	N	N	Provides improvements to the capacity of Lee Road, but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
44	ATC 45: This ATC proposed to utilize the same back-up generators at toll gantries for ITS and toll equipment.	Y	N	N	Y	N	N	This ATC eliminated the purchase of separate power generators for tolling equipment and ITS equipment by upsizing the generators and using one for both equipment's. This constitutes a reduction in scope that provided an improvement in cost of $346K; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
45	ATC 49 Option 1*: SR408 WB reconfiguration.	Y	N	N	Y	N	N	The reconfiguration of the interchange provides enhanced mobility form the original design and created an estimated $28 MM in savings; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
					US36			
#	Description	A	B	C	D	E	F	Meets Threshold
46	ATC 1: Proposed 22 feet offset in pivot point to change the profile grade line creating a bifurcated profile to reduce the quantity of earthwork and retaining walls.	Y	N	N	Y	N	N	Provides schedule and cost savings; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
47	ATC 2: Modified a specification that required daily roughening of slopes to only as determined by an Erosion Control Supervisor.	Y	N	N	Y	N	N	This is expected to reduce 50% of the costs related to the roughening of slopes; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
48	ATC 3: Proposed to "plug and fill" existing drainage structures with suitable material instead of removing them.	Y	N	N	Y	N	N	Provides potential savings in costs related to the removal of the existing structures and subsequent compaction of the backfill, it also provides improvements in safety due to the elimination of excavations near traffic; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
49	ATC 4: Modified the specifications for the subbase and subgrade material to be used in a bikeway in the project.	Y	N	N	Y	N	N	The RFP called for the excavation of clay and replacement of more permeable material on the bikeway. This would have created maintenance issues because of differential movements in the pavement given the water trapped in the clay given the new permeable material been used. By using treated on-site material the "bathtub" effect was eliminated. This provided improvements in maintenance costs and hauling costs; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
50	ATC 8: Modified the minimum pipe size allowed in cross drains from 36 inches to 24 inches to avoid raising the profile of the roadway.	Y	N	N	N	N	N	This allowed the optimization of the roadway profile design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
51	ATC 9: Requested the use of on-site material with R-value of less of 10 to be used in non-structural parts of embankments to reduce the disposal of on-site material and hauling of new material.	Y	N	N	Y	N	N	The use of on-site material and reduction of new material needed provides cost savings; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
52	ATC 10: Requested the use of DR 11 HDPE pipes perpendicular to soil reinforcement to avoid the construction of several manholes and a trunk line in the median.	Y	Y	Y	Y	Y	Y	The use of this new pipe for CDOT will allow the avoidance of construction of new manholes in the median which according to the proposer provides design challenges given the configuration and are difficult to maintain. While the cost of construction of manholes and the new pipe cancel each other, this provides substantial potential savings in maintenance costs.

#	Description	A	B	C	D	E	F	Meets Threshold
53	ATC 19: Requested modifications to the pavement design; more specifically the use of overlay, the reduction in thickness in the subbase, and the reduction of pavement thickness by using the American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Pavement Design Guide (MEPDG).	Y	Y	Y	Y	Y	Y	The use of overlay and the reduction in thickness of the subgrade are not deviations in standard practice, and do not provide a new PPS or are novel. However, the use of the AASHTO MEPDG, not used and allowed in CDOT specifications is novel. AASHTO adopted the MEPDG in 2007, while CDOT and other state transportation agencies have studied it; it has been adopted in seven states, but not Colorado. The use of the MEPDG allows a design that fits and adapts better to site-specific characteristics. The use of the MEPDG will provide potential construction cost savings by allowing the reduction in pavement thickness.

* Due to a change in over 5ft in vertical or horizontal alignment from the original project configuration

Appendix D

Identified Technical Enhancements

All of the these identified technical enhancements and ATCs form part of the proposal submitted by the winning proposers and were actually used in the projects, hence all comply with element 'A' of the rubric employed in this research to identify and assess innovation.

- Actual use - Was it applied in the project?
- Nontrivial - Does it entail more than a scope or cost reduction in the project?
- Change - Does it deviate from current practice and standards?
- Improvement - Does it provide a positive change?
- Process, product, or system - Does it entail a new process, product or system (PPS)?
- Novel - Is it novel to the jurisdiction, client, or company?

#	Description	A	B	C	D	E	F	Meets Threshold
SH288								
1	ATC 5A: Reconfiguration of IH 610 interchange; this ATC relocates toll lanes at grade instead of having them at a fifth level flyover in the interchange, it also increases connectivity between SH288 and IH 610 towards the general purpose lanes and new managed lanes	Y	Y	N	Y	N	N	Alters interchange from original configuration and provides substantial savings by eliminating a fifth level flyover, and is expected to increase revenue; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
2	ATC 5D: This ATC is contingent to ATC 5A; it provides improvements to the toll configuration by eliminating ingresses an egresses to the managed lanes at Reed Road given the new connectors added in ATC 5A	Y	Y	N	Y	N	N	Increases safety due to the elimination of the ingresses and egresses of the managed lanes toward the general purpose lanes and vice versa given the new movements incorporated in ATC 5A; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
3	"Innovative Concept" from proposal document: Potential to increase design speed from 60 to 65 mph north of Belfort and from 60 to 70 mph south of Belfort, improving traffic and functionality	Y	Y	N	Y	N	N	The change in design speed will improve traffic and the functionality of the managed lanes providing a nontrivial improvement to the usage of the managed lanes; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
4	"Innovative Concept" from proposal document: Realignment of ramps south of IH 610 between Almeda and SH288 providing a reduction on right of way acquisition from 40 feet to 15 feet	Y	Y	N	Y	N	N	The realignment will provide savings in right of way acquisition costs, providing a nontrivial improvement in the cost of the project; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
5	"Innovative Concept" from proposal document: Realignment of a portion of SH288 to avoid the re-localization of two existing storm water pumps, an opening in the inside barrier will be left in place to provide access to maintenance vehicles	Y	Y	N	Y	N	N	The realignment of SH 288 in Brays Bayou provides a nontrivial improvement in project cost by avoiding the re-localization of two storm water pumps and the respective utilities; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
I77								
#	Description	A	B	C	D	E	F	Meets Threshold
6	ATC-1: Optimization of I-77/I-85 interchange design by reallocating the HOT lanes eliminating a third level structure and reducing noise impacts to residential community	Y	Y	N	Y	N	N	The optimization of the interchange eliminates a third level flyover providing substantial savings; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
7	ATC 9: Provide a variance to bridge widths over Lake Norman allowing the widening of the existing structures towards the median instead of outside avoiding encroaching on the lake	Y	N	N	Y	N	N	By widening the bridge in the median instead of towards the lake there are improvements by diminishing potential environmental impacts to the lake; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
8	ATC 16: Sound barriers to remain and not demolished as original scope by reducing shoulder width	Y	N	N	N	N	N	By reducing the shoulder with, sound barriers built ten years prior will remain in place; but this does not comply with any of the elements of the rubric except actual use.

#	Description	A	B	C	D	E	F	Meets Threshold
9	"Other Innovations" from proposal document: Temporary detour road to alleviate impacts during construction	Y	N	N	N	N	N	The use of a temporary detour road alleviates traffic during construction; but this does not comply with any of the elements of the rubric except actual use.
10	"Other Innovations" from proposal document: Construction access directly from existing overpasses to median to minimize disturbances in traffic	Y	N	N	N	N	N	The use of the existing overpasses to provide access points to the construction of the managed lanes minimizes impacts to traffic and improves safety; but this does not comply with any of the elements of the rubric except actual use.
11	"Other Innovations" from proposal document: Maximizing the use of existing pavement by separating HOT lanes in a portion of highway	Y	N	N	N	N	N	The alignment of the managed lanes avoided new construction by using existing pavement; but this does not comply with any of the elements of the rubric except actual use.
12	"Other Innovations" from proposal document: Optimization of I-277/I-77 Interchange design by modifying horizontal alignment and reducing the use of straddle bents to just one	Y	Y	N	Y	N	N	The improvement in horizontal alignment allowed a reduction in straddle bents; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
13	"Other Innovations" from proposal document: I-77 realignment to minimize impacts to historical properties	Y	N	N	N	N	N	The realignment of the highway reduced impacts to historical properties; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
14	"Other Innovations" from proposal document: Compatibility with Charlotte Railroad Improvement and Safety Program (CRISP) and current design	Y	N	N	N	N	N	Realigning the expansion of the highway to avoid reconstruction given a foreseen expansion of the railroad; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
15	Reducing shoulder pavement thickness	Y	N	N	N	N	N	The reduction of shoulder thickness is just a cost reduction; it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
16	Addition of lanes to avoid weaving from managed lanes to general purpose lanes	Y	Y	N	Y	N	N	The addition of lanes to avoid weaving between the ingress and egress points of the managed lanes increases the safety aspects of the project; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
				EEC				
#	Description	A	B	C	D	E	F	Meets Threshold
17	ATC 3: Replace a crossover diverging diamond and traffic signals with two multi-lane roundabouts	Y	Y	Y	Y	Y	N	The use of the roundabout in lieu of the original design provided a solution that saved in: right of way acquisition, construction cost, and time; it will also have lower O&M costs and increase traffic safety. Additionally, it provides a potential reduction of $900K in monthly availability payments (MAP); but the use of roundabouts is novel to the region of the project but not to InDOT or the state of Indiana.
18	ATC 4: Provide an alternative access road instead of the realignment of existing road and construction of new bridge	Y	Y	N	Y	N	N	The use of an alternate access point allowed the avoidance of realigning an existing road and the construction of a new bridge structure improving traffic in the community, and lowering environmental impacts while providing a potential MAP saving of $70K; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
19	ATC 5: Shorten tunnel length by 220 feet on the south and 50 feet on the north, additionally reduced pillar width from 40 to 35 feet on south portal and widen to 40 feet subsequently inside the tunnel	Y	N	N	Y	N	N	Shorten tunnel length by 270 feet, avoided shale layer to reduce temporary support, shortened project duration as tunnel was on critical path, avoided the disposition of 500K CY of material. The MAP will be lowered by an estimated $1.1MM; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
20	ATC 6: Elimination of a 840 feet flyover ramp and replacement with a single point interchange	Y	N	N	Y	N	N	The elimination of the flyover ramp provided an increase in safer operations and provides saving in estimated MAP of $225K; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
21	ATC 9: Use of uncoated weathering steel instead of painted structural steel	Y	Y	Y	Y	Y	N	The use of weathering steel which creates protective rust instead of structural steel which requires costly maintenance and upkeep of the paint provides savings in construction and O&M, this translates to an estimated $738K saving in MAP; but it is novel to InDOT.

#	Description	A	B	C	D	E	F	Meets Threshold
22	ATC 14: Optimized tunnel cross section and utilities within it	Y	Y	Y	Y	Y	Y	The optimization of the tunnel cross section allowed the reduction of the width of the walkway, minimized the liner thickness, and improved the efficiency of the ventilation and fire suppression systems; all of this provided a potential discount of $620K in MAP.
23	ATC 15: Request for concessionaire to design shoulder pavement to its choice (accepted with conditions)	Y	N	N	N	N	N	The reduction of shoulder thickness is just a cost reduction; it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
NTE								
#	Description	A	B	C	D	E	F	Meets Threshold
24	Extension of managed lanes south by 1.2 miles	Y	Y	Y	Y	N	N	The extension not previously considered as part of the project and not included in the at the time ongoing environmental impact statements studies allowed a deduction of $150 MM in government contribution after paying for itself and providing additional revenue to the SPV, by alleviating congestion in an important intersection which increased traffic considerably for the project; but the construction itself is not novel.
25	Rearrangement of I35W/I-820 interchange	Y	Y	N	Y	N	N	The rearrangement of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
26	Revision of general purpose lanes and managed lanes vertical alignment configuration	Y	Y	N	Y	N	N	The at grade solution provided with this technical enhancement provided a cost improvement from the original design; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
27	Design bridge to use shorter span and reduce steel and concrete instead of using a longer span steel beams	Y	N	N	Y	N	N	The reduction in scope to design for shorter span concrete instead of longer span steel beams provided improvements in cost savings; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
28	Additional general purpose lanes	Y	Y	N	Y	N	N	Additional general purpose lanes improve the level of service; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
29	Conveyer system for reuse of pavement instead of trucks	Y	Y	Y	Y	Y	Y	The use of a conveyer system to transport recycled pavement from its source to its final placement place instead of having trucks hauling the material reduced costs and increased traffic safety by not having trucks in traffic. This type of construction method had not been previously seen by TxDOT personnel and was novel to them.
ERT								
#	Description	A	B	C	D	E	F	Meets Threshold
30	Use of jet-fans for ventilation system instead of transverse ventilation system	Y	Y	Y	Y	Y	Y	The longitudinal jet-fan system is a new technology not previously used by VDOT who is a substantial improvement over the transverse ventilation system used by VDOT.
31	Immersed concrete tunnel (box culvert) instead of steel tube encased in concrete tunnel	Y	Y	Y	Y	Y	Y	All tunnels in Virginia had previously been steel-shell tunnels; the immersed concrete tunnel brought new construction and design methods and processes in Virginia.
32	Tunnel cross section (box type)	Y	Y	Y	Y	Y	Y	Having a box type cross section instead of a circular cross section as previously used in Virginia allowed less excavation and allowed the selection for concrete over steel as the tunnel material.
33	Use of a deluge fire suppression system	Y	Y	Y	Y	Y	Y	The deluge fire suppression system is a new technology not previously used by VDOT; it increases substantially the safety of the users of the tunnel.
34	Use of weathering steel instead of painted structural steel (specified by owner after analysis of initial cost vs. long term investment)	Y	Y	Y	Y	Y	N	The use of weathering steel which creates protective rust instead of structural steel which requires costly maintenance and upkeep of the paint provides savings in construction and O&M; but it is novel to VDOT.

#	Description	A	B	C	D	E	F	Meets Threshold
35	Replacement of stainless steel reinforcing for bridge decks for epoxy coated reinforcing steel	Y	N	N	N	N	N	The replacement of stainless reinforcing steel which provides a better solution and a longer life over epoxy coated reinforcing steel was a reduction in cost; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
					I4			
#	Description	A	B	C	D	E	F	Meets Threshold
36	ATC 4R2: Build 11 feet wide lanes on urban arterials instead of 12 feet as prescribed in specifications	Y	N	N	Y	N	N	A reduction in scope that will allow faster construction and construction savings estimated at $2.4 MM. This is allowed in AASHTO Greenbook and is not a deviation in standard practice, does not provide a new PPS, and is not novel.
37	ATC 6 R1: This ATC proposes to use recycled concrete aggregate (RCA) from the I4 project as aggregate for the base	Y	Y	N	Y	N	N	Provides a potential $5.2 MM in savings by using RCA instead of new material. This cost reduction provides an improvement in construction cost. However, although a materials bulletin did not allow its use in projects with Federal aid, a new FDOT specification allowed its use, predicated in research performed at the University of Florida. It is not a deviation in standard practice, does not provide a new PPS, and is not novel.
38	ATC 7 R2: This ATC proposed the use of precast edge girders that incorporate a curb along the external edge of the girder that eliminates the need for overhang falsework in the bridge deck	Y	Y	Y	Y	Y	Y	FDOT specifications considered typical girders and did not consider the deck form curb. The use of this modified precast beam was previously used by the proponent in projects in North Carolina, but not used before in Florida and is expected to provide $450K in schedule savings and $140K in construction. It also provides increased safety by reducing the need for forming the overhang.

#	Description	A	B	C	D	E	F	Meets Threshold
39	ATC 14: Use maturity meters to test concrete compressive strength instead of waiting 14 days for testing representative cylinders	Y	Y	Y	Y	Y	Y	While ASTM 1074 was adopted by ASTM in 1987, it is not adopted by FDOT; their standards require that test cylinders be performed or that 14 have passed in order to open a segment to traffic. This complies with all elements of the rubric.
40	ATC 15*: Wymore-Riddle overpass reconfiguration	Y	N	N	Y	N	N	The rearrangement of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
41	ATC 19*: Michigan-Kaley interchange realignment	Y	N	N	Y	N	N	The rearrangement of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
42	ATC 20 R2*: I-4/SR 408 direct connection proposal	Y	Y	N	Y	N	N	Providing a direct connection alleviates traffic; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
43	ATC 21: Use reclaimed limerock aggregate for new aggregate base	Y	N	N	Y	N	N	Provides an improvement in estimated costs of $3.7MM by utilizing reclaimed limerock from the existence base instead of new material, but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
44	ATC 24*: Redesign Formosa Curve to comply with stopping sight distance	Y	N	N	N	N	N	Provides a typical section instead of a wide section to comply with stopping sight distance due to the elimination of a toll gantry in the final RFP. This is not a deviation in standard practice, does not provide a new PPS, and is not novel.
45	ATC 26 R1*: Provide an optimization to the fly-under ramp at Orange Blossom Trail (OBT)	Y	N	N	Y	N	N	The optimization of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
46	ATC 27*: Kirkman Road pedestrian bridge	Y	Y	N	Y	N	N	The construction of a new pedestrian bridge not previously considered in the RFP increases safety; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
47	ATC 28: recently installed pipes to remain	Y	N	N	Y	N	N	The reduction of scope of allowing the recently installed pipes to remain instead of installing new ones provides cost savings; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
48	ATC 29 R2*: This ATC provided additional auxiliary lane – EB I-4 Princeton to Fairbanks to improve capacity	Y	Y	N	Y	N	N	This ATC added $1.23 MM of additional scope in the project improving the level of service. However, the construction of new general purpose lanes does not deviate from current practice, provide a new PPS, or is novel.
49	ATC 30 R1*: This ATC provided additional auxiliary lane – WB I-4 Maitland to Lee to improve capacity and reduce weaving distance between ramps	Y	Y	N	Y	N	N	This ATC added $1.28 MM of additional scope in the project improving the level of service and increasing the weaving distance between two ramps; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
50	ATC 31*: Elimination of median rail corridor	Y	N	N	Y	N	N	Eliminates the rail corridor depicted in the design plans but eliminated from the RFP, it provides an estimated $8.7MM in savings, but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
51	ATC 32: Use of high definition CCTV instead of analog as required in the RFP	Y	Y	Y	Y	Y	N	Provides an improved technology over the required in the RFP and not currently used by FDOT; however it is used by other agencies in Florida.
52	ATC 34*: This ATC provided additional auxiliary lane – WB I-4 OBT to Conroy to improve capacity	Y	Y	N	Y	N	N	This ATC added $2.18 MM of additional scope in the project improving the level of service which includes the widening of an overpass bridge; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
53	ATC 36: This ATC proposes to increase the floor plan of the toll equipment buildings to allow space to house the ITS equipment in a separate room, instead of building two separate structures	Y	N	N	N	N	N	This ATC provides a trivial reduction in scope. That does not deviate in standard practice, does not provide a new PPS, and is not novel.
54	ATC 38 R1*: This ATC provides additional auxiliary lane – EB I-4 Colonial To Princeton to improve capacity and improves an exit that used to overflow with traffic previously	Y	Y	N	Y	N	N	This ATC added $1.91 MM of additional scope in the project improving the level of service and includes improvements to an exit to alleviate traffic overflow; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
55	ATC 39 R1*: Division-Kaley intersection improvements	Y	N	N	Y	N	N	The improvements of the interchange provided enhanced mobility form the original design; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
56	ATC 41 R1 Option 2*: Maitland Summit Boulevard grade separation and geometric realignment to convert to a tight urban diamond interchange	Y	Y	N	Y	N	N	This ATC added $9 MM of additional scope in the project improving the level of service and reducing traffic overflow; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
57	ATC 42*: Garland Avenue alignment modification	Y	N	N	Y	N	N	The refinement of the original design provided a potential saving of $3.8MM; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.
58	ATC 43*: Lee Road Lane revision	Y	N	N	Y	N	N	Provides improvements to the capacity of Lee Road, but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.
59	ATC 45: This ATC proposed to utilize the same back-up generators at toll gantries for ITS and toll equipment	Y	N	N	Y	N	N	This ATC eliminated the purchase of separate power generators for tolling equipment and ITS equipment by upsizing the generators and using one for both equipment's. This constitutes a reduction in scope that provided an improvement in cost of $346K; but it is not a deviation in standard practice, does not provide a new PPS, and is not novel.

#	Description	A	B	C	D	E	F	Meets Threshold
60	ATC 49 Option 1*: SR408 WB reconfiguration	Y	N	N	Y	N	N	The reconfiguration of the interchange provides enhanced mobility form the original design and created an estimated $28 MM in savings; but this is not a deviation in standard practice, does not provide a new PPS, and is not novel.

* Due to a change in over 5ft in vertical or horizontal alignment from the original project configuration