A FRAMEWORK

FOR ASSESSING INNOVATION POTENTIAL

AS A FUNCTION OF PROCUREMENT MODE IN

INFRASTRUCTURE PROJECT DELIVERY

by

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ABSTRACT

The delivery of infrastructure projects in almost all cases is impacted by critical issues of budget constraints, programme delays, quality and safety concerns, and an increasingly complex stakeholder environment. Innovation as it relates to the physical, process, organisational/contractual and financial dimensions of a project has a central role to play in not only meeting the demands of a wide variety of project performance metrics (e.g. technical, economic, quality, etc.) but also improving upon them and overall project efficiency. The use of public-private partnerships, or P3's has increased in popularity with governments on a worldwide basis as a means of driving innovation and efficiency to overcome the procurement and performance challenges of delivering infrastructure such as highways, water supply, and hospitals. One of several arguments forwarded by P3 advocates in support of one or more of its variants as a procurement mode, in place of traditional design-bid-build procurement for delivering such infrastructure, is the ability of P3 to harness more of the innovative capability of the private sector. It is asserted that this capability results in lower capital and/or life cycle costs and shorter delivery time, and in enhanced long-term project performance.

This thesis examines the notion that the innovation potential of a project is a function of delivery mode, and describes findings from case studies to identify evidence that supports / contradicts such a viewpoint. Identified and defined here are 22 factors or conditions and their states that can act as drivers or inhibitors of innovation for infrastructure projects as a function of procurement mode and project context (e.g. project type, project scale, nature of competition). The thesis, thus presents a framework to assist with the selection and structuring of procurement mode to maximise innovation/efficiency potential for a specific project from the perspective of a government agency making decision to procure an infrastructure facility. The product, process, organizational / contractual, and financial / revenue innovations achieved on 3 major transportation projects are reviewed to test the concepts developed in the framework. The factors and conditions influencing the choice of procurement mode for a large-scale student housing facility are also discussed.

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CHAPTER 1

1.1. Introduction

Infrastructure performance and procurement pose significant challenges to governments around the world. These age-old challenges include project time delays and cost overruns, long periods of underinvestment and increased fiscal pressures which often result in a piecemeal approach to infrastructure procurement, or in some instances, infrastructure declines/gaps in spite of population growth. Consequently the quest for solutions to these challenges has spawned the search for and use of creative public procurement processes. Such 'innovative' procurement systems are meant to allow new ideas, new technologies, new capital and new firms (Miller, 1996) entry into the project delivery process to improve performance, quality and satisfy other stakeholder requirements. The active re-emergence and use of Public-Private Partnerships (P3s) or Private Finance Initiatives (PFIs) – the UK equivalent of P3 - as alternative procurement methods, alongside other re-engineered conventional public procurement routes have expanded governments' procurement options to consider in the infrastructure delivery decision-making process[1]. The expanded options represents attempts by government to drive innovation and efficiency at the project level, when renewing (maintaining and modernising) existing infrastructure or building new infrastructure. A major challenge in selecting a procurement mode from a range of options is how to 'forecast' *a priori* the kinds of innovations and related benefits that might be achieved by the adoption of one mode over another i.e. attempts at quantifying incremental innovation at the front-end of the procurement process. Past and current research studies (Rowlinson & McDermott, 1997; Ogunlana, 1999; Walker & Hampson, 2003) into efficient procurement systems for infrastructure development and delivery highlight the critical role/capabilities of the client and the project team among a number of the factors necessary for appropriate technology adaptation and implementation on a project.

The objectives of the procurement selection process should look beyond the conventional criteria of time, cost and quality. They need to consider not only a single project focus but embrace as well considerations of the totality of the client's (in this, government or public institution) operation. In developing a selection methodology and/or structure for procurement systems certain value-enhancing key factors and issues (such as project complexity, the project

[1] The use of the word re-emergence has been selected because in the past, major infrastructure projects have been procured in this manner – e.g. the Suez Canal.

environment, competition, technical capabilities, etc.) have been identified as crucial to addressing the shortcomings/weaknesses of commonly-used conventional procurement methods and are particularly important in the pursuit and implementation of innovation in the procurement process. This thesis presents an extensive list of factors and discusses the issues pertaining to innovation potential maximisation at the project level through the selection of the most appropriate procurement mode for an infrastructure project based on its unique context and circumstances.

The thesis is structured in a three-part series of manuscripts that discuss the relationship between procurement mode and innovation as part of government's objective of assessing incremental innovation as a function of procurement mode in order to maximise project innovation and efficiency while possibly achieving other benefits. Following this introductory chapter is a paper that discusses the innovative potential of the private sector and how it relates to the project delivery process. It represents the first pass at how to think about the problem and at establishing a taxonomy of factors that can either drive or inhibit innovation at the project level and the interplay among them i.e. it fleshes out the skeleton presented in Chapter 2. Chapter 3 gives a more detailed discussion of the ideas, concepts and issues raised in the preceding exploratory paper. Chapter 4 discusses the influence of procurement mode on project innovation/efficiency and vice versa. It further investigates the relationship between procurement and innovation and outlines a conceptual framework for selecting and/or structuring a procurement mode (having selected a particular mode from a list of candidate modes) to maximise project innovation/efficiency potential. It provides a refinement of the list of factors and the possible states they can assume to either drive or inhibit innovation.

1.2. Background and Motivation

The perception and attitude of the construction industry towards the pursuit of innovation have generally been described as being dominated by conservatism, particularly due to the risks inherent in most innovative technologies and concepts, and slow in adopting/adapting new knowledge in comparison with other industries, such as manufacturing. Berstein & Lemmer (1996) likened such pursuits and the complexities of design and construction innovations in the US construction industry to the process of assembling a jigsaw puzzle involving all the project parties (designers, constructors, suppliers, owners, policy makers/governments, regulators, etc.) who must work together as a perfect project team in moving productive new ideas into practice.

Studies conducted on performance improvement in the construction delivery process (Gyle Report, 1992; Latham Report, 1994; Egan Report, 1998; Australian Cole Commission Enquiry Report, 2003; Seaden et al., 2001; Anderson & Schaan, 2001; Pryke, 2004) underscore the need for the industry to improve productivity and quality through key structural and cultural reforms of which creative procurement and contracting strategies are included. These reports catalogue the inefficiencies, client dissatisfactions and poor project quality/performance that characterise construction project delivery, and the challenges associated with delivering infrastructure projects with superior performance in an increasingly complex and hostile stakeholder environment.

Certainly, innovation can play a significant role in surmounting many of the challenges found in the construction delivery process. Eaton (2001:1), Gann (2000:220) and Barret et al. (2001:1) highlight the potential for innovation development and implementation at the industry and project levels to meet the demands for improvement in performance, quality and productivity as well as to increase the competitive advantage of individual construction firms. Innovation development leads to a differentiation in the products/services provided by these firms. In pursuance of this objective, Manseau & Seaden (2001) present an international review of the effectiveness of public policies and interventions to drive innovations and efficiencies in the construction industry. In addition to such macro-level efforts and initiatives to intensify innovation, there has been a pervasive use and resurgence, on a global scale, of alternative procurement routes (particularly variants of P3s) over the last decade driven, in part, by the belief or perception that alternative procurement modes encourage and drive innovations/efficiencies. Government's call for improvement in infrastructure project delivery has spawned the adoption of alternative procurement strategies to encourage innovation in the provision of infrastructure and related ancillary services, which in turn have led to some specific response initiatives and their reviews in the UK and Australia (Treasury Committee UK, 1996; Hogdson & Davies, 1997; National Audit Office, 1997, 2003; Partnerships Victoria Policy, 2000; Fitzgerald, 2004).

The objective of driving project innovation and efficiencies through the use of a variety of procurement modes has been extensively discussed by several researchers and practitioners in the construction project delivery industry. Design/build (D/B) mode has been identified as one procurement mode that can drive innovations in infrastructure project delivery (Molenaar and

Johnson, 2003; Songer & Molenaar, 1996; Brockmann, 2005; Yates, 1996; McGinnity, 2001). The opportunities for innovation have been described as high in infrastructure projects adopting partnering and/or alliancing procurement approaches (Thompson & Sanders 1998; Thorpe 2004; Manley 2004; Walker & Hampson 2003; PricewaterhouseCoopers 2004; Winch 2000; Matthews 1999). Other authors (Lemos 1997; Garvin 2003; Levy 1996; Liddle 1997; Leiringer 2003; Grimsey & Darren 2004) have argued for more integrated procurement systems and processes (i.e. variants of P3/PFI) - to drive and realise innovations in infrastructure delivery. Whilst most of the foregoing propositions have attempted to solve the project innovation puzzle through the use of a particular procurement mode, Miller (1997, 1999) and Miller et. al. (2000) advocate a multi-faceted approach to infrastructure project delivery. There is a growing recognition that choice of project delivery/procurement method impacts the timing and scope of innovation at each phase of the infrastructure delivery process – i.e. the choice of procurement mode directly affects the choice of technology, design approach, construction methods, facility operations and project financing. Miller (1997) therefore contends that purely public and purely private delivery mechanisms are, among others, inimical to innovation and therefore proposes a mixed strategy to encourage innovation and address the challenges of infrastructure procurement and performance. The strategy is based on an all-encompassing analysis that encapsulates the interplay between two important project dimensions: the means of project delivery and the means of project finance when procuring a portfolio of infrastructure facilities.

In providing a conceptual framework for assessing incremental innovation in the project procurement mode selection process, this research study has adopted an eclectic approach in investigating the relationship of innovation as a function of procurement mode. Procurement modes considered embrace but are not limited to DBB (traditional design-bid-build and its variants), DBBo (design-bid-build optimized with value engineering, allowance for alternatives, etc.), DB (design-build) and its variants (e.g. novation (Walker & Hampson, 2003)), DBM (design-build-maintain), DBOM (design-build-operate-maintain), FDBOM (finance-design-build-operate-maintain), FDBOMSD (finance-design-build-operate-maintain-service delivery), Project Partnering, and Alliancing. The study adopts a simple hybrid definition of innovation between its general definitions (Freeman and Soete, 1997; OECD, 1997a) and construction industry definitions (Tatum, 1987; Slaughter, 1993; Toole, 1998;) as the kinds of novelties achieved at the project level within the time frame for planning, designing, building and operating/maintaining a specific infrastructure project. Innovation is defined as the use of

advanced concepts, technologies or methodologies that results in a positive incremental change in basic project performance metrics such as time, cost (capital and life cycle), revenue, quality, scope/capacity (including service levels), safety, and environmental impact. The perspective assumed is that of a government agency making decisions about procuring a major infrastructure facility and related services.

1.3. Research Hypothesis/Objectives

The relationship of procurement strategies with innovation has been the subject of investigation among researchers and practitioners in industry. Findings and recommendations of CIB W92 conference as reported by Davidson (1998) viewed the relationship between project procurement and innovation as one of a continuum. The conference proposed the following working hypotheses representing the two ends of the procurement-innovation relationship spectrum: that *"the procurement strategy adopted by any one building owner, particularly if he/she is a major player, directly affects the scope for innovation in the response by the building industry, in design, manufacture and construction; collectively, improved procurement enables major innovations to occur"* and a counter hypothesis that *" contemporary building owners are only concerned with the quality and effectiveness of the building being acquired, and do not wish to be involved in the building process in any way; consequently, innovation is the responsibility of designers, manufacturers and builders (i.e. of the industry) and is independent of procurement strategies."* The first hypothesis of the CIB W92 Proceedings and considerations of the growing shifts in the views and policies of government with regards to the comparative advantages of the public and private sectors in infrastructure delivery, based on economic and management theories, have provided the impetus for proposing the following research hypotheses for testing:

(i) ***Innovation achieved on an infrastructure project is a function of the procurement mode adopted*** and

(ii) ***Innovations in infrastructure projects procured using the Public-Private Partnership (P3)/Private Finance Initiative (PFI) procurement route tend to be greater (in magnitude and/or scope) than those realised under traditional procurement.***

Hypothesis II follows from I: Assuming a relationship exists between innovation and procurement mode, can it then be established that some project procurement modes tend to yield greater potentials for innovation and realisation of it than others? The mechanism for exploring and testing these hypotheses are driven by the following research objectives:

a) To devise a framework for thinking about project innovation as a function of key project descriptors or factors;

b) To identify specific project cases and instances where innovation(s) occurred, the procurement mode adopted, the factors or conditions that brought about the innovation(s) and the benefits/savings accrued in comparison with some industry-wide performance indices and/or alternative public sector procurement process (in the case of P3/PFI). Thus the objective is to attempt to populate the matrix shown in Table 1.1 with the view of observing any trend between the occurrence(s) of innovation(s) and the project procurement mode selected;

c) To examine the relationship (if any) between the innovation factors and the procurement mode selected, as well as the influence of the factors or conditions on the choice of procurement mode and vice versa; and

d) To attempt to outline a conceptual framework, based on objectives (a) and (b), for selecting and/or structuring the most appropriate or innovation-based procurement process to drive and maximise project innovation/efficiency potential.

Table 1.1 Matrix to depict the trend between procurement and innovation occurrence

Project Procurement Mode	**Opportunities for Innovation**								
	Project Phases					**Innovation Types**			
	Plan	Design	Build	Finance	Operate	Process	Product	Organisational	Financial
Traditional Design-bid-build (DBB)	<X>	<X>	<X>	<X>	<X>	<X>	<X>	<X>	<X>
↕									
Build-Own-Operate (BOO)	<.....X.....>					<.....X.....>			

1.4. Scope of Work

The research work covers a study into and an assessment of incremental project innovation realised within the time frames for procuring building and (civil) infrastructure projects with particular interest in transportation, drinking water/waste water and power projects from around the world where project novelties have been claimed. Procurement modes of interest span the full gamut from traditional design/bid/build (DBB), through to a full blown P3 arrangement such as FDBOM (finance, design, build, operate & maintain) and BOO (build, own, operate).

1.5. Methodology

The research methodology used includes an extensive literature review (from both the academic literature and industry/trade journals), case studies, and semi-structured interviews/discussions with individuals who have been involved with projects that involved one or more significant innovations under different procurement modes. The interviews lasted between one and two hours per interviewee. The results of the interviews can be found under the appendix section of this document.

1.6. References

Anderson, F. and Schaan, S (2001) *Innovation, Advanced Technologies and Practices in the Construction and Related Industries: National Estimates,* Statistics Canada. 88F0006XIB.

Barret, P. S., Sexton, M. G., Miozzo, M., Wharton, A., and Leho, E. (2001) *Base Report: Innovation in Small Construction Firms,* University of Salford: Salford.

Bernstein, H. M. and Lemer, A. C. (1996) *Solving the Innovation Puzzle – Challenges facing the U.S. Design & Construction Industry.* ASCE Press, 127p.

Brockmann, C. (2005) *Breaking innovation barriers through design/build contracts,* International Symposium on Procurement Systems, The Impact of Cultural Differences and System on Construction Performance, Feb. 8 – 10, Las Vegas, USA.

Cole Royal Commission (2003a), *Cole Royal Commission into the Building and Construction Industry,* tabled in the Federal Parliament on 26 and 27 March.

Cole Royal Commission (2003b), *Overview of the Nature and Operation of the Building and Construction Industry* Discussion Paper One, Royal Commission into the Building and Construction Industry, May.

Davidson, C. H. (1998) *Procurement – the way forward:* Proceedings of CIB W92 Symposium, University of Montreal, Montreal, CIB publication 203. ISBN 0-9682215-0-5.

Department of Treasury and Finance (2000) *Partnerships Victoria infrastructure policy*, 16p. Victoria, Australia. http://www.partnerships.vic.gov.au

Eaton, D. (2001) *A temporal topology for innovation within the construction industry,* Construction Innovation, 1: 165 – 179.

Egan, T. (1998) *Rethinking Construction, 'The Egan Report'* Department of Transport and the Regions (DETR), London, UK.

Fitzgerald, P. (2004). *Review of Partnerships Victoria Provided Infrastructure.* Final Report to the Treasurer of Victoria, Australia. 55p.

Freeman, C. and Soete, L. (1997) *The Economics of Industrial Innovation*, 3rd edition Frances Printer, London, UK.

Gann, D. M. (2000) *Building Innovation: Complex constructs in a changing world,* Thomas Telford: London.

Garvin, M. J. (2003) *Role of Project Delivery Systems in Infrastructure Improvement.* Proceedings of Construction Research Congress, Honolulu, Hawaii.

Grimsey, D. and Lewis, M. K. (2004) *Public Private Partnerships – the world wide revolution in infrastructure provision and project finance,* Edward Elgar.

Gyles Royal Commission (1992), *Gyles Royal Commission into Productivity in the Building Industry in NSW*, Report Number 7, Final Report, tabled in the State Parliament in 1992.

Hogdson, G. J. and Davies, J. A. (1997) *Can Value for Money be realised by using private sector finance for the procurement of public sector service infrastructure?* Int. Council for Building Res. Studies Documentation (CIB) Symposium, Working Comm. W92. Univ. of Montreal, Publication 203, ISBN 0-9682215-0-5.

Latham, M. (1994) *Constructing the Team. HMSO: London.*

Leiringer, R. (2003) *Technological innovations in the context of public-private partnership projects.* Doctoral thesis, KTH Industrial economics and management, Stockholm, Sweden.

Lemos, de T., Almeida, L., Betts, M. and Eaton, D. (2003) *An examination of the sustainable competitive advantage of Private Finance Initiative (PFI) projects.* Construction Innovation, 3(4), 249 – 259.

Lemos, de T., Almeida, L., Betts, M. and Eaton, D. (2003) *An examination of the sustainable competitive advantage of Private Finance Initiative (PFI) projects.* Construction Innovation, 3(4), 249 – 259.

Levy, S. M. (1996). *Build, operate, transfer*, Wiley, New York.

Liddle, B.T., (1997) *Privatization decision and civil engineering projects.* Journal of Management in Engineering, ASCE, 13(3), 73-78.

Manley, K and Blayse, A. (2004) *Implementing Innovation on Commercial Building Projects in Australia,* Clients Driving Innovation International Conference, 25 - 27 October, Australia.

Manseau, A. and Seaden, G. (2001) *Innovation in Construction – An international review of public policies,* Spon Press.

Matthews, J. (1999) *Applying Partnering in the supply chain,* in Steve Rowlinson and Peter McDrmott (eds) Procurement Systems – A Guide to best practice in construction, E &FN Spon.

McGinnity, B. (2001) Using *'design and construct' to drive innovation,* Case study 035 integrating design and construction / culture and people / transport, Department of trade and industry, Construction Best Practice Programme.

Miller, J. B. (1996) *Towards a new American infrastructure development policy for the 21st Century,* Infrastructure 1(3):1.

Miller, J. B. (1997) *Procurement Strategies which encourage Innovation: The Fundamental Element of Sustainable Public Infrastructure Systems?* Int. Council for Building Res. Studies Documentation (CIB) Symposium, Working Comm. W92. Univ. of Montreal, Publication 203, ISBN 0-9682215-0-5.

Miller, J. B. (1999) *Applying multiple project procurement methods to a portfolio of infrastructure projects,* in Steve Rowlinson and Peter McDrmott (eds): Procurement Systems – A Guide to best practice in construction, E &FN Spon.

Miller, J., Garvin, M., Ibbs, C. and Mahoney, S. (2000) *Toward a New Paradigm: Simultaneous Use of Multiple Project Delivery Methods,* J. of Mgmt. in Engrg, ASCE, 16(3), 58 – 67.

Molenaar, K. and Johnson, D.E. (2003) *Engineering the procurement phase to achieve best value*, Leadership and Management in Engineering, 3(3), 137-141.

National Audit Office (NAO) UK (1997): *The Private Finance Initiative: The First Four Design, Build, Finance and Operate Road Contracts,* HC 476, Session 1997-98, London: HMSO.

National Audit Office (NAO) UK (2003): *PFI Construction Performance.* Report by the Comptroller and Auditor General. HC 371 Session 2002-2003: 5 February.

OECD (1997a) *Proposed guidelines for collecting and interpreting technological innovation data* – Oslo Manual. Paris, France.

Ogunlana, S. O. (1999) *Profitable Partnering in Construction Procurement,* E & FN Spon.

PricewaterhouseCoopers (2004) *Partnering in practice New approaches to PPP delivery, HM Treasury Standardisation of PFI Contracts Version 3.*

Pryke, S. D. (2004) Twenty first century procurement strategies: Analysing networks of inter-firm relationships, RICS Foundation Research Paper Series October, 4(27),

Rowlinson, S. and McDermott, P. (1997) *Procurement Systems – A guide to best practice in construction,* E & FN Spon.

Seaden, G., Guolla, M., Doutriaux, J. and Nash, J. (2001) *Analysis of the survey on innovation. advanced technologies and practices in the construction and related industries,* 88F0017MIE No. 10 Inst. for Res. in Construction of the National Council of Canada

Slaughter, S. E. (1993) *Builders as sources of innovation,* Journal of Construction Engineering and Management, 119(3).

Songer, A. D. and Molenaar, K. R. (1996) *Selecting design-build: Public and Private Sector Owner Attitudes*, Journal of Management in Engineering, 12(6), 47 – 53.

Tatum, C. B. (1987) *Process of Innovation in Construction Firm*, Journal of Construction Engineering and Management, 113(4).

Thompson, P. J. & Sanders, S. R. (1998) *Partnering Continuum*, Journal of Management in Engineering. 14(5), 73 – 8.

Thorpe, D. and Dugdale, G. (2004) *Use of Alliance Contracting for Delivering Local Government Engineering Projects,* Clients Driving Innovation International Conference, 25 - 27 October, Australia.

Toole, M. T. (1998) *Uncertainty and Home Builder's Adoption of Technological Innovations,* Journal of Construction Engineering and Management, 124(4),

Treasury Committee (1996) *The Private Finance Initiative,* HC146 1995/996, London: HMSO.

Walker, D. & Hampson, K. (2003) *Procurement Strategies – A Relationship-based Approach*, Blackwell Publishing.

Winch, G (2000), *Institutional Reform in British Construction: Partnering and Private Finance*, Building Research and Information, 28(2), 141-155.

Yates, J. K. (1995) *Use of Design/Build in E/C Industry*, Journal of Management in Engineering, 11(6), 33 – 38.

CHAPTER 2

Innovation Potential of the Private Sector and its Relation to Project Delivery Mode[1]

2.1. Introduction

Public-private partnerships or P3s have seen lots of advocacy, both for and against their use in infrastructure procurement. From a naysayers' point of view, P3s entail higher borrowing costs and a bidding process that is likely to be much more expensive and lengthy. According to the Treasury Taskforce Limited (2000), the weighted average cost of private sector capital on PPP projects is between one to three percentage points higher than for public sector borrowing. Additionally, the public sector has to make extensive use of external consultants for legal, technical, and financial advice during a longer and more complex bidding process (Ball, Heafey, and King 2000). This results in higher costs in comparison to the bidding process associated with traditional public-led procurement. However, proponents of the P3 delivery mode contend that the high costs of both the bidding process and the financing of a PPP project is balanced or outweighed by additional benefits that are brought on by a widened involvement of the private sector. The opportunities provided to the private sector for innovation in terms of funding, designing, constructing and in the delivery of services, and the ability of the private sector to innovate under such circumstances is touted as one of the major benefits of P3 delivery (Garvin 2003, Liddle 1997).

In spite of their significance to the debate surrounding P3's, studies that examine and document the correlation between an infrastructure project's procurement mode and the innovation that occurs are scarce. A study undertaken by Arthur Anderson and Enterprise LSE highlights an average percentage savings of 17% in the Net Present Cost (NPC) of the P3 option versus the NPC of the Public Sector Comparator (PSC) in projects undertaken under the Private Finance Initiative (PFI) in the UK (The Treasury Taskforce Limited 2000). (In assessing these savings, both the cost of finance and value of risk transfer were included. 10 of the 17 percentage points arose from the valuation of the risk transfer achieved (Construction Industry Council 2000).) These savings are attributed to private sector efficiencies that would include contributions from

[1] This is a paper presented at the 1st International Conference, World of Construction Project Management, May 27 – 28, 2005, Toronto, Canada.

product, process, organizational/contractual, and financial/revenue innovations. However, the scope of the study does not extend to identifying particular examples of innovations that occurred in the infrastructure projects and the resultant cost savings and/or other benefits. Some very useful findings based on informed but subjective assessments of savings were presented in the Construction Industry Council (2000) study on cost saving and innovation for 67 PFI projects. The median reported cost saving was in the 5 to 10% range. Broken out by project type, savings in the 10 to 20% range were reported for custodial and transportation projects, while savings for education and health care projects ranged from minus 5 to 5%. For civil engineering projects, innovations were mainly technological in nature, and involved standardization of designs, prefabrication and the use of more equipment as opposed to labour intensive construction operations. Innovations in building projects were mainly in the form of businesses processes. In the United States, an analysis of the Tolt and Cedar water treatment plants has shown that the design-build-operate approach to procurement resulted in savings of 40% and 30% respectively (Haskins, Gale, and Kelly 2002). While some of the innovations that occurred on the Cedar and Tolt plants have been identified in the study, their contribution to the cost savings has not been documented. A study of the Oresund Tunnel in Scandinavia by Marshall (1999) attributes several innovations to the design-build approach that was adopted for the project. However, the benefits of these innovations in terms of improvements in project performance measures are not documented. A PricewaterhouseCoopers survey of the Australian building and construction industry reveals that the impact of the client-contractor contractual relationship on innovation is minimal between projects procured under a build, own, operate and transfer mode, and projects that are virtually fully documented prior to the bidding process (Australian Construction Industry Forum 2002). Alliance contracting (a collaborative, incentive driven method of contracting where all the participants work co-operatively to the same end, sharing the risk and rewards of bringing in the project within time and budget) was viewed by the survey respondents as the procurement mode with the highest innovation score.

Therefore, in our study, we seek to: (i) identify instances where innovation has occurred on infrastructure projects; (ii) determine the relationship of the occurrence of innovation with the procurement mode that was adopted; and, (iii) assess the cost saving and other benefits that arose due to innovation. Specifically we look for evidence in support of or against two hypotheses: (a) Innovation in an infrastructure project is a function of the procurement mode adopted; and (b) Innovation that is realized in projects undertaken as P3 projects is greater than the innovation

that would have been achieved using traditional design-bid-build or design-build for the same projects. Our interest herein is with full-fledged P3s that involve design-financing-construction-commissioning and operation by the P3 entity, and in some cases, the provision of services in addition to the provision of the physical infrastructure itself. In addition to the foregoing objectives, we wish to examine the role of important factors or conditions (e.g. competition, risk sharing) that could drive/inhibit innovation. Identifying the most significant factors and having a greater understanding of their impacts would assist in creating an environment conducive to innovation by maximizing the presence of drivers and by removing or reducing barriers. A further benefit that should arise from an understanding of the relative importance of these factors is increased insight into the innovations that could be realized on a given infrastructure project, leading to a more accurate estimation of potential time and cost savings for use in developing the Public Sector Comparators and shadow bids used in the analysis of P3 projects. This is a very important benefit, because two challenges faced by government when deciding upon the most suitable procurement mode for a given project are the a priori estimation of innovation potential for all facets of a project as a function of procurement mode, and how best to set the conditions to maximize innovation potential for a given procurement mode. Described in this paper are findings from the exploratory phase of our study which has been directed at identifying various concepts of innovation as they apply to the industry in general and infrastructure projects in particular, the main drivers / inhibitors of innovation, and documented examples of actual innovations and how they came about. Subsequent phases will be directed at developing an enhanced data set of actual project innovations, correlating them with procurement mode and project conditions, and to the extent possible, assessing in quantitative terms the benefits achieved.

2.2. Innovation in Infrastructure Projects

The term innovation has been used in a wide variety of ways in describing novel technologies, products, processes, and organizational practices. A popular definition provided by Freeman (1982) describes innovation as "actual use of nontrivial change in a process, product, or system that is novel to the institution developing the change". Schumpeter (1961) defines innovation as an effort made by one or more individuals that produces an economic gain, either by reducing costs or through increased incomes. While none of the definitions above or any other has been universally accepted, there has been noticeable convergence as to the principle characteristics of

innovation. Innovation is increasingly being viewed as a process that enhances the competitive position of a firm through the implementation of new ideas (Seadan et. al. 2001).

An important point to note about the foregoing definitions is that most of them view innovation from the perspective of a single firm and its economic well being, whereas our focus is on individual infrastructure projects that may be executed by a large number of conjoined firms, in some cases coalescing only for the single project instance. Additionally, infrastructure projects typically have a lengthy lifecycle and involve a multitude of disparate stakeholders such as governments, end users, and developers that results in metrics such as safety, durability, and environmental impact playing a role in the measurement of the benefits of innovative solutions. For example, the primary benefit of an innovative lining technology used in the North Downs tunnel in the UK is that it improved worker safety by reducing risk of injuries due to unstable tunnel roof material (Anonymous, 2003). Furthermore, the more commonly held Research and Development (R&D) based perception of innovation views it as a process that involves invention, development, and implementation (Widen 2002) carried out over an extended period of time. It is highly unlikely that the tight time frames available to the private sector for contesting a project and executing it if selected would accommodate an extended innovation process. Therefore, in the context of our study, we are concerned with the impetus the choice or procurement mode gives to the private sector to adapt and use the latest technologies or novel approaches for a specific project in order to maximize project performance. Consequently, we have opted to use a variation of the approach taken by Seadan et al. (2001) in characterizing innovation as the use of advanced practices.

As used herein, innovation is defined as the use of advanced technologies or methodologies that results in a positive incremental change in basic project performance metrics that include time, cost (capital and life cycle), revenue, quality, scope/capacity (including service levels), safety, and environmental impact. It is noted that the last four ultimately get expressed in terms of time, cost, and revenue, and then in terms of global project variables such as project timelines, net present value (NPV), debt service coverage ratio (DSCR), and internal rate of return (IRR) that are used in project evaluation and as determinants of overall project success. Each of these metrics is a prediction of future events, and hence involves uncertainty. The level of uncertainty in the estimate of a metric is in turn a function of the solutions adopted for a project, plus the interplay between the solutions and other exogenous uncertain variables. The adoption of

innovative solutions may increase or decrease project risks. In characterizing the benefits of project innovations we have taken into account that the innovation can impact metrics at different levels in the hierarchy of performance measures and have sought to identify: (i) the performance measures that the innovation has an impact upon; and (b) the magnitude of the impact in either quantitative or qualitative terms, including the impact on the amount of uncertainty. Sources of innovation can be divided into product, process, organizational/contractual, and financial/revenue innovations, as shown in figure 2.1. For discussion purposes, these classes are defined briefly as follows:

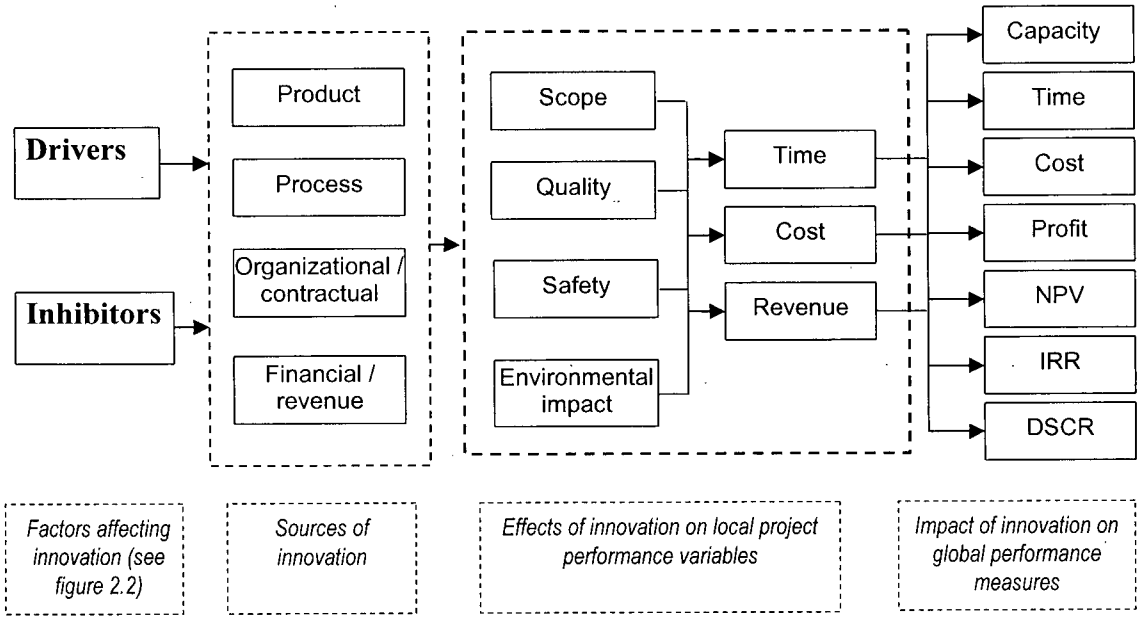

Figure 2.1 Innovation and its impact on project performance measures

Product Innovations – The construction industry is essentially an adopter of innovative products as opposed to being a mainstream producer of them (Anderson and Schaan 2001). We have therefore considered the use of advanced products (e.g. equipment, tools), novel product assemblies (designs), and materials as product innovation. Different ways of delivering services in the operating and maintenance phase of a project may also be considered as product innovations.

Process Innovations – Anderson and Schaan (2001) identify 3 types of process innovations that can occur during the construction phase of an infrastructure project. They are logistical technologies, site preparation, and assembling technologies. Innovation can also occur during the

operational phase of a project, for example, new technology in the form of ultraviolet disinfection is being used on a design-build-operate water treatment plant in Seattle (Haskins, Gale and Kelly 2002).

Organizational/Contractual Innovations – Practices such as the use of new information technology (IT) tools in project management, and new or significantly improved organizational practices (e.g. computerized inventory control) (Anderson and Schaan 2001) and partnering can be considered as organizational innovations. In terms of contractual relationships, the negotiation of the assignment of risks as opposed to the unilateral imposition of risks could also result in contractual innovations, as could the development of contractual terms dealing with performance-based revenue or payment mechanisms.

Financial/Revenue Innovations – Novel financing arrangements that lead to off-book financing, the minimization in the increment of cost for private as opposed to public sector financing, desirable patterns of cost and revenue, and the identification of innovative revenue streams (e.g. renting out school facilities during after school hours) can play a crucial role in procuring infrastructure projects under P3 arrangements. They can lead to improvements in project metrics such as the DSCR and the NPV that ultimately determine project viability.

2.3. Drivers and Inhibitors of Innovation

As mentioned previously the identification of factors or conditions that drive or encourage innovation or that inhibit innovation, as a function of their values is an important part of our study. This section contains a review of past literature that has focused on the topic, with particular emphasis on construction and infrastructure development. (For an extensive bibliography on construction innovation that has mainly a North American focus, see the article by Miller et al. (2001).)

Several authors (e.g. Dalpe 1994, Marsh 2003) have discussed the role of the public sector in stimulating industrial innovation through funding for R&D (directly or indirectly through mechanisms such as tax breaks), and accommodative procurement policies that encourage innovation. Such discussions are directed more at the long term development of construction industry capabilities as opposed to innovation at the individual project level. Policies that have

been cited include acting as the lead user of innovations, and provision of significant order values that allows the supplier to reduce the risk associated with the innovation.

Tatum (1984) describes six innovative construction methods from nuclear generating plant projects and uses those examples to identify conditions that foster construction innovation. Common conditions identified from among the case studies include: (1) challenging engineering and construction requirements as well as schedule requirements; (2) availability of sufficient lead time to develop detailed schedules and to plan construction methods; (3) a positive approach by the design team towards evaluation of alternative methods that could require changes in the original design; (4) availability of a champion for a proposed innovation; (5) large construction operations gaining significant management attention, rather than smaller scale work activities that are repeated on a frequent basis; and (6) the same firm serving as both the designer and constructor or construction manager (this was identified as being present as an innovation stimulus on a subset of the projects studied). Adversarial contractual relationships, rigid use of standard requirements, budgets preventing evaluation of alternatives, unwillingness to undertake risks, and rigid barriers to communication were found to be absent in the sample of projects studied.

The utilization of performance specifications to increase innovation has been described by Molenaar and Johnson (2003) with respect to highway engineering projects undertaken using design-build. It is their belief that if procuring agencies continue to use prescriptive specifications and simply transfer design detailing to design/builders, they will not realize the full potential for innovation. Marshall (1999) examines the advantages of an integrated design/ build process utilizing the Oresund tunnel between Sweden and Denmark as an example. Several innovations that can be attributed to design and construction being procured as a single entity are presented. They include a novel method of horizontally aligning tunnel elements, and an alternative joint design that simplified construction.

Craig (1999) reinforces the view forwarded by Tatum that a positive approach towards the evaluation of alternatives is a desirable precursor to innovation by offering evidence that the lack of such an approach hinders innovation. Developments in common law associated with the traditional design-bid-build process are revealed that result in contractual obligations for the procurer which could preclude the selection of more economical innovative solutions as the

procurer becomes obliged to treat all tenders equally and fairly. *Pratt Contractors v Palmerston North City Council* (1995) is cited as an example. The role of statutes in inhibiting the potential for innovation has also been discussed by Molenaar and Johnson (2003).

Leiringer (2003), Slaughter (1998) and Keegan and Turner (2002) discuss innovation and its implementation in the context of project-based firms. Leiringer (2003) discusses 3 types of inhibitors to innovation. They are: (a) economic factors such as lack of sources of finance, excessive perceived risks, and high pay-off periods; (b) organizational factors such as lack of skilled personnel, and resistance to change; and (c) external factors such as customers being unresponsive to new products and legislation, norms, regulations, standards, and taxation. Based on a study of project-based firms, Keegan and Turner (2002) identify tight planning and control systems adopted and a desire for efficiency as being a barrier to the identification and adoption of innovations. However, these organizations were found to have an environment in which communication is free flowing and informal, a characteristic that has been deemed to be supportive of innovation.

Tatum (1986) identifies several elements of the US construction industry that have restrained innovation. These include investment reluctance, lack of competitive conditions due to a firm holding a sizeable market share in a geographical region or a specialty segment of the industry, institutional framework, seasonal and economic cycles, and reluctance of suppliers in introducing novel technologies. The fragmentation of the industry, with a large number of firms specialized both by geographic region of operation and by type of construction has also been identified as a restraining factor on innovation as it limits the resources available to individual firms for innovation. Tatum (1986) identified several characteristics of the construction industry that are advantageous for innovation in comparison to other sectors such as manufacturing. They include: (a) the creation and disbanding of a separate team for each project offers a degree of autonomy. This is similar to "skunk work" organizations advocated as being conducive to innovation by Peters and Waterman (1982); (b) the uniqueness of individual projects presents a high level of necessity and challenge for results, and creates a driver for innovative solutions; (c) the integration of engineering and construction in some instances allowing construction experience to be input to the design leading to innovative solutions; and (d) the availability of technologically experienced personnel such as engineers and superintendents in most construction companies.

The extent to which the design of the organization facilitates or inhibits innovation has also been discussed by Winch (2000) through a comparison of French and British project organizations. Relatively innovative project organizations have been found to feature a flat organization with ambiguous and overlapping roles and responsibilities. In such organizations that are more reflective of the French approach, the employees display a high commitment to work and colleagues, and reliance is placed upon strong project leaders for coordination of work.

The high cost of innovation, and the lack of skilled workers have been identified as the major obstacles to innovation in a study of the construction and other related industries in Canada (Seadan et. al. 2001). A study of the Australian building and construction industry (Australian Construction Industry Forum 2002) has identified internal resource pressure, lack of capital or finance, risk involved in commercializing innovations, and government policy and legislative environment as the primary inhibitors of innovation.

As seen from the foregoing discussion, a variety of factors encourages or inhibits innovation. In carrying out an extensive review of the literature along with an analysis of innovations that have occurred on infrastructure projects, we have found it useful to create a taxonomy of factors or conditions that can act as drivers or inhibitors in order to examine each case study in a consistent manner. Our primary perspective is that of government trying to assess innovation potential as a function of procurement mode (with the latter being the decision that government is trying to make), along with how to set conditions that will maximize the potential for innovation as measured through one or more project performance measures, all for a specific project context. To date, based on our review of the literature and discussions with industry personnel, we have identified some 21 factors that should be considered by government as part of its decision making process. A challenge for government is how to exert either direct or indirect control over the value or state of a factor so that it acts as a driver, given the assumption of a particular procurement mode. Ongoing work is directed at determining possible states or values for each factor, and assessing their relative values with respect to innovation potential for a prescribed procurement mode.

Before listing and briefly describing each factor, we draw attention to the following. First, the assessment of the role of each condition as a contributor to innovation is conditioned both on the

procurement mode being assessed and the specific project context. The latter is important, as it is impossible to conduct a 'one size fits all' analysis that applies to all project types and project contexts. Procurement modes considered embrace but are not limited to DBB (traditional design-bid-build), DBBo (design-bid-build optimized with value engineering, allowance for alternatives, etc.), DB (design-build), DBM (design-build-maintain), DBOM (design-build-operate-maintain), FDBOM (finance-design-build-operate-maintain), and FDBOMSD (finance-design-build-operate-maintain-service delivery). Second, the various procurement options involve different phases of a project – and, hence, thought must be given as to how a factor may act as a driver during different project phases – it is possible that a factor could be a driver say in the construction phase, and an inhibitor in the operating and maintenance phase (e.g. for DBB, stringent cost and time constraints may drive innovation in construction processes, but create long term operating and maintenance difficulties because of quality problems). Finally, not all factors are independent of one another. Each can act as a driver or inhibitor, but their presence can reinforce or diminish the contribution of other factors as a driver.

Project type - project type can be both an inhibitor and driver for innovation. The nature of some project types (e.g. university student-housing) leaves little opportunity for seeking significant innovation because project/human/regulatory requirements provide a tightly defined constraint set. Contrast this with large scale transportation projects where topographical considerations combined with various physical solutions and construction technologies create a much broader solution set.

Project scale - larger projects typically provide the opportunity for the slack resources required to evaluate a greater range of potential design solutions, especially ones that maximize repetition of elements, thereby allowing the use of more equipment intensive production processes that permit economies of scale. Government is therefore faced with determining whether it is better to divide a large project into smaller pieces in order to encourage competition or bid it as a single project.

Project complexity/uniqueness - by complexity, we mean a high level of technical sophistication both in the design and related construction processes, and stringent project performance requirements. By uniqueness, we mean projects that are not built very often on a recurring basis, or each project of a similar type has highly varying site conditions which reduce the opportunity

for transferring experience gained on one to another. Project complexity and uniqueness may be an inhibitor for innovation because of lack of prior experience, established guidelines or standards, etc. However, this factor can also be an innovation driver, as complex and previously un-encountered conditions create a necessity for novel solutions.

Opportunity for other projects of similar type – the incentive to seek innovation, especially if product or process concepts can be protected, is heightened if projects of a similar type can be pursued within a reasonable time period. This opportunity need not be in the same geographical location as the project under consideration, especially if a firm is national or international in its reach.

Responsibility integration – some procurement modes provide more opportunities than others to bring together specialists in all phases of a project life cycle – design, construction, facilities management, and even marketing, thus providing the opportunity to make the tradeoffs necessary (e.g. capital cost vs. life cycle cost) to optimize overall performance. However, given that each project team is unique for each project, it is not a certainty that effective responsibility integration will take place even for a full P3. Proposal evaluation criteria should be formulated to encourage real integration of the project participants (design, construction, facilities management, service delivery).

Source of competition – the more broadly interest is sourced in a project, the more likely that novel ideas for one or more project phases will occur. Geographically dispersed interest (local, regional, national, international) is also a function of project type and scale.

Number of competitors – the number of competitors is a function of other factors (e.g. type, scale, repeatability of project type, risk assignment, economic climate, etc.) – the issue becomes how to package a project and establish terms so that maximum interest is generated.

Project performance requirements/thresholds/constraints – this factor treats the broad spectrum of performance requirements that characterize a project, including cost (capital, life cycle), time, quality, service levels, etc. On the one hand, the more stringent the requirements, the potentially greater the incentive for innovation, assuming that performance can be accurately predicted. On

the other hand, stringent requirements and constraints can limit competition, or increase the risks associated with novel technologies.

Requirements for broader socio-economic benefits – the need to bring benefits to a larger audience (e.g. create work and supply opportunities for local labour, consultants and suppliers, provide training to upgrade local skills, developing domestic capability in order to compete in other market places, etc.) can introduce additional costs and lessen opportunities for innovation.

Statement of product solution – the opportunity to explore a wider variety of product solutions is enhanced by stating objectives or performance requirements, as opposed to providing solutions that are believed to provide the required performance levels. Possible states for this factor include prescriptive, performance-based or objective based requirements, or some combination of the two.

Statement of process solution – the opportunity to explore a wider variety of process solutions (e.g., construction methods) and possibly even service delivery processed is enhanced by stating objectives or performance requirements, as opposed to providing solutions that are believed to provide the required performance levels. Possible states for this factor include prescriptive, performance-based or objective based requirements, or some combination of the two.

Product risks – product risks can be both a driver and inhibitor. Novel solutions that have not been proven before (e.g. a submerged tunnel for transportation) may have a risk profile that outweighs other performance dimensions. These product risks may also impact negatively on opportunities for other dimensions (process, organizational / contractual, financial / revenue).

Process risks – deals with innovations directed at constructing the project (offsite and onsite), operating and maintenance processes, and possibly service delivery processes. The known and unknown risks that accompany novel methods may weigh against their use, and may impact variable values for other project dimensions.

Natural environment risks – this factor impacts both product and process innovation potential. Innovative design and construction processes can help mitigate or even avoid some environmental risks. However, innovation may be thwarted if the consequences for negative

impacts on the environment are set so high that they drive project participants to stick with only proven design solutions, construction technologies, or standard operating and maintenance procedures.

Certainty of economic environment – this factor deals with a myriad number of sub-factors, including availability of skilled labour, labour relations environment (short and long term), price stability (short and long term), stability of supply of input materials, interest rates, etc. This factor, while beyond the direct control of government and any bidders, is reflected in the potential terms of a contractual or concession agreement. How the economic environment is treated in such an agreement can enhance or detract from the desire to pursue novel solutions.

Certainty of political environment – a source of considerable uncertainty is the behaviour of government both in the short and long term. Will government stick to a decision in the face of concerted political pressure, will the commitment by one government be honoured by another, etc. Lack of confidence in government is an inhibitor to making the investments necessary for innovation, especially if it is founded on previous actions by government (e.g. reversal of decisions, expropriation, lack of political will).

Certainty of regulatory environment – significant difficulties can be involved in gaining approval for innovative product and process design. In general, lack of certainty in the regulatory environment as to how an innovation will be treated can act as an inhibitor.

Certainty of stakeholder environment – in general, stakeholder environment is an inhibitor to innovation. Opposition can coalesce around the concept of the project itself, the design of one or more aspects, the belief that public sector jobs are being given away, etc. In some circumstances, stakeholder concerns can act as a driver for innovation.

Reasonableness of risk assignment between public and private sectors and risk attitudes – this is a very important condition for innovation. If the belief of government is that all risk (product, process, economic, etc.) should be passed on to the private sector, then this will be a significant inhibitor of innovation, and also an inhibitor to broad based competition. The willingness to share risk and potential rewards for innovative solutions can be a powerful driver for innovation.

Penalties for inadequate project performance – the current belief is that the private sector should be "incentivised" to achieve various thresholds of performance. What this means is that payment is tied to performance achieved. This can induce a double risk to bidders – the risk of any innovation not fulfilling expectations, and a loss of revenue due to reduced performance. Draconian penalties can inhibit the desire for innovation.

Proposal evaluation criteria & relative weights, decision & negotiation processes – the public sector can signal to the private sector the reward structure and risks associated with pursuing innovation. Evaluation criteria can also provide indirect assistance to bidders as to how to select, structure and manage themselves in order to maximize the opportunities for innovation. Properly formulated, this factor is a driver; improperly formulated an inhibitor. Too often evaluation criteria imply almost no partnership at all, and a total offloading of risk to the private sector.

As noted previously, factors tend to interact with one another. Shown in Figure 2.2 is a first attempt at identifying how they interact. For example, competition, both in terms of source and number of competitors is influenced by a number of other factors, including project scale, complexity and uniqueness, risks, and risk assignment. The interplay amongst these factors is the subject of further ongoing investigation. Table 2.1 depicts a first pass at assessing the relative importance of the factors as drivers or inhibitors of innovation independent of a specific procurement mode. Shaded areas indicate primary importance, while crossed-hatched areas indicate secondary importance. White areas indicate little or no importance. Work is currently directed at developing specific examples for each of the cells in the table, and further refining it as a function of specific procurement modes.

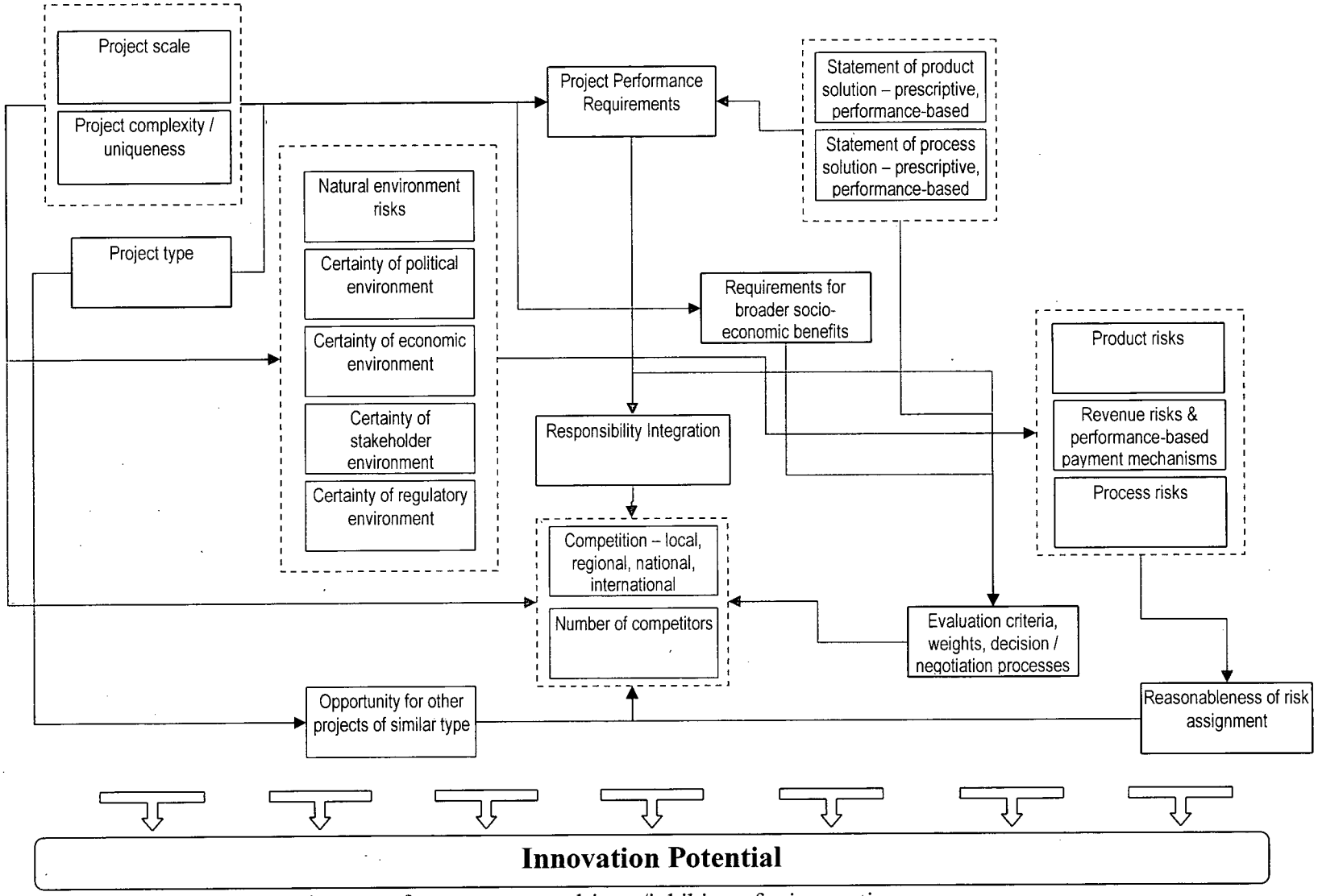

Figure 2.2 Interaction between factors to create drivers/inhibitors for innovation

Table 2.1 Factors that act as drivers/inhibitors for innovation

Factors (Drivers/Inhibitors) for Innovation	**Product Innovation**	**Process Innovation**	**Organizational / contractual Innovation**	**Financial / Revenue Innovation**
Project type				
Project scale				
Project complexity/uniqueness				
Responsibility integration				
Opportunity for other projects of similar type				
Source of competition				
Number of competitors				
Project performance requirements/thresholds/ constraints				
Requirements for broader socio-economic benefits				
Statement of product solution				
Statement of process solution				
Product risks				
Process risks				
Natural environment risks				
Certainty of economic environment				
Certainty of political environment				
Certainty of regulatory environment				
Certainty of stakeholder environment				
Reasonableness of risk assignment				
Penalties for inadequate project performance				
Proposal evaluation criteria, decision & negotiation processes				

To promote innovation, the states or values for the factors (e.g. for competition, local versus national versus international) identified above that are most conducive to innovation need to be identified and a metric developed to indicate innovation potential. Starplots (Spears 1999) have the potential to be a useful tool in characterizing and visualizing the role of n-variables or factors in contributing to innovation potential, and is one tool that we are actively exploring for use in the study. (Ongoing work is directed at refining the list of factors, their relative importance in relation to their contribution to innovation potential, possible states or values for each, and the relative contribution each state makes to innovation potential). An example starplot based on

hypothetical values of the factors is shown in figure 2.3. Thus, if we looked at the conditions for innovation in terms of the starplot, on a given project an attempt should be made to maximize the area within the plot in order to foster innovation. Note that we have used a slight variation of the starplot such that the ordering of the axes plays a minimal role in determining the area contained within the plot (i.e. all factors own equal angles on the two side of the axes). Such a visualization can give several valuable insights such as highlighting areas or factors that should be scrutinized or controlled to provide a more facilitating environment for innovation, or conversely in identifying factors that are hindering the innovation effort. Additionally, the area of the starplots can assist in determining how much innovation can be expected on a given project, thus providing valuable information to financial and economic analysis of the project. A number of plots may be required, in order to reflect innovation potential in terms of the various project metrics described in figure 2.1. Our primary interest is in terms of the risk-adjusted value of net present value, which corresponds to the public sector comparator, and which has the virtue of capturing all time and cost impacts throughout the life cycle of the project.

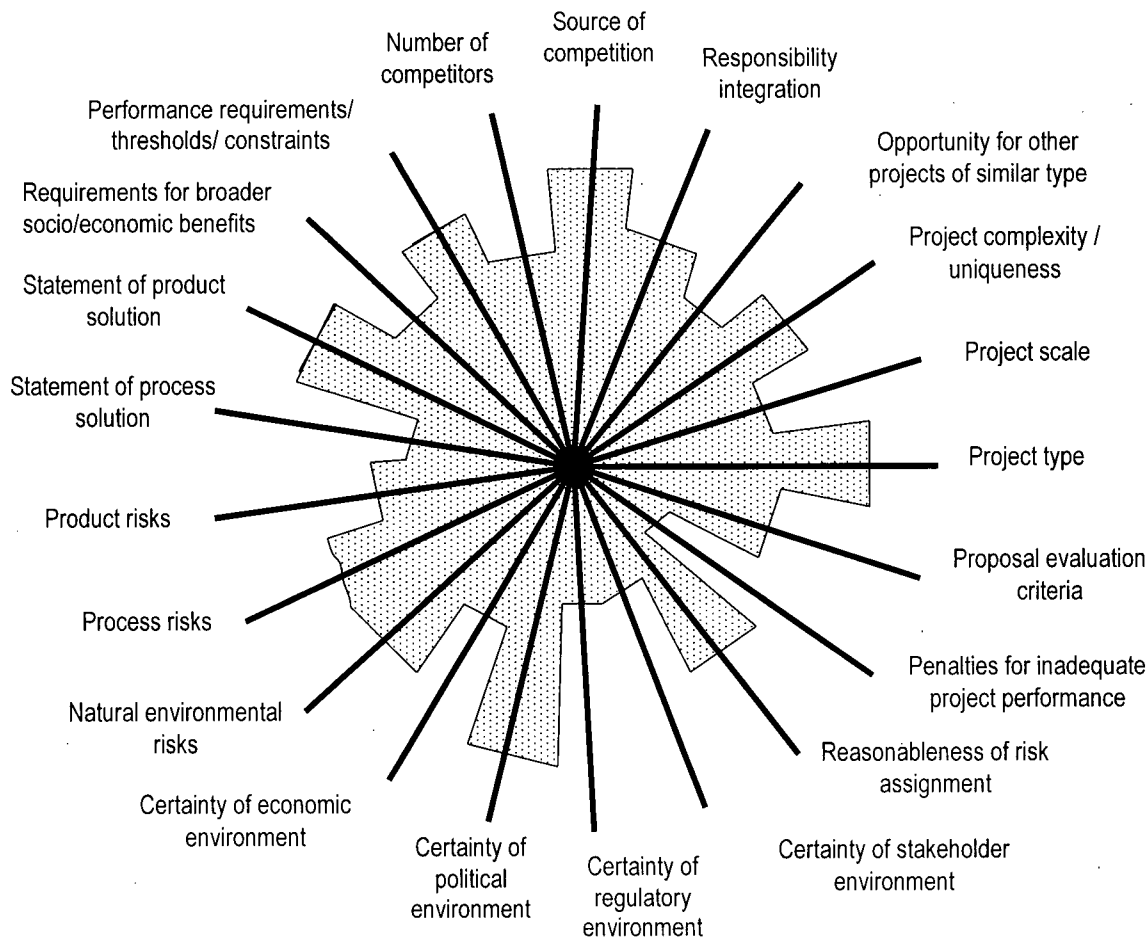

Figure 2.3 Starplot of factors driving/inhibiting innovation in infrastructure projects

2.4. Case Study

As described previously, important objectives of our study include determining the degree of correlation that exists between innovation and procurement mode and identifying the value of project factors that can maximize the innovation potential of P3 projects. As part of the first phase of our study, an extensive literature review is currently being conducted to identify examples of product, process, organizational / contractual, and financial / revenue innovations that occurred on infrastructure projects, the relationship of the procurement mode with the realization of the innovation, and the benefits that arose from the innovation. Two case studies, namely the Confederation Bridge in Canada and the Oresund tunnel in Scandinavia are underway. Some of the preliminary findings from the analysis of the Confederation Bridge project are described briefly here.

Highlighted in Table 2.2 are several of the features of the Confederation Bridge project that relate to the theme of innovation, and conditions that acted as drivers or inhibitors for innovation. As seen from this table, innovation occurred in all four innovation classes or dimensions identified previously. In Table 2.3, an attempt has been made to identify the relative importance of the various factors in contributing to innovation for the FDBOM or BOT procurement mode adopted for this project. Shaded areas represent factors of primary importance, cross-hatched of secondary importance, and white areas of no significant importance. In the view of the authors, the primary drivers were the project type (tolled bridge), the massive scale of the project, which combined with the hostile environment in which the project had to be built and then operated, influenced greatly both the project's product and process design. These drivers were aided by an organization which brought together skills from the international design and construction communities. What is unclear, however, is how important the choice of procurement mode was for the product and process innovations. For large scale bridge projects, the market is already an international one, and significant progress has been made on merging design and construction processes in order to take advantage of prefabrication, modularization, and technology developments in terms of concrete (strength, durability) and lifting capabilities, to name a few. On the other hand, the organizational/contractual arrangement can be seen as a significant innovation and as a partial model for other projects of similar type procured using FDBOM. The reasons for this include the need to provide continuity of performance throughout the project life cycle, the need to deliver significant socio-economic benefits to the region, the need to accommodate the needs of several political jurisdictions, and finally the need to optimize

taxation treatment. All of the foregoing was achieved. Finally, the willingness of government to provide payment in the form of an indexed subsidy, separate from project performance, allowed for innovations in financing to be achieved, especially in terms of the modest interest rate premium that had to be paid for private over public financing.

Table 2.2 Case Study of Innovation and Conditions of Confederation Bridge

Project:	Confederation Bridge
Description/Location:	A 13-km high level bridge structure linking New Brunswick and Prince Edward Island.
Project Type:	Bridge Structure
Duration:	May 1997 and took 44 months to construct.
Project Procurement Mode:	Finance-Design-Build-Operate-Maintain(FDBOM)
Project Value:	$840 million (CDN) (planned); actual cost in excess of $1 billion (CDN)

INNOVATION	
Innovation Type (Source)	**Condition Dimension**
Innovative Physical Components (Permanent Structure) a) Pier Design and Foundation: Consists of hollow pre-cast concrete shaft and pier base of standard cones. b) Pier spacing: 43 250-metre spans at the marine conditions. c) Installation of "ice cones" (shields) at water level to minimise possible dynamic amplification effect of ice forces on the cylindrical piers.	Besides being the 1st significant build-own-operate-transfer (BOOT) project in Canada, the unique environmental (physical) conditions posed design and construction challenges which has resulted in an innovative structure for such an icy terrain. Concerns were raised about the possible adverse effect of the structure on existing ice that may increase delays in ice-out. The high natural environmental risks, aroused stakeholder (community) concerns about the effect of the proposed structure on ice movements which culminated in the commissioning of 2 independent environmental impact studies at significantly different times in a protracted negotiation process. The project's complexity and uniqueness of its natural environment, combined with a stakeholder environment of intense scrutiny, prescribed a structure with high performance requirements.
Innovative Construction Method - Casting of the double cantilever main girder (which is one of 2 components of the bridge superstructure) used a cast-in-place balanced cantilever method with the girder changing location while the forms for each segment were stationary. This is reverse of the normal balanced cantilever method (Tadros, 1997). Construction of all major components was done on-shore.	An assembly of international construction joint venture companies – Strait Crossing Inc. (Canada), Dumez-GTM (France), and Ballast Nedam (Netherlands) created conducive grounds for innovative methods of construction. The scale of the project, in combination with its tough schedule that incorporated serious liquidated damages clauses, necessitated the design and use of quicker more efficient construction methods

	that ensured high product quality to meet the project's stringent performance requirements in a unique natural environment setting.
Financing - The project financing involved the issuance of bonds with AAA Standard & Poor and Moody's rating at the close of agreements drawn on a lump sum basis. Usually such development projects would have been financed through substantial bank loans drawn down on a progress basis.	This was facilitated by government's decision of guaranteed annual indexed subsidy payments and exclusion of competition for the 35-year period during which the project developer will operate the bridge facility. The general certainty of the economic and political environments, in addition to the benefits, reduced the financial/revenue risks. Credit default risks were low and these indicators ultimately increased investor confidence in the financing/revenue arrangements and agreements.
Delivery Process - Stringent Project Requirements set by the government were achieved through the design criteria and quality assurance measures. The independent engineer had access to the books of the contractor to certify cost items and forecasts in order to authorise draw downs.	Responsibility integration was particularly prominent from the congenial forms of cooperation among the project participants. Open transparent working relationship, including the use of effective communication channels, existed between the contractor and the independent engineer which enhanced the latter's role.
Organizational/contractual – a complex organizational structure was set up to reflect provincial vs federal prerogatives, to maximize taxation benefits, and to comply with the requirements for substantial socio-economic benefits for the Atlantic provinces.	Significant socio-economic benefits had to be derived for the Atlantic provinces. The project involved three political jurisdictions – Federal, and the provinces of Prince Edward Island and New Brunswick. Tax regulations/laws also required novel structuring of the organization.
Risk Management - All risk issues including process, government, financing and contractual were identified and allocated prior to financial closing, and even thereafter, in a process that was different from the conventional public and/or private sector linear approaches to risk in traditional bid processes.	The scale and complexity of the project required that all contractual and financial issues in addition to clear definition of roles and responsibilities/liabilities be proactively and satisfactorily addressed to meet the project's tough schedules and performance requirement set out by government.
Innovation Metric (Benefit)	The result is a bridge structure that met its design criteria and stringent performance requirements with minimal adverse environmental impact. The effective forms of cooperation between the independent engineer and the contractor enhanced the attainment of the project specifications in terms of its durability consistent with its proposed service life of 100 years with non-recourse financing.

(References: Buckland et al. 1997, Confederation Bridge 2003, Pirie 1997)

Table 2.3 Confederation Bridge - Factors that act as drivers/inhibitors for innovation

Factors (Drivers/Inhibitors) for Innovation	**Product Innovation**	**Process Innovation**	**Organizational/ Contractual Innovation**	**Financial/ Revenue Innovation**
Project Type				
Project Scale				
Project Complexity/uniqueness				
Responsibility Integration				
Opportunity for other projects of similar type				
Source of Competition				
Number of Competitors				
Project performance requirements/thresholds/constrai nts				
Requirements for broader socio-economic benefits				
Statement of product solution				
Statement of process solution				
Product risks				
Process risks				
Natural environment risks				
Certainty of economic environment				
Certainty of political environment				
Certainty of regulatory environment				
Certainty of stakeholder environment				
Reasonableness of risk assignment				
Penalties for inadequate project performance				
Proposal evaluation criteria & decision and negotiation process				

2.5. Conclusions

This paper provides insights gained from the initial phase of a study directed at assessing the validity of two hypotheses that tend to form the basis of current government decision-making with respect to the procurement of large infrastructure projects. These hypotheses are: (a) Innovation in an infrastructure project is a function of the procurement mode adopted; and (b) Innovation that is realized in projects undertaken as P3 projects is greater than the innovation that would have been achieved using traditional design-bid-build or design-build for the same projects. In assessing support for these hypotheses, we have sought to identify factors or

conditions that act as either drivers or inhibitors for innovation. To date, some 21 factors have been identified, and they have proven to be of assistance in helping to explain the degree of innovation achieved on actual projects. Regrettably the literature pertaining to innovations in the context of specific projects and quantification of the benefits derived is quite thin, and where it does exist, it is either very general in nature or focuses at great length on a narrow aspect of the project. Claims made for success, while surely true in many cases, are anecdotal in nature, and seldom are explanations offered that include significant back up documentation to justify these claims.

Realistically, as it is never possible to carry out identical projects using different procurement modes, at best only paper benchmarks exist with which to compare performance. Further, our history with P3 projects is short, so little real data exist that describe actual long term life cycle performance versus what was forecast. Nevertheless, the authors are continuing to examine a number of projects to identify innovations achieved along with imputed benefits, and the role that procurement mode played in generating them. As part of this effort, and in addition to careful scrutiny of the literature and available project documentation, detailed discussions will be held with public and private individuals experienced in the delivery of infrastructure projects under different procurement modes. Work will also continue on refining the list of factors identified as possible drivers of inhibitors for innovation, the range of values or states they can assume, and their relative importance for encouraging or discouraging innovation as a function of procurement mode.

2.6. References

Anderson, F. and Schaan, S. (2001) *Innovation, Advanced Technologies and Practices in the Construction and Related Industries: National Estimates.* Statistics Canada.

Anonymous (2003) *LaserShell Leads the Way for SCL Tunnels*, Tunnels & Tunneling International, June, pp 38-42.

Australian Construction Industry Forum (2002) *Innovation in the Australian Building and Construction Industry – Survey Report.* Price Waterhouse Coopers, Australia.

Ball, R., Heafey, M, and King, D. (2000) *Private Finance Initiative – a good deal for the public purse or a drain on future generations.* Policy and Politics, 29(1), 95-108.

Buckland, P. G., Boyd, D. E., Leal, A. J, and J. E. Torrejon (1997) *The Confederation Bridge: the role of the independent engineer in theory and in practice.* Canadian Journal of Civil Engineering, 24, 875 – 881.

Construction Industry Council (2000) *The role of cost saving and innovation in PFI projects,* Thomas Telford Publishing, London, U.K.

Craig, R. (1999) *How innovative is the common law of tendering?* Journal of Construction Procurement, 5(1), 15-26.

Dalpe, R. (1994) *Effects of government procurement on industrial innovation.* Technology in Society, 16(1), 65-83.

Freeman, C. (1982) *The economics of industrial innovation*, 2nd Edition, Pinter, London, UK.

Garvin, M.J.(2003) *Role of Project Delivery Systems in Infrastructure Improvement.* Proceedings of Construction Research Congress, Honolulu, Hawaii. March.

Haskins, S., Gale. D. and Kelly, L. (2002) *Creating and optimizing new forms of public-private partnerships in Seattle.* Water Science and Technology: Water Supply, 2(4), 211-218.

Confederation Bridge (2003) http://www.confederationbridge.com (15th Dec.)

Keegan, A. and Turner, J.R. (2002) *The management of innovation in project-based firms.* Long Range Planning, 35, 367-388.

Leiringer, R. (2003) *Technological innovations in the context of public-private partnership projects*. Doctoral thesis, KTH Industrial economics and management, Stockholm, Sweden.

Liddle, B.T. (1997) *Privatization decision and civil engineering projects.* Journal of Management in Engineering, 13(3), 73-78.

Marsh, D. (2003) *Does New Zealand have an innovation system for biotechnology?* Technovation, 23, 103-112.

Marshall, C. (1999) *The Oresund tunnel – Making success of design and build.* Tunneling and Underground Space Technology, 14(3), 355-365.

Miller, C. K., Carr, R. I., and Cheung, W. (2001) *Construction Innovation – an Annotated Bibliography,* Journal of Construction Innovation, electronic journal published by the Construction Innovation Forum, Michigan, USA, www.CIF.org, 16 pgs. October.

Molenaar, K. and Johnson, D.E. (2003) *Engineering the procurement phase to achieve best value,* Leadership and Management in Engineering, 3(3), 137-141.

Peters, T.J. and Waterman, R.H. (1982) *In search of excellence: Lessons from America's best-run companies*. Harper & Row, New York.

Pirie, J. D. (1997) *The Confederation Bridge: Project Structure and Risk,* Canadian Journal of Civil Engineering, 24, 867 – 874.

Pratt Contractors v Palmerston North City Council (1995) 1 NZLR pp. 469-472, New Zealand.

Schumpeter, J.A. (1961) *The theory of economic development : an inquiry into profits, capital, credit, interest, and the business cycle.* Oxford University Press, NY.

Seadan, G., Guolla, M., Doutriaux, J., and Nash, J. (2001) *Analysis of the survey on innovation, advanced technologies and practices in the construction and related industries.* Statistics Canada.

Slaughter, S.E. (1998) *Models of construction innovation,* Journal of Construction Engineering and Management, 124(3).

Spears, W.M. (1999) *An Overview of Multidimensional Visualization Techniques.* Proceedings Genetic and Evolutionary Computation Conference, Orlando, Florida, July.

Tadros, G. (1997) *The Confederation Bridge: An Overview,* Canadian Journal of Civil Engineers, 24, 850 – 866.

Tatum, C.B. (1984) *What prompts construction innovation?* Journal of Construction Engineering and Management, 110(3), 311-323.

Tatum, C.B. (1986) *Potential Mechanisms for Construction Innovation,* Journal of Construction Engineering and Management, 112(2), 178-191.

Treasury Taskforce Limited (2000) *Value for Money Drivers in the Private Finance Initiative,* report prepared by Arthur Andersen and Enterprise LSE, HM Treasury, U.K.

Widen, K. (2002) *Innovation in the Construction Process – A Theoretical Framework.* Licentiate thesis, Lund University, Lund, Sweden.

Winch, G. (2000) *Innovativeness in British and French construction: the evidence from Transmanche-Link,* Construction Management and Economics, 18, 807-817.

CHAPTER 3

Project Innovation – A Function of Procurement Mode?[1]

3.1. Introduction

Public-private partnerships or P3s have seen considerable advocacy, both for and against their use in infrastructure procurement. From a naysayers' point of view, P3s entail higher borrowing costs and a procurement process that is likely to be much more expensive and lengthy. According to Treasury Taskforce Limited (2000), the weighted average cost of private sector capital on P3 projects is between one to three percentage points higher than for public sector borrowing. Additionally, the public sector has to make extensive use of external consultants for legal, technical, and financial advice during a longer and more complex bidding process (Ball, Heafey, and King 2000). Roberts (1999) indicated that the need for checking and rechecking of criteria under P3 procurement leads to a complex negotiation process that can be time consuming particularly to bidders, resulting in higher costs in comparison with the bidding process associated with traditional public-led procurement. Birnie (1998) found tender costs for Private Finance Initiative (PFI) (the UK equivalent of P3) projects to be higher than traditional public sector-led projects; with tender costs ranging from 0.48 - 0.62% of total project costs, in comparison with 0.18 – 0.32% for design-build projects, and 0.04 – 0.15% for traditional projects (Kumaraswamy and Zhang, 2001). The transaction cost of the P3 process of the Sierra-Yoyo-Desan resource road upgrade project in British Columbia, Canada represented about 3% of the total project cost in present value terms (Partnerships BC, 2004).However, proponents of the P3 delivery mode contend that the higher costs of both the bidding process and private sector financing are balanced or outweighed by additional benefits that are brought on by a widened involvement of the private sector in achieving greater efficiencies and economies primarily through the implementation of innovation and greater discipline in terms of scope and budget control.

The opportunities provided to the private sector for innovation in terms of funding, designing, constructing and in the delivery of services, and the ability of the private sector to innovate under

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such circumstances is touted as one of the major benefits of P3 delivery (Garvin 2003, Liddle 1997, Miller 1997). Jones (2004) contends that private toll roads can be built faster, more efficiently and are typically better maintained than taxpayer funded roads (For the latter we observe that government won't demand of itself what it demands of others through a P3 arrangement of infrastructure e.g. consistent maintenance to defined standards). Studies conducted in Australia, New Zealand and the UK quote 10 – 15% reductions in capital expenditure for private sector-led procurement i.e. from planning to facility construction completion (Anonymous, 2004). Pirie & Giannelia (2004) argue that time-related considerations influence the cost savings in private delivery, and that there is a greater flexibility in the ability to innovate or implement innovations during construction under private-led delivery compared to a longer more complex approval process in traditional public delivery. Capital constraints and uncertainties associated with public investment programmes which are often administered on an annual budgetary basis depending on availability of funds tend to stifle innovation by not maintaining a balance between initial project capital outlay and life-cycle cost. Hence it's been argued that capital rationing by the public sector in its selection of infrastructure projects for implementation often leads to a piecemeal approach of infrastructure delivery and distorts the objective of optimising investment and achieving long-term economies of scale which are some of the preconditions for investments in technology and innovation.

The recurring theme, from the perspective of P3 proponents therefore, has been one of greater discipline and efficiency of the private sector, usually incentivised by profit motive and competition, that spawn innovations in the P3 delivery process to bring projects on stream faster in which two or more major project functions (i.e. design, construction, operation & maintenance, financing) are integrated/bundled and performed by a single source private sector-led responsibility. Under such project circumstances, Gomez-Ibanez & Meyer (1993) conceptualise that the private sector is better able to capture the benefits of the learning curve effect or scope/scale economies through replication by establishing continuity, stabilization and cumulative experience in a manner that few public sector agencies can. However, it could be argued that since the private sector consortium is made up of fundamentally the same entities (design and construction firms, suppliers) that could deliver a project under traditional public procurement mode, the opportunities for cost economies are slim considering the magnitude and proportion of construction and financing costs in relation to total project costs. The private

sector's efficiency or cost saving techniques perhaps lie in the flexibility of its procedures for overseeing construction and maintenance activities.

3.2. PPP Procurement and Innovation/Efficiency Review

In spite of their importance to the debate surrounding P3's, studies that examine and document the correlation between an infrastructure project's procurement mode and the innovation that occurs are scarce. Hodgson and Davies (1997) reviewed the Private Finance Initiative (PFI) as a procurement policy in terms of its value for money implications and indicated that although PFI is economic and efficient it is less effective. Nonetheless PFI has got much potential for developing its operational effectiveness. A study undertaken by Arthur Anderson and Enterprise LSE (Treasury Taskforce Limited 2000) highlights an average percentage savings of 17% in the Net Present Cost (NPC) of the P3 option versus the NPC of the Public Sector Comparator (PSC) in projects undertaken under the Private Finance Initiative (PFI) in the UK. (In assessing these savings, both the cost of finance and value of risk transfer were included. 10 of the 17 percentage points arose from the valuation of the risk transfer achieved (Construction Industry Council 2000)). These savings are attributed to private sector efficiencies that would include contributions from product, process, organizational / contractual, and financial / revenue innovations. However, the scope of the study does not extend to identifying particular examples of innovations that occurred in the infrastructure projects and the resultant cost savings and/or other benefits.

Some very useful findings based on informed but subjective assessments of savings were presented in the Construction Industry Council (2000) study on cost saving and innovation for 67 PFI projects. The median reported cost saving was in the 5 to 10% range. Broken down by project type, savings in the 10 to 20% range were reported for custodial and transportation projects, while savings for education and health care projects ranged from minus 5 to 5%. For civil engineering projects, innovations were mainly technological in nature, and involved standardization of designs, prefabrication, and the use of more equipment as opposed to labour intensive construction operations. Innovations in civil engineering projects are mainly *technological* in nature (material components, installations, production methods, and design concepts) where as building project innovations tend to be mainly *organisational* in terms of business processes, contractual relations, and management systems.

An empirical study conducted by Lemos et al (2003) on the PFI in the UK and Portugal indicates that PFI has increased the competitive advantage of construction undertakings through innovations in more efficient and cost effective designs. A National Audit Office (NAO) report, (*PFI: Construction Performance*, February 2003) assessed the performance of 'traditionally procured projects' and PFI projects and found that in contrast to traditionally procured projects, the PFI projects were being delivered largely on time (76% versus 30%) and on budget (78% versus 27%). A more recent UK National Audit Report (HC 644 & HC645 2004) on the assessment of the P3 arrangement for the modernisation of the London Underground rail system identified a number of novel organisational/contractual features: a responsibility split between a major private sector-led infrastructure programme and public sector management of train operations, an output-based performance and payment regime that has a built-in periodic review mechanism to enable the parties to re-specify requirements within the PPP scope and re-price the deals every $7^1/_2$ years for the 30-year concession period. However bidding and negotiation costs, as a result of contract re-bidding and legal challenges, constituted 1.5% of the undiscounted deal value (or 2.8% of the discounted deal value).

In the United States, an analysis of the Tolt and Cedar water treatment plants has shown that the design-build-operate approach to procurement resulted in savings of 40% and 30% respectively (Haskins, Gale, and Kelly 2002). Similarly the design-build-operate procurement mode recommended by private sector proponents in the city of Phoenix's waste water treatment project led to estimated savings of 15 – 20% in total cost compared to a design-build delivery; and the winning bid came in at a further 8% cheaper than the city's benchmark estimates (Waer et. al. 2004). While some of the innovations that occurred on the Cedar and Tolt plants have been identified in the study, their contribution to the cost savings has not been documented.

A study of the Oresund Tunnel in Scandinavia by Marshall (1999) attributes several innovations to the design-build approach that was adopted for the project. In the Build-Operate-Transfer (BOT) Western Harbour Crossing tunnel project in Hong Kong, Kumagai-Gumi (1993) reported substantive innovations in the BOT procurement process which included tunnel profile design, construction processes/methods and shorter design/construction schedules. However, the quantitative benefits of these innovations in terms of improvements in project performance measures of the Oresund and Western Harbour projects are not well documented.

A PricewaterhouseCoopers survey of the Australian building and construction industry reveals that the impact of the client-contractor contractual relationship on innovation is minimal between projects procured under a build, own, operate and transfer mode, and projects that are virtually fully documented prior to the bidding process (Australian Construction Industry Forum 2002). Alliance contracting (a collaborative, incentive driven method of contracting where all the participants work co-operatively to the same end, sharing the risk and rewards of bringing in the project within time and budget) was viewed by the survey respondents as the procurement mode with the highest innovation score. In a review of 8 projects under the *Partnerships Victoria* infrastructure policy in Australia, Fitzgerald (2004) finds credible evidence of the benefits that may flow from private sector investment in public infrastructure including innovation of design, timeliness of delivery, certainty of price and whole-of-life-approach to maintenance. By comparing their costs to a PSC, each of the eight projects was declared, at the time the contracts were entered into, as being equal to or having better value than the option of public sector provision. The weighted average savings was 9% against the risk-adjusted PSC using the then prevailing discount rate. In the Echuca/Rochester wastewater treatment plant, the build-own-operate-transfer mode of procurement showed a 28% savings to the public agency over the risk-adjusted cost of the PSC. These substantial cost savings have been attributed to a range of innovations introduced by the private developer. The innovative technical design solution provided by the private concessionaire in the Enviro Altona build-and-operate waste water facility to tackle salt infiltration uncertainties led to cost savings and in totality a 6% saving against the risk-adjusted cost of the PSC. However many of the claimed benefits of the projects evaluated were observed to be modest upon closer scrutiny, according to Fitzgerald (personal communication 2004). The Echuca/Rochester and Altona projects had lower costs than otherwise budgeted because the final design differed from the initial specifications - the operators had a [design+operate] mindset in an industry where sequential non-optimal procurement was common (i.e. low cost design and capital costs followed by high operations and maintenance costs). The gains were primarily due to the switch to a whole-of-life procurement approach that lent itself to a long-life operations contract preceded by a design and construct contract. The specific conditions that allowed the 'innovations' were less-than-optimal asset management approaches by the public authority utilities, aided and abetted by suboptimal regulatory/pricing and borrowing policies.

In Canada, detailed information/reports on value for money analysis of P3 projects are scanty, apparently due to a small population of projects in an emerging P3 market. The winning proposal for a state-of-the-art 300-bed capacity Abbortsford Regional Hospital and Cancer Centre in British Columbia procured under a finance-design-build-operate-maintain (FDBOM) arrangement created and captured significant project innovations and efficiencies. The final contract proposal exhibited novel design concepts/technical solutions and facilities management service delivery that met the project's objectives in terms of its operational efficiency (Partnerships BC, 2004). A value for money project report, Partnerships BC (2005), of the P3 delivery approach indicates a projected savings, achieved primarily through the pursuit of innovation and efficient concepts/technologies, of about 8.5% in net present value terms over the PSC.

The Auditor-General's Report (1995) on the Confederation Bridge P3 project reviewed the financing, taxation, and environmental aspects of the procurement process and concluded that the process satisfactorily met the government's key project objectives and requirements. No PSC was conducted as a government-guaranteed indexed subsidy, channelled from its fiscal commitment to the running of an existing ferry to the private consortium, served as government's direct annual expenditure cap on the project and was the maximum price target for the competitive procurement process. The report however found that the estimates for the private sector-led project financing cost could have been reduced by about $45million CDN (equivalent to about 7% of the project bond issued) had the government raised the project debt through its own borrowing programme.

The Ontario Provincial Audit Report (1996) reviewed Phase 1 of the Highway 407 project and commended the government for incorporating value engineering in the design of the highway and in meeting a number of its project objectives. The report however expressed concern about the very general nature of the highway design criteria issued in the project briefs vis-à-vis the trade-off between the benefits of providing flexibility to the private sector to be innovative and the potential difficulty of evaluating very different bids/proposals on price.

Although innovations and efficiencies have been reported on the projects and initiatives discussed here so far, in-depth discussions on the cause-effect relationships, if any, between the occurrences of those innovations, their direct benefits to project performance and their respective

procurement modes are difficult to find. Analysis on the influence of innovation on procurement mode choice and vice versa at the project level is limited.

Therefore, in our study, we sought to: (i) identify instances where innovation has occurred on infrastructure projects; (ii) determine the relationship of the occurrence of innovation with the procurement mode that was adopted; and, (iii) assess the cost saving and other benefits that arose due to innovation. Specifically we looked for evidence in support of or against two hypotheses: (a) Innovation in an infrastructure project is a function of the procurement mode adopted; and (b) Innovation that is realized in projects undertaken as P3 projects is greater than the innovation that would have been achieved using traditional design-bid-build or design-build for the same projects. Our interest herein is with full-fledged P3s that involve design-financing-construction-commissioning and operation by the P3 entity, and in some cases, the provision of services in addition to the provision of the physical infrastructure itself. In addition to the foregoing objectives, we wish to examine the role of important factors or conditions (e.g. competition, risk sharing) that could drive/inhibit innovation. Identifying the most significant factors and having a greater understanding of their impacts would assist in creating an environment conducive to innovation by maximizing the presence of drivers and by removing or reducing barriers (in fact that's the original motivation for the work). A further benefit that should arise from an understanding of the relative importance of these factors is increased insight into the innovations that could be realized on a given infrastructure project, leading to a more accurate estimation of potential time and cost savings for use in developing the Public Sector Comparators and shadow bids used in the analysis of P3 projects. This is a very important benefit, because two challenges faced by government when deciding upon the most suitable procurement mode for a given project are the a priori estimation of innovation potential for all facets of a project as a function of procurement mode, and how best to set the conditions to maximize innovation potential for a given procurement mode. In fact the original motivation for our study was to determine how innovation potential could be quantified in order to provide input into PSC studies.

Described in this paper are findings from the extensive literature review of our study and consultation with industry experts phase of our study which has been directed at identifying various concepts of innovation as they apply to the industry in general and infrastructure projects in particular, the main drivers / inhibitors of innovation, and documented examples of actual innovations and how they came about. Subsequent study phases will be directed at developing

an enhanced data set of actual project innovations, correlating them with procurement mode and project conditions, and to the extent possible, assessing in quantitative terms the benefits achieved.

3.3. Innovation in Infrastructure Projects

The term innovation has been used in a wide variety of ways in describing novel technologies, products, processes, and organizational practices. A popular definition provided by Freeman (1982) describes innovation as the "actual use of nontrivial change in a process, product, or system that is novel to the institution developing the change". Schumpeter (1961) defines innovation as an effort made by one or more individuals that produces an economic gain, either by reducing costs or through increased incomes. While none of the definitions above or any other has been universally accepted, there has been noticeable convergence as to the principal characteristics of innovation. Innovation is increasingly being viewed as a process that enhances the competitive position of a firm through the implementation of new ideas (Seadan et. al. 2001).

An important point to note about the foregoing definitions is that most of them view innovation from the perspective of a single firm and its economic well being, whereas our focus is on individual infrastructure projects that may be executed by a large number of conjoined firms, in some cases coalescing only for the single project instance. Additionally, infrastructure projects typically have a lengthy lifecycle and involve a multitude of disparate stakeholders such as governments, end users, and developers that results in metrics such as safety, durability, and environmental impact playing a role in the measurement of the benefits of innovative solutions. For example, the primary benefit of an innovative lining technology used in the North Downs tunnel in the UK is that it improved worker safety by reducing risk of injuries due to unstable tunnel roof material (Anonymous, 2003). Furthermore, the more commonly held Research and Development (R&D) based perception of innovation views it as a process that involves invention, development, and implementation carried out over an extended period of time (Widen 2002). It is highly unlikely that the tight time frames available to the private sector for contesting a project and executing it if selected would accommodate an extended innovation process. Therefore, in the context of our study, we are concerned with the impetus the choice of procurement mode gives to the private sector to adapt and use the latest technologies or novel approaches for a specific project in order to maximize project performance. Consequently, we have opted to use a variation of the approach taken by Seadan et al. (2001) in characterizing

innovation as the use of advanced practices, to which we add the use of creative concepts as they apply to the design of: the physical project; the delivery organization; terms of agreements; methods of executing a function or activity; and, financing arrangements.

Thus as used herein, innovation is defined as the use of advanced technologies, methodologies and creative concepts that result in a positive incremental change in basic project performance metrics that include time, cost (capital and life cycle), revenue, quality, scope/capacity (including service levels), safety, and environmental impact. It is noted that the last four ultimately get expressed in terms of time, cost, and revenue, and then in terms of global project variables such as project timelines, net present value (NPV), debt service coverage ratio (DSCR), and internal rate of return (IRR) that are used in project evaluation and as determinants of overall project success. Each of these metrics is a prediction of future events, and hence involves uncertainty. The level of uncertainty in the estimate of a metric is in turn a function of the solutions adopted for a project, plus the interplay between the solutions and other exogenous uncertain variables. The adoption of innovative solutions may increase or decrease project risks, as innovations which are often employed to mitigate project risks, often tend to come with their own risks. In characterizing the benefits of project innovations we have taken into account that the innovation can impact metrics at different levels in the hierarchy of performance measures and have sought to identify: (i) the performance measures that the innovation has an impact upon; and (ii) the magnitude of the impact in either quantitative or qualitative terms, including the impact on the amount of uncertainty. Sources of innovation can be divided into product, process, organizational/contractual, and financial/revenue innovations, as shown in figure 3.1. The innovations achieved in these four categories can bring about positive increments in one or more of the 7 local project performance measures identified.

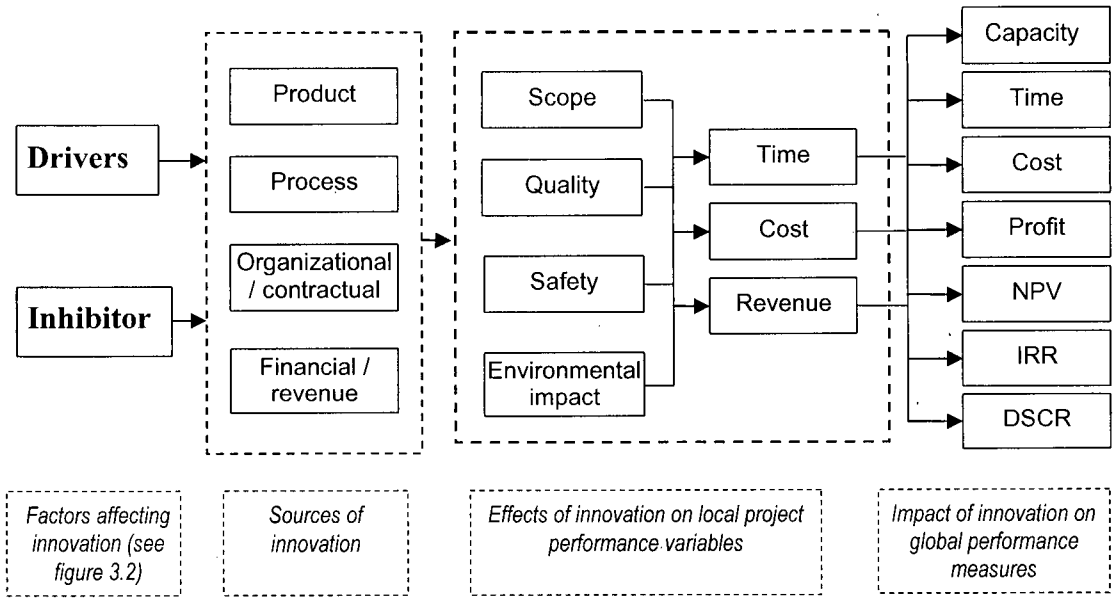

Figure 3.1 Innovation and its impact on project performance measures

A practical illustration of the relationship between the sources of innovation and project performance measures could be in a concession arrangement/agreement in which a contractual innovation allows a concessionaire to generate additional revenue by renting out facilities during after-school hours on a school project resulting in a significant positive impact on the project's revenue stream. Thus in evaluating the project (such as constructing a PSC as part of the value-for-money (VFM) analysis), the positive increments in these performance measures translate into favourable changes in global measures such as the Net Present Value (NPV) or the Debt Service Coverage Ratio (DSCR) which are some of the foremost project economic determinants. It is worth-noting that the four sources or classes of innovation, i.e. product, process, organizational/contractual, and financial/revenue are themselves influenced by a number of factors. In some cases these factors act as inhibitors while in other instances they act as drivers that enhance the innovation achieved on an infrastructure project. The next section gives a detailed description of these drivers/inhibitors of project innovation. For discussion purposes, these classes are defined briefly as follows:

Product Innovations – The construction industry is essentially an adopter of innovative products as opposed to being a mainstream producer of them (Anderson and Schaan 2001). We have therefore considered the use of advanced products (e.g. equipment, tools), novel product assemblies (designs), and materials as product innovation. Different ways of delivering services

in the operating and maintenance phase of a project may also be considered as product innovations.

Process Innovations – Anderson and Schaan (2001) identify 3 types of process innovations that can occur during the construction phase of an infrastructure project. They are logistical technologies, site preparation, and assembling technologies. Process innovations also include practices that utilise emerging technologies such as the use of information technology (IT) tools (e.g. 3D/4D CAD systems) in project design and management processes. Innovation can also occur during the operational phase of a project, for example, new technology in the form of ultraviolet disinfection is being used on a design-build-operate water treatment plant in Seattle (Haskins, Gale and Kelly 2002).

Organizational/Contractual Innovations – new or significantly improved organizational practices (e.g. computerized inventory control) (Anderson and Schaan 2001) and partnering can be considered as organizational innovations. In terms of contractual relationships, the negotiation of the assignment of risks as opposed to the unilateral imposition of risks could also result in contractual innovations, as could the development of contractual terms dealing with performance-based revenue or payment mechanisms.

Financial/Revenue Innovations – Novel financing arrangements that lead to off-book financing, the minimization in the increment of cost for private as opposed to public sector financing, desirable patterns of cost and revenue, and the identification of innovative revenue streams (e.g. generating third-party revenues or externalities from renting out school facilities during after-school hours) can play a crucial role in procuring infrastructure projects under P3 arrangements. They can lead to improvements in project metrics such as the DSCR and the NPV that ultimately determine project viability.

3.4. Drivers and Inhibitors of Innovation

As mentioned previously the identification of factors or conditions that drive or encourage innovation or that inhibit innovation, as a function of their values is an important part of our study. This section contains a review of past literature that has focused on the topic, with particular emphasis on construction and infrastructure development. For an extensive

bibliography on construction innovation that has mainly a North American focus, see the article by Miller et al. (2001).

Several authors (e.g. Dalpe 1994, Marsh 2003) have discussed the role of the public sector in stimulating industrial innovation through funding for R&D (directly or indirectly through mechanisms such as tax breaks), and accommodative procurement policies that encourage innovation. Such discussions are directed more at the long term development of construction industry capabilities as opposed to innovation at the individual project level. Policies that have been cited include acting as the lead user of innovations, and provision of significant order values that allows the supplier to reduce the risk associated with the innovation and achieves economies of scale.

Tatum (1984) describes six innovative construction methods from nuclear generating plant projects and uses those examples to identify conditions that foster construction innovation. Common conditions identified from among the case studies include: (1) challenging engineering and construction requirements as well as schedule requirements; (2) availability of sufficient lead time to develop detailed schedules and to plan construction methods; (3) a positive approach by the design team towards evaluation of alternative methods that could require changes in the original design; (4) availability of a champion for a proposed innovation; (5) large construction operations gaining significant management attention, rather than smaller scale work activities that are repeated on a frequent basis; and (6) the same firm serving as both the designer and constructor or construction manager (this was identified as being present as an innovation stimulus on a subset of the projects studied). Adversarial contractual relationships, rigid use of standard requirements, budgets preventing evaluation of alternatives, unwillingness to undertake risks, and rigid barriers to communication were found to be absent in the sample of projects studied.

The utilization of performance specifications to increase innovation has been described by Molenaar and Johnson (2003) with respect to highway engineering projects undertaken using design-build. It is their belief that if procuring agencies continue to use prescriptive specifications and simply transfer design detailing to design/builders, they will not realize the full potential for innovation. Marshall (1999) examines the advantages of an integrated design and build process utilizing the Oresund tunnel between Sweden and Denmark as an example.

Several innovations that can be attributed to design and construction being procured as a single entity are presented. They include a novel method of horizontally aligning tunnel elements, and an alternative joint design that simplified construction.

Craig (1999) reinforces the view forwarded by Tatum (1984) that a positive approach towards the evaluation of alternatives is a desirable precursor to innovation by offering evidence that the lack of such an approach hinders innovation. Developments in common law associated with the traditional design-bid-build process are revealed that result in contractual obligations for the procurer which could preclude the selection of more economical innovative solutions as the procurer becomes obliged to treat all tenders equally and fairly. *Pratt Contractors v Palmerston North City Council* (1995) is cited as an example. The role of statutes in inhibiting the potential for innovation has also been discussed by Molenaar and Johnson (2003).

Leiringer (2003), Slaughter (1998) and Keegan and Turner (2002) discuss innovation and its implementation in the context of project-based firms. Leiringer (2003) discusses 3 types of inhibitors to innovation. They are: (a) economic factors such as lack of sources of finance, excessive perceived risks, and long pay-off periods; (b) organizational factors such as lack of skilled personnel, and resistance to change; and (c) external factors such as customers being unresponsive to new products and restrictive legislation, norms, regulations, standards, and taxation. Based on a study of project-based firms, Keegan and Turner (2002) identify tight planning and control systems adopted and a desire for efficiency as being a barrier to the identification and adoption of innovations. At the same time, however, these organizations were found to have an environment in which communication is free-flowing and informal, a characteristic that has been deemed to be supportive of innovation.

Tatum (1986) identifies several elements of the US construction industry that have restrained innovation. These include investment reluctance, lack of competitive conditions due to a firm holding a sizeable market share in a geographical region or a specialty segment of the industry, institutional framework, seasonal and economic cycles, and reluctance of suppliers in introducing novel technologies. The fragmentation of the industry, with a large number of firms specialized both by geographic region of operation and by type of construction has also been identified as a restraining factor on innovation as it limits the resources available to individual firms for innovation. Tatum (1986) identified several characteristics of the construction industry

that are advantageous for innovation in comparison to other sectors such as manufacturing. They include: (a) the creation and disbanding of a separate team for each project offers a degree of autonomy. This is similar to "skunk work" organizations advocated as being conducive to innovation by Peters and Waterman (1982); (b) the uniqueness of individual projects presents a high level of necessity and challenge for results, and creates a driver for innovative solutions; (c) the integration of engineering and construction in some instances allowing construction experience to be input to the design leading to innovative solutions; and (d) the availability of technologically experienced personnel such as engineers and superintendents in most construction companies.

The extent to which the design of the organization facilitates or inhibits innovation has also been discussed by Winch (2000) through a comparison of French and British project organizations. Relatively innovative project organizations have been found to feature a flat organization with ambiguous and overlapping roles and responsibilities. In such organizations that are more reflective of the French approach, the employees display a high commitment to work and colleagues, and reliance is placed upon strong project leaders for coordination of work.

The high cost of innovation, and the lack of skilled workers have been identified as the major obstacles to innovation in a study of the construction and other related industries in Canada (Seadan et. al. 2001). A study of the Australian building and construction industry (Australian Construction Industry Forum 2002) has identified internal resource pressure, lack of capital or finance, risk involved in commercializing innovations, and government policy and legislative environment as the primary inhibitors of innovation. Findings of structured interviews conducted with industry experts have reinforced most of the views from the literature on factors that drive/inhibit innovation at the project level.

As seen from the foregoing discussion, a variety of factors encourages or inhibits innovation. In carrying out an extensive review of the literature along with an analysis of innovations that have occurred on infrastructure projects, we have found it useful to create a taxonomy of factors or conditions that can act as drivers or inhibitors in order to examine each case study in a consistent manner. Our primary perspective is that of government trying to assess innovation potential as a function of procurement mode (with the latter being the decision that government is trying to make), along with how to set conditions that will maximize the potential for innovation as

measured through one or more project performance measures, all for a specific project context. Based on our review of the literature and discussions with industry personnel, we have identified some 22 factors that should be considered by government as part of its decision making process. The factors have been gleaned from the construction/innovation literature, the authors' experiences and personal observations of the construction project delivery process as well as results of structured interviews held with industry experts. A challenge for government is how to exert either direct or indirect control over the value or state of a factor so that it acts as a driver, given the assumption of a particular procurement mode. Ongoing work is directed at determining possible states or values for each factor, and assessing their relative values with respect to innovation potential for a prescribed procurement mode (see Tawiah and Russell (2005) and a paper to be submitted to Construction Management & Economics journal). The 22 factors can be grouped into 5 major categories of innovation factors - project-specific characteristics, commercial/business factors, project requirements, project risks and socio-economic/political considerations. In exerting any form of control over the possible state or value of a factor, it is important to note that some of the factors are within the direct control of a project grantor (in this case a government agency making decisions about procuring an infrastructure project) whilst others are beyond the control and capabilities of the project grantor and are often fixed. Engineering/technical factors relating to project characteristics operate within the physical environment and can be described as fixed. They fall within the domain and competencies of project engineering/management teams. However creating the most suitable commercial contracts to meet a project's requirements are either directly or indirectly controlled by the project grantor through a particular procurement structure chosen and are strongly linked to a project's economic needs and functions. Socio-economic and political factors are normally beyond the control of project teams but can be managed through the structure and allocation of project risks. A detailed explanation of the role of these factors in acting as drivers or inhibitors of innovation is given in the next section.

Before listing and describing each factor, we draw attention to the following. First, the assessment of the role of each condition as a contributor to innovation is conditioned both on the procurement mode being assessed and the specific project context. The latter is important, as it is impossible to conduct a 'one size fits all' analysis that applies to all project types and project contexts (despite the efforts of some advocates of P3 as a preferred mode of procurement). Procurement modes considered embrace but are not limited to DBB (traditional design-bid-

build), DBBo (design-bid-build optimized with value engineering, allowance for alternatives, etc.), DB (design-build), DBM (design-build-maintain), DBOM (design-build-operate-maintain), FDBOM (finance-design-build-operate-maintain), and FDBOMSD (finance-design-build-operate-maintain-service delivery). Uncertainties of the political, economic and regulatory environments, for instance, are not particularly relevant in influencing project innovations in a design-build (DB) setting, whereas these factors in a finance-design-build-operate-maintain-service-delivery (FDBOMSD) procurement mode will certainly influence the kinds of novel solutions (product, process, organisational/contractual and financial/revenue innovations) sought. Second, the various procurement options that can be adopted for a project involve different project phases – and, hence, thought must be given as to how a factor may act as a driver during different project phases. For example it is possible that a factor could be a driver say in the construction phase, and an inhibitor in the operating and maintenance phase (e.g. for DBB, stringent cost and time constraints may drive innovation in construction processes, but create long term operating and maintenance difficulties because of quality problems). Schedule constraints can serve as an inhibitor of innovation at the design phase of a project but may drive innovation at the construction stage through the use of faster methods and novel activity sequencing techniques. In a similar vein, Bossink (2004) identified several different drivers of construction innovation (champions, inter-firm networks, stimulating regulation) and recognised the characteristics, influences and abilities of 4 broad categories of factors to act as drivers of innovation at different ***levels*** of construction practice, these being industry, institutional & firm, and project level. Thus an analysis and identification of drivers/inhibitors of innovation should be cognisant of the variable role of a factor as a driver or inhibitor depends on the level of abstraction. Even at the project level a particular factor may have different impacts depending on the project phase (development, design, construction, O&M, decommissioning) where it occurs.

Not all the factors are independent of one another. A factor may act as a driver or inhibitor, but its presence can reinforce or diminish the contribution of other factors as a driver. Natural environment risks/requirements can suddenly become a prominent factor for project innovation in green field project types where the stakeholder environment can be quite hostile; or project complexities associated with certain projects, say a nuclear plant, will attract specialty firms with specific expertise, sometimes internationally. It may therefore be possible that a group of factors acting in concert at a particular project phase under a given procurement mode may create an optimum condition for a maximum potential for innovation whereas individually they may act as

innovation inhibitors or be of less ability to drive innovation – i.e. under the best conditions, the whole can be greater than the sum of the parts.

Project-specific Factors/Characteristics

Project type - project type can be both an inhibitor and driver of innovation. The nature of some project types (e.g. university student-housing) leaves little opportunity for seeking significant innovation especially in the physical solutions because project/human/regulatory requirements provide a tightly defined constraint set. Contrast this with large scale transportation projects (tunnels, long-span bridges, roads etc.) where topographical considerations combined with various physical solutions and construction technologies create a much broader solution set. Available evidence supports the assertion that the potential for innovation tends to be higher in heavy civil engineering projects (roads, rails, tunnels, bridges) in comparison with buildings (residential, commercial, industrial facilities). Size, scope, project complexity and the sensitivity of the natural environment for such projects usually require "ingenious" design concepts, physical components and construction methods to effectively address specific performance and environmental impact concerns.

Project scope/scale - larger projects typically provide the opportunity for the slack resources (time, capital, etc.) required to evaluate a greater range of potential design solutions, especially ones that maximize repetition of elements, thereby allowing the use of more equipment intensive production processes that permit economies of scale. Government is therefore faced with determining whether it is better to divide a large project into smaller pieces in order to encourage competition or bid it as a single project. Size and scope economies influence innovation – such as the production of pre-cast elements on large-scale projects. For example on the Millennium Line transit project in Vancouver, B.C., a $200-million plus project, contracting for pre-cast elements from a single producer offered greater economies of production and efficiencies (Anon. 2004) and hence process innovations. Tatum and Fawcett (1986) examine conceptually the impact of project size (scope) on organisational structure and present 5 organisational alternatives for delivery of construction projects based on the characteristics of size, objectives and goals, external influences, technology, and phase. These project factors (particularly size) can impact the type and extent of organisational innovations. A project's scale/scope can either act as a driver or inhibitor of various project innovations depending on their magnitude and intensity.

Project complexity/uniqueness - project complexity implies a high level of technical sophistication both in the design and related construction processes, and stringent project technical and performance requirements. Project complexity includes the skills and expertise required for understanding the enormous resource requirements needed to deliver certain projects in terms of the labour, equipment and material quantities (e.g. reinforcements, embedments etc.), physical configuration (interaction and interference among structural components) and the assemblage of special components and their interfaces as well as precision in tolerances and plumbness measured in terms of thickness, diameter, height, densities of structural components (Tatum, 1983). A project could also be described as very complex in terms of its ability to be financed. Project uniqueness refers to projects that are not built very often on a recurring basis, or each project of a similar type has highly varying site conditions which reduce the opportunity for transferring experience gained on one to another. Project uniqueness constitutes a level of project complexity for non-common projects such as nuclear plants or for very lengthy bridge projects such as the Confederation Bridge. Project complexity/uniqueness may be an inhibitor of innovation because of lack of prior experience, established guidelines or standards, etc. However, this factor can also be an innovation driver, as complex and previously un-encountered conditions create a necessity for novel solutions (concepts, methods, techniques) which might expand the boundaries of existing guidelines, codes and standards.

Commercial/Business Factors

Responsibility Integration - this relates to procurement mode in disguise. Some procurement modes provide more opportunities than others to bring together specialists in all phases of a project's life cycle – design, construction, facilities management, and even marketing, thus providing the opportunity to make the tradeoffs necessary (e.g. capital cost vs. life cycle cost) to optimize overall performance leading to a whole-of-life approach in delivering the infrastructure. Greater integration may lead to a higher potential for efficiency and innovation, especially in design. However, given that each project team is unique for each project, it is not a certainty that effective responsibility integration will take place even for a full P3. Proposal evaluation criteria should be formulated to encourage real integration of the project functions (design, construction, facilities management, service delivery). To address the fragmented process associated with the traditional delivery of infrastructure projects, Love et. al. (1997) advocate the use of Concurrent Engineering (CE) - a concept adopted from the manufacturing sector which describes an effort to

effectively integrate all aspects of product development activities, through concurrent performance by a multi-disciplinary team, which used to be done sequentially with the objective of developing innovative design solutions. Utilising the CE approach leads to detection and resolution of downstream problems early in the design development process, enabling project cost and time to be reduced by as much as 30% on some design-build infrastructure projects (Evbuomwan and Anumba, 1996).

Nature & Composition of Project Team

Innovations may require special resources (such as specially trained personnel) and such special resources may exist in certain specialty firms (Slaughter, 1998).Team cohesion, motivations and alignment of individual/firm goals and objectives to project objectives are essential ingredients for the project innovation process. Past experiences of a team on previous projects, particularly with regards to innovation and their outcomes, and the team's reputation for project excellence can be some of the measures for assessing a team's ability to drive innovation on a project. Individuals on a project and their personality traits/characteristics are also critical to achieving project innovation. The roles of clients as drivers of project innovation (Nam & Tatum, 1992b; Brochner & Grandison, 1992; Mitropoulos & Tatum, 2000) as well as those of other key project participants across the supply chain require champions of innovation with the requisite technical knowledge/authority to conceive feasible innovations and overcome the uncertainties/resistance associated with the implementation of such creative ideas and concepts (Nam & Tatum, 1997).

The project team or consortium (in the case of P3 projects) must be constituted to include innovation champions and to have a structure that can create an environment in which innovation can come from several sources - owners (who can embrace new ideas), designers and contractors. The challenge for controlling this factor to drive innovation is about getting the project team right using provisions set out in the initial phases of the procurement process such as at the prequalification stage; to find the optimum mix of firms and individuals which when constituted appropriately can act as a driver of innovation through their design of effective innovation implementation mechanisms.

Opportunity for other projects of similar type - the incentive to seek innovation, especially if product or process concepts can be protected, is heightened if projects of a similar type can be pursued within a reasonable time period because of the greater opportunity to appropriate

benefits of the innovation. Such opportunities, however, depend on the type of innovation. Technological innovations adopted from other industries where competitive advantage is solely maintained by the pace or rate of innovation, face the risks of technological obsolescence and hence potentially lower potential for appropriating their benefits over the long-term. This opportunity need not be in the same geographical location as the project under consideration, especially if a firm is national or international in its reach. The question however is whether an innovation first used in a particular geographical jurisdiction can still be described as such during its subsequent application in the same location. The ability of this factor to drive innovation is however contingent on the certainty of some socio-economic and political considerations of the general economy to ensure work continuity and future demand functions to spur continuous investments in long-term innovative solutions and concepts. However the project-based nature of construction where the next project can be different from the previous in both functionality and sub-components (architectural, structural, mechanical, electrical) can constrain the ability of this factor as a driving force for innovation.

Source and extent of Competition - bringing competitive forces to bear encourages experimentation, diversified sources of design ideas and techniques, lower prices/cost, and enables foreign access which can drive the innovation process (Mokyr, 2002). This leads to innovations in project design, construction and operation & maintenance phases. However price-based competition can restrict innovation because of the consequences of failure and potential damages associated with creating and implementing an innovation. ***Technical competition*** which focuses more on design and solution concepts to drive value and reliability has resulted in significant innovations but is a process which is rarely used on its own. The more broadly interest is sourced in a project, the more likely that novel ideas for one or more project phases will occur. Geographically dispersed interest (local, regional, national, international) is also a function of project type and scale. However, a procurement mode, on the basis of particular local needs and efforts to boost local economy/industry, may exclude national or international parties from participating in project tendering and thus limit the potential use of proven and novel concepts and technologies used elsewhere.

Competition in the area of project funding for P3 projects leads to financial innovations that drive financing costs down which may then transform into cost savings to the public. A report by the UK Comptroller and Auditor General (HC 328 Session, 2001) indicates that, in spite of its

potential downsides and risks, ***funding competition*** in PFI projects enhances financing innovation and raises benefits (cost savings) when the project funding is competitively bid among financiers. The success of a funding competition is, however, contingent on the pre-existence of a commercially viable contract. Smith (2004) suggests that the UK Treasury's pilot credit guarantee finance (CGF) scheme can increase the intensity of the funding competition process among potential project financiers (commercial banks) as government can borrow at lower rates and lend at sub-market rates with the potential to deliver significant cost savings not only to the government agency/department procuring the infrastructure but more importantly to the general public or end-users of the facility.

Number of Competitors - Carr (1983) discusses the impact of the number of bidders on contractors' profit margins (undercut of mark-ups) and hence estimated construction costs, using mathematical (probabilistic) models. The greater the number of competitors (bidders) for a project the slimmer the probability of winning and the higher the proclivity to trim estimated construction costs and mark-ups. Reduced construction costs can imply higher cost savings to the project procurer, and greater efficiencies to the constructor that may lead to increased innovation (predominantly in the construction process). Too many competitors, on the other hand can cause a loss of interest in the process by potential bidders and hence, less competition and commitment as chances of winning a bid become slimmer. There should be an optimum number of competitors to attract for a project to encourage competition and innovation. The number of competitors is a function of other factors (e.g. type, scale, repeatability of project type, risk assignment, economic climate, etc.) – the issue becomes how to package a project and establish terms so that maximum interest is generated. This factor interacts with source of competition, project type and scope. Breaking a project into small packages may reduce international interests, whereas bundling a project may exclude some local competitors who may lack the experience and resources to participate in the process.

Proposal evaluation criteria & relative weights, decision and negotiation processes - traditional price-driven project proposal selection may limit the ability and flexibility of design and construction teams to explore novelty and innovation for optimal project performance. The least cost project alternative, especially capital cost, is most likely not the best option. Thus selection criteria that attempt to seek value beyond just price and include other considerations such as past

experience with innovation even at the pre-qualification stage and a whole-of-life approach to project decision making can drive project innovation and efficiency.

The public sector can signal to the private sector the reward structure and risks associated with pursuing innovation. Evaluation criteria can also provide indirect assistance to bidders as to how to select, structure and manage themselves in order to maximize the opportunities for innovation. Also important is whether there is a willingness to negotiate terms on the part of public sector. Properly formulated, this factor is a driver; improperly formulated an inhibitor. Too often evaluation criteria in most P3 negotiations imply almost no partnership at all, and a total offloading of risk to the private sector.

Project Requirements

Project performance requirements/thresholds/constraints - this factor treats the broad spectrum of performance requirements that characterize a project, including cost (capital, life cycle), time (schedule), quality (service life), service levels/capacity, availability etc. On the one hand, the more stringent the requirements, the potentially greater the incentive for innovation, assuming that performance can be accurately predicted. On the other hand, stringent requirements and constraints can limit competition, or increase the risks associated with novel technologies and therefore inhibit innovation.

Time/schedule constraints can be a driver or inhibitor of innovation depending on the phase of project delivery. Unrealistic time and schedule pressures have been cited by several designers (Veshosky, 1998; Salter & Gann, 2003) as a dominant inhibitor that encumbers design teams in seeking innovative design concepts and ideas. However, in the construction phase, schedule constraints can spur innovation with regards to the adaptation and application of novelty construction methods/sequencing and technologies that often tend to accelerate the actual construction process and lead to savings in time and perhaps costs (Tatum, 1989). Thus schedule constraints whilst engendering innovative construction approaches (process innovation) are likely to impede innovation in the design of the final finished product (product innovation).

The ability of performance requirements/thresholds/constraints to act as either drivers or inhibitors of innovation will depend on finding the balance between their measures and project team's competencies and capabilities to deliver based on the most appropriate risk allocation and

penalties for non-compliance. Two important observations came out of the discussion with industry experts on the topic of constraints. First, it is important to know what 'hard' constraints vs. 'soft' constraints are i.e. which constraints can be challenged and perhaps removed or modified. Second, what the basis for a constraint is i.e. does it represent someone's view of the properties required of a design solution (e.g. number or spacing of bridge piers in a river) in response to a problem (e.g. scour)? If the answer is yes, the view then is tell us what the problem is and let us try and deal with it, as opposed to specifying a constraint that represents only one possible solution.

Requirement for broader socio-economic benefits - the need to bring benefits to a larger audience (e.g. create work and supply opportunities for local labour, consultants, contractors and suppliers, provide training to upgrade local skills, develop domestic capability in order to compete in other market places, etc.) can introduce additional costs to the developer and lessen opportunities for innovation (source of competition, number of competitors) by limiting participation by "foreign" parties who possess specialised knowledge and expertise which may not exist locally. However, the use of local resources and knowledge can sometimes speed-up the construction delivery process and increase the predictability of costs and construction activities in labour intensive production processes. Local knowledge and experience can often lead to a more effective control and sourcing of construction materials and equipment. Requirements for broader socio-economic benefits, often incorporated into contracts and concession agreements through compliance clauses, can act as a driver or inhibitor of innovation depending on the type of innovation in question – product innovations may be constrained but stability/predictability in local labour, material and equipment supply may spawn efficiencies in the construction phase leading to some process innovations.

Statement of Product Solution - the opportunity to explore a wider variety of product solutions is enhanced by stating objectives or performance requirements/outputs, as opposed to providing detailed technical solutions or constraints that are believed to provide the required performance levels (see also the comments under performance requirements/constraints). The role of this factor as a driver or inhibitor of innovation is dependent upon the purpose and the extent of detail of the preliminary designs usually issued as part of a project brief. A preliminary design developed almost close to completion and based on prescriptive codes from which all project solutions and costs estimates are to be prepared may leave very little room or flexibility for

exploring alternative solutions and thus may hamper innovations. Specification of outcomes (e.g. "move 10,000 people" between A and B) vs. functions (build a highway to move 8000 vehicles between A and B) vs. end product (build a 4-lane road and two interchanges in an area) vs. methods (use 30 MPa concrete and 15M rebar at 150 mm o/c) is very crucial for driving innovation. Thus, choosing the right level of specificity of requirements is critical. Possible states for this factor include prescriptive (technical), performance- or objective-based requirements, functional requirements, or some combination of the three based on the nature and type of project.

Statement of Process Solution - the opportunity to explore a wider variety of process solutions (e.g., construction methods) and possibly even service delivery processes is enhanced by stating objectives or performance requirements, as opposed to providing detailed technical solutions that are believed to provide the required performance levels. The requirements for method statements included in bid documents when based on functional/performance output specifications can create more latitude for evaluating alternative solutions and innovative methods. Possible states for this factor include prescriptive (technical), performance-based or objective-based requirements, functional requirements or some combination of the three based on the nature and type of project. Product and solution processes definitions are intricately linked to the project scope, objective functions and complexity. It is important to define a project scope which is feasible in terms of binding or hard constraints e.g. zoning regulations that cannot be changed.

Penalties for inadequate project performance - the current belief is that the contractor or private sector consortium (in the case of P3 negotiations) should be "incentivised" to achieve various thresholds of performance. What this means is that payment is tied to performance achieved or availability of certain service levels. This mechanism can drive novelty to achieve higher quality and service/performance levels during a project's operation and maintenance phase. However in attempting to drive project efficiencies such performance-related penalties can induce a double risk to bidders – the risk of any innovation not fulfilling expectations, and a loss of revenue due to reduced performance. Draconian penalties can inhibit the desire for innovation. Stiff and unreasonable penalties for inadequate performance in a lopsided risk assignment/allocation scheme in favour of the public sector may force the private sector partner to spend all its time ensuring compliance and to eschew innovation, especially if the contract stipulates a strict adherence to detailed/prescriptive product and process solutions.

Project Risks

Product risks - product risks can be both a driver and inhibitor. Novel solutions that have not been proven before (e.g. a submerged tunnel for transportation) may have a risk profile that outweighs other performance dimensions or for example the huge product design and performance risks/uncertainties associated with the building of a floating bridge structure that must still meet durability requirements. These product risks may also impact negatively on opportunities for other dimensions (process, organizational / contractual, financial / revenue) or may challenge existing design standards and codes to drive innovations.

Process risks - process risks deal with innovations directed at constructing the project (offsite and onsite), operating and maintenance processes, and possibly service delivery processes that must meet safety and other requirements. The known and unknown risks that accompany novel methods may weigh against their use, and may impact variable values for other project dimensions. Like product risks, process risks can act as driver or inhibitor of innovations, particularly process-related novel solutions, which may also impact organisational/contractual and financial/revenue innovations.

Natural environment risks/ requirements - this factor greatly impacts both product and process innovation potential. Innovative design and construction processes can help mitigate or even avoid some environmental risks. An innovative caisson dredging technique developed by an environmental firm was driven by strict water-quality requirements for work in the Fraser River of BC, Canada, and the high costs associated with the disposal of water with contaminated sediments (Construction Innovation, 2004). However, innovation may be thwarted if the consequences for negative impacts on the environment are set so high that they drive project participants to stick with only proven design solutions, construction technologies, or standard operating and maintenance procedures. Natural environment risks can also impact financial innovations. On some infrastructure projects in certain jurisdictions, the type and sources of project financing arrangements are strongly influenced by a set of voluntary principles (called Equator Principles) that seek to assess a project's potential environmental impact to ensure that set environmental and social performance benchmarks/standards are met prior to financial close (Glasgow, 2003).

Reasonableness of risk assignment between public and private sectors and risk attitudes -if the belief of government is that all risk (product, process, environmental, economic, etc.) whether or not it can be meaningfully managed should be passed on to the private sector, then this will be a significant inhibitor of innovation, and also to broad-based competition. The willingness to share risk and potential rewards for innovative solutions can be a powerful driver for innovation. The willingness to share/manage risk is linked to the risk attitudes of project actors and their understanding of the risk/ innovation relationship.

Socio-Economic & Political Factors

Certainty of economic environment - this factor deals with a myriad number of sub-factors, including availability/mobility of skilled labour with the requisite training and experience, labour relations environment (short and long term), price stability (short and long term), stability of supply of input materials, interest rates, currency exchange rates, etc. This factor, while beyond the direct control of government and any bidder, is reflected (or should be) in the potential terms of a contractual or concession agreement. How the economic environment is treated in such an agreement can enhance or detract from the desire to pursue novel solutions vis-à-vis the opportunities to appropriate benefits of an innovation.

Certainty of political environment - a source of considerable uncertainty is the behaviour of government both in the short and long term. For example will government stick to a decision in the face of concerted political pressure, and will the commitment by one government be honoured by another? Lack of confidence in government policies is an inhibitor to making the investments necessary for innovation, especially if it is founded on previous actions by government (e.g. reversal of decisions, expropriation, and lack of political will). On Highway 407 a unilateral rescission of a contractual commitment by a succeeding government not to enforce certain provisions of the concession agreement originally entered into by the project developer with the predecessor provincial government led to a legal dispute between the two partners (Globe and Mail, 2004). Interestingly, that contractual provision constituted a motivating factor for developing, installing and maintaining a major innovation of the highway (i.e. the electronic tolling/billing system).

Certainty of Regulatory System/Environment - significant difficulties can be involved in gaining approval for innovative product and process design. In general, lack of certainty in the

regulatory environment as to how an innovation will be treated can act as an inhibitor, particularly the influence of existing standards and codes on the acceptance of innovative concepts in the design and construction stages of a project.

The type of regulatory mechanism employed at the O&M phase can influence the nature and extent of novelty approaches used for service pricing, user-fee collection and facility maintenance, especially for civil infrastructure projects procured P3 arrangements where service provision, maintenance and/or ownership of the constructed facility remains a private sector responsibility during the concession period. The certainty of the regulatory environment can thus influence the opportunities for appropriating the benefits of an innovation developed and implemented by the project concessionaire.

Certainty of stakeholder environment – a project's stakeholder environment can be an inhibitor to innovation. Opposition can coalesce around the concept of the project itself, the design of one or more aspects, the method of construction to be used (e.g. open-cut tunnelling in a commercial district), the belief that public sector jobs are being given away, etc. In some circumstances, stakeholder concerns, especially about the potential environmental and socio-economic impacts of the project, can act as a driver for innovation in one or more project phases when these issues get addressed, and depending on who takes leadership role.

3.5. Interaction amongst the factors

As noted previously, the factors tend to interact with one another. In Figure 3.2 we have attempted to identify the interactions among the factors (outflows are represented either from left to right or top to down). For example, competition, both in terms of source and number of competitors is influenced by the state values of a number of other factors, including project scale, complexity/uniqueness, repeatability of project type, the requirement for broader socio-economic benefits and responsibility integration. Repeatability of project type in turn is influenced by the economic and political climate. The certainties of the regulatory and stakeholder environments influence the kinds of novel solutions generated in response to product, process and natural environment risks. The client as a member of the project team can influence the nature of product and process solution statements required to build the project. The interplay amongst the factors is a subject of further ongoing investigation.

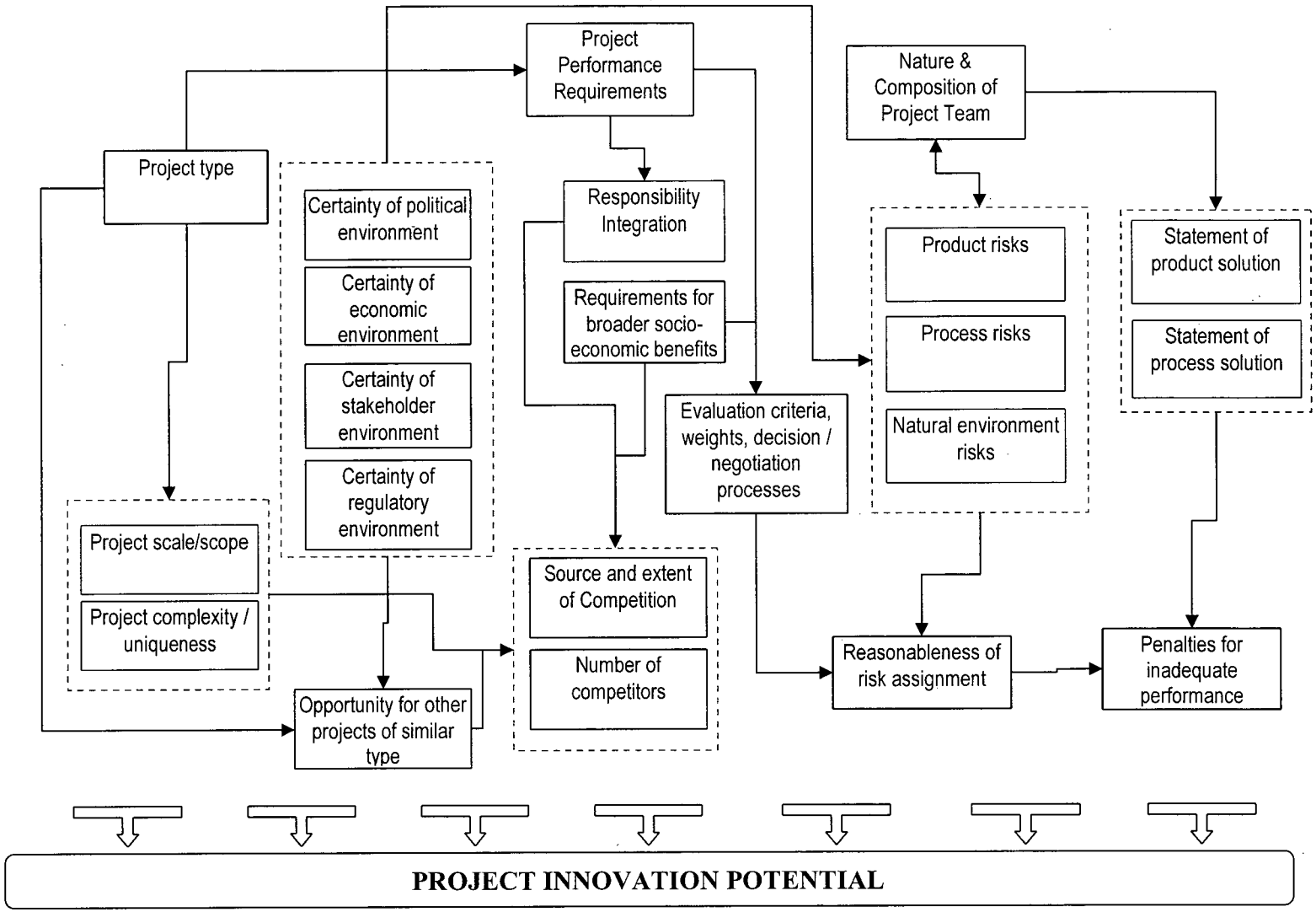

Figure 3.2 Interaction between factors/conditions to create drivers/inhibitors for innovation

Table 3.1 Factors that act as drivers/inhibitors of innovation and their impacts

Factors (Drivers/Inhibitors) for Innovation	**Product Innovation**	**Process Innovation**	**Organizational / contractual Innovation**	**Financial / Revenue Innovation**
Project type				
Project scale				
Project complexity/uniqueness				
Responsibility integration				
Opportunity for other projects of similar type				
Source of competition				
Number of competitors				
Project performance requirements/thresholds/constraints				
Requirements for broader socio-economic benefits				
Statement of product solution				
Statement of process solution				
Product risks				
Process risks				
Natural environment risks				
Certainty of economic environment				
Certainty of political environment				
Certainty of regulatory environment				
Certainty of stakeholder environment				
Reasonableness of risk assignment				
Penalties for inadequate project performance				
Proposal evaluation criteria, decision & negotiation processes				

Table 3.1 depicts an attempt at assessing the relative importance of the factors as drivers or inhibitors of innovation independent of a specific procurement mode, and independent of the interaction amongst the factors. Shaded areas indicate primary importance, while crossed-hatched areas indicate secondary importance. White areas indicate little or no importance. Project type coupled with the complexity and scope of work can drive more technological (product and process) innovations in a high-risk natural environment setting. Project scale in monetary terms can influence the types of novel and applicable project financing instruments used for a particular project.

To promote innovation, the states or values for the factors (e.g. for competition, local versus national versus international) identified above that are most conducive to innovation need to be identified and a metric developed to indicate innovation potential. For example in its highest state of driving project innovation, project type can be represented by heavy civil infrastructure projects (long-span bridges, tunnels, roads, maritime/port and off-shore structures, nuclear plants

etc.). Generally the potential for project type to drive innovation decreases in moving from heavy civil infrastructure to industrial/commercial facilities/structures, utilities and is lowest in residential projects. The potential for project innovation is highest for project scales greater than $100million, with a decreasing potential for the $10 - $100 million and sub-$10million ranges. The potential for innovation is likely to be highest in Finance-Design-Build-Operate-Maintain-Service Delivery projects i.e. complete integration of project functions compared to a fragmented/sequential process where project phases/sections are contracted out to distinct and disparate parties. Product and process solution statements in moving from performance through functional to technical/prescriptive specifications decrease their ability to drive innovations, and so on. The issue of factor states and their impact on innovation potential is more fully addressed in Tawiah and Russell (2005).

Starplots (Spears 1999) have the potential to be a useful tool in characterizing and visualizing the role of the factors in contributing to innovation potential. An example starplot based on hypothetical values of the factors and assuming equal weight in terms of the importance of each factor is shown in figure 3.3. Thus, if we looked at the conditions for innovation in terms of the starplot, on a given project an attempt should be made to maximize the area within the plot in order to foster innovation. Note that we have used a slight variation of the starplot such that the ordering of the axes plays a minimal role in determining the area contained within the plot (i.e. all factors own equal angles on the two side of the axes). Such a visualization can give several valuable insights such as highlighting areas or factors that should be scrutinized or controlled to provide a more facilitating environment for innovation, or conversely in identifying factors that are hindering the innovation effort. Additionally, the area of the starplots can assist in determining how much innovation can be expected on a given project, thus providing valuable information to financial and economic analysis of the project. A number of plots may be required, in order to reflect innovation potential in terms of the various project metrics described in figure 3.1. Our primary interest is in terms of the risk-adjusted value of net present value, which corresponds to the public sector comparator, and which has the virtue of capturing all time and cost impacts throughout the life cycle of the project.

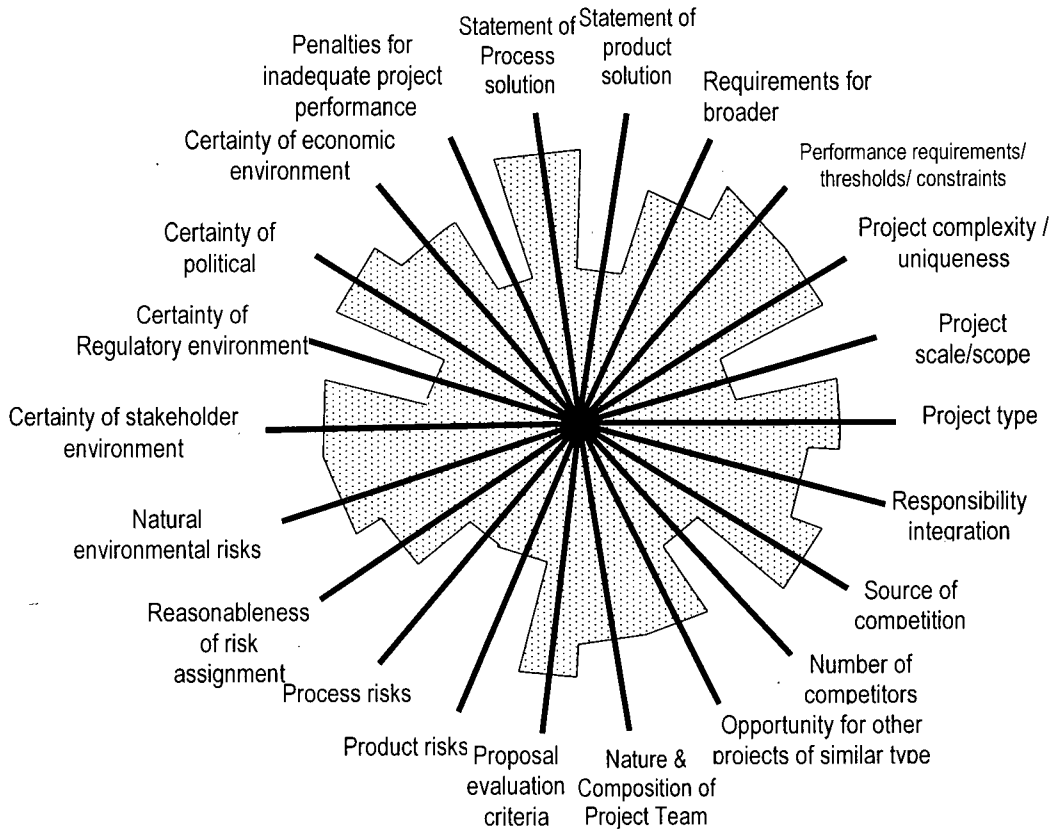

Figure 3.3 Starplot of factors driving innovation in infrastructure project

3.6. Case Studies

As described previously, important objectives of our study include determining the degree of correlation that exists between innovation and procurement mode and identifying the value of project factors that can maximize the innovation potential of P3 projects. As part of our study, an extensive literature review was conducted to identify examples of product, process, organizational / contractual, and financial / revenue innovations that occurred on infrastructure projects, the relationship of the procurement mode with the realization of the innovation, and the benefits that arose from the innovation. Well very disappointing – little in the way of findings, especially objective ones could be found. This may imply either such a relationship is practically non-existent or there hasn't been sufficient documentation by practitioners of their experiences in project delivery in that respect. Three case studies, namely the Confederation Bridge in Canada (P3) and the Oresund tunnel in Scandinavia (Design-build) have been conducted. Also included

is a university student housing project in Canada that was considered for a P3 but which was ultimately built using traditional procurement mode. Findings from the analysis of the 3 projects are described briefly here.

Highlighted in Table 3.2 are several of the features of the Confederation Bridge project that relate to the theme of innovation, and conditions that acted as drivers or inhibitors for innovation. As seen from this table, innovation occurred in all four innovation classes or dimensions identified previously. Innovations achieved on the Confederation Bridge project are incremental in nature and came about through adaptations, improvements and unique applications of existing technologies, concepts and methods (Pirie and Giannelia, 2004). In Table 3.3, an attempt has been made to identify the relative importance of the various factors in contributing to innovation for the FDBOM or BOT procurement mode adopted for this project. Shaded areas represent factors of primary importance, cross-hatched of secondary importance, and white areas of no significant importance. In the view of the authors, the primary drivers of innovation were the project type (tolled bridge), the massive scale of the project, which combined with weather risks and the hostile natural environment in which the project had to be built and then operated, influenced greatly the project's product and process design; as well as the bridge's design standards and performance/schedule requirements. These drivers were aided by an organization which brought together skills from the international design and construction communities. From Table 3.3 the project type, scale and complexity served as the primary drivers for achieving the project's product and process innovations. These factors were, however, of secondary importance in the project's financial and organisational innovations which were primarily driven by the certainties of the political and socio-economic environments. The BOT structure allowed for a whole-of-life cost approach to design and construction of the bridge structure to have a 100-year service life, which is extensible to 250 years with a proper maintenance scheme in place. Design/build procurement would have resulted in a 4-lane design of the bridge deck, but the long term economics of building and maintaining a 4-lane system was unfavourable and unsupported by traffic volume projections (personal communication, Pirie and Giannelia 2004). For large scale bridge projects, the market is already an international one, and significant progress has been made on merging design and construction processes in order to take advantage of prefabrication, modularization, and technology developments in terms of concrete (strength, durability) and lifting capabilities, to name a few. Construction strategy was to minimise marine-based activities in order to reduce construction schedule risk and cost overruns risks (which were

borne by the private developer) and also to meet capital market requirements. The strategy included: (1) the extensive use of on-shore pre-cast production of most bridge elements and the drawing of a schedule based on a 12-hour weather window within which every activity should be completed, (2) use of a specially adapted floating crane to lift 176-metre main girder and an erection equipment incorporating GPS technology to erect girders, thus allowed girder erection activity to continue during late work hours even in the dark, and to place all of the precast elements – piers, cones etc. The innovative organizational/contractual arrangement can serve as a model for other projects where there a need to provide continuity of performance throughout the project life cycle, deliver significant socio-economic benefits to a region, accommodate the needs of several political jurisdictions, and finally optimize taxation treatment. All of the foregoing was achieved. Finally, the willingness of government to provide payment in the form of an indexed subsidy, separate from project performance, allowed for innovations in financing to be achieved, especially in terms of the modest interest rate premium that had to be paid for private over public financing. The seemingly unprecedented role of the independent engineer in the contractual arrangements increased capital market confidence and thus enhanced the project bond issuance – an example of a direct relationship between organisational/contractual and financial innovations without a fundamental re-allocation or re- distribution of risks.

Table 3.2 Case Study of Innovation and Conditions of Confederation Bridge

Project:	Confederation Bridge
Description/Location:	A 13-km high level bridge structure linking New Brunswick and Prince Edward Island.
Project Type:	Bridge Structure
Completion Date/ Duration:	May 1997 and took 44 months to construct.
Project Procurement Mode:	Finance-Design-Build-Operate-Maintain(FDBOM)
Project Value:	$840 million (CDN) (planned); actual cost in excess of $1 billion (CDN)
INNOVATION	
Innovation Type (Source)	**Condition Dimension**
Innovative Physical Components (Permanent Structure) a) Pier Design and Foundation: Consists of hollow pre-cast concrete shaft and pier base of standard cones. b) Pier spacing: 43 250-metre spans at the marine conditions. The pier design introduced a template at base of main girder and pier shaft using a design idea borrowed from pre-cast segmental design and construction concept.	Besides being the 1st significant build-own-operate-transfer (BOOT) project in Canada, the unique **environmental (physical) conditions** posed design and construction challenges which has resulted in an innovative structure for such an icy terrain. Concerns were raised about the possible adverse effect of the structure on existing ice that may increase delays in ice-out. The **high natural environmental risks**, aroused stakeholder (community) concerns about the effect of the proposed structure on ice movements which

c) Installation of "ice cones" (shields) at water level to minimise possible dynamic amplification effect of ice forces on the cylindrical piers. Innovative Construction Method - Casting of the double cantilever main girder (which is one of 2 components of the bridge superstructure) used a cast-in-place balanced cantilever method with the girder changing location while the forms for each segment were stationary. This is reverse of the normal balanced cantilever method (Tadros, 1997). Construction of all major components was done on-shore. Financing/Revenue - The project financing involved the issuance of bonds ($661 million real rate project bonds) with AAA Standard & Poor and Moody's rating at the close of agreements drawn on a lump sum basis. Usually such development projects would have been financed through substantial bank loans drawn down on a progress basis. Unidirectional toll payment (only from PEI) and has both manual and electronic tolling systems. Organizational/contractual – a complex organizational structure was set up to reflect provincial vs. federal prerogatives, to maximize taxation benefits, and to comply with the requirements for substantial socio-economic benefits for the Atlantic provinces. Novel taxation arrangements to handle the 3 different tax regimes of the Federal and the two Provincial governments involved which included the use of a common sales/service tax rate across board for capital goods and services purchased from the different jurisdictions. Role of independent engineer in progress certification/approval during design and construction and operation & maintenance costs approvals. All risk issues including process, government, financing and contractual were identified and allocated prior to financial closing, and even thereafter, in a process that was different from the conventional public and/or private sector linear approaches to risk in traditional bid processes.	culminated in the commissioning of 2 independent environmental impact studies at significantly different times in a protracted negotiation process. The **project's complexity and uniqueness** of its natural environment, combined with a **stakeholder environment** of intense scrutiny, prescribed a structure with high **performance requirements**. An assembly of **international construction** joint venture companies – Strait Crossing Inc. (Canada), Dumez-GTM (France), and Ballast Nedam (Netherlands) created conducive grounds for innovative methods of construction. The **scale of the project**, in combination with its **tough schedule** that incorporated serious liquidated damages clauses, necessitated the design and use of quicker more efficient construction methods that ensured high product quality to meet the project's **stringent performance requirements** in a unique natural environment setting. Financing was facilitated by the **government's decision** of guaranteed annual indexed subsidy payments and exclusion of competition for the 35-year period during which the project developer will operate the bridge facility. The **general certainty of the economic and political environments,** in addition to the benefits, reduced the financial/revenue risks. Credit default risks were low and these indicators ultimately increased investor confidence in the financing/revenue arrangements and agreements. The independent engineer had access to the books of the contractor to certify cost items and forecasts in order to authorise draw downs boosting capital market confidence in the process. Significant **socio-economic benefits** had to be derived for the Atlantic provinces. The project involved three political jurisdictions – Federal, and the provinces of Prince Edward Island and New Brunswick. Tax regulations/laws also required novel structuring of the organization. The scale and complexity of the project required that all contractual and financial issues in addition to clear definition of roles and responsibilities/liabilities be proactively and satisfactorily addressed to meet the

	project's tough schedules and performance requirement set out by government.
Innovation Metric (Benefit)	The result is a bridge structure that met its design criteria and stringent performance requirements with minimal adverse environmental impact. The effective forms of cooperation between the independent engineer and the contractor enhanced the attainment of the project specifications in terms of its durability consistent with its proposed service life of 100 years with non-recourse financing. In the 7-year operation history of the bridge facility, O & M costs have consistently been under-budget due to a good bridge design and consistent maintenance.

(Sources: Buckland et al. 1997, Confederation Bridge 2003, Pirie 1997)

Table 3.3 Confederation Bridge - Factors that act as drivers/inhibitors for innovation

Factors (Drivers/Inhibitors) for Innovation	Value/ State	Product Innovation	Process Innovation	Organizational/ Contractual Innovation	Financial/ Revenue Innovation
Project Type	Bridge				
Project Scale	$1billion (CDN)				
Project Complexity/uniqueness	Unique				
Responsibility Integration	High (FDBOM)				
Opportunity for other projects of similar type	Moderate				
Source of Competition	International				
Number of Competitors	12 – 7 – 3 - 1				
Project performance requirements/thresholds/constraints	High, Stringent				
Requirements for broader socio-economic benefits	Moderate				
Statement of product solution	Performance Specification				
Statement of process solution	Performance Specification				
Product risks	High Risk				
Process risks	High Risk				
Natural environment risks	Highly complex				
Certainty of economic environment	Highly certain				
Certainty of political environment	Highly certain				
Certainty of regulatory environment	Highly flexible				
Certainty of stakeholder environment	Hostile but engaging, quite uncertain				
Reasonableness of risk assignment	Appropriate/ Balanced				
Penalties for inadequate project performance	Performance-based				
Proposal evaluation criteria & decision and negotiation process	Full evaluation of alternatives				

Key: Primary Importance; Secondary Importance; Little/No Importance

Table 3.4 depicts almost all the significant innovations realised on the design-build Oresund Tunnel project in Scandinavia, constructed as part of the Oresund Link between Denmark and Sweden. Significant innovations occurred in both design and construction under a process where both project functions were fully integrated. The Oresund tunnel is by far the world's longest immersed tunnel for both road and railway traffic. Project innovations realised included permanent works design and construction. According to Marshall (1999) the design/build procurement process allowed for closer interaction/collaboration between design and construction activities thus spurring the innovations achieved, particularly in design, which would have been impossible, had design been decoupled from construction. Table 3.5 indicates the factors that drove the innovations (product, process and revenue) and their respective relative importance in influencing the realisation of the various project innovations. The project was delivered using traditional public financing arrangements under organisational/contractual structures that were not substantially new.

Table 3.4 Case Study of Innovation and Conditions of Oresund Tunnel

Project:	Oresund Tunnel
Description/Location:	A 3.5-km rail/road immersed tunnel which is part of the Oresund Link between Copenhagen (Denmark) and Malmo (Sweden), the first ever fixed link between the 2 countries. Its major components include 5km 2X2 lane highway, a 4-km twin track railway, 500m and 700m of approach ramp on the respective Danish and Swedish ends, and a 300m long tunnel on both ends of the 3.5km immersed tunnel.
Project Type:	Immersed Tunnel
Completion Date:	March 1999 (First vehicle drove through the tunnel)
Procurement Mode:	Design/Build Mode
Project Value:	DKK 3.98 billion
Project Client:	Oresundskonsortiet – a company set up which is jointly and equally owned by the Swedish and Danish governments.
Project Contractors:	Oresund Tunnel Contractors (OTC) – a consortium of NCC AB (Sweden), Dumez-GTM SA (France), John Laing Ltd (UK), E. Phil & Son A/S (Denmark), and Boskalis Westminster (Netherlands), with Symonds Group (UK) as the designers.

INNOVATION	
Innovation Type (Source)	**Condition Dimension**
Permanent Works/Design a) Tunnel Design A segmental concrete tunnel, which was the cheapest (showing 7% saving) among several options was selected. Its design excluded the use of separate water-proofing membrane and a substantial reduction in the quantity of reinforcement required in comparison with traditional designs. b) Segment Length In-depth studies of thermal stresses carried out at the tender design stage that demonstrated and	The contractor (OTC) appointed its designer 6 months prior to the invitation for tender and this allowed for an early exchange of ideas on the tunnel construction and engendered a good initial team building. The Oresund Strait connects the Baltic Sea to the North Sea, and thus **environmental concerns** included the possible blocking effect and a potential regional impact on water exchange in

determined an optimum segment length of 25m beyond which primary thermal stresses in the section are intensified by secondary effect of longitudinal bending.

c) Tunnel Joints

Provision for positive horizontal alignment together with a specially designed gasket allowed for both primary and permanent water tightness and made it possible to relax the normally stringent tolerances on tunnel immersion joints and frame. This resulted in a simplified joint detailing with an L profile replacing the conventional H profile with no secondary welded plate. (Marshall, 1999)

d) Tunnel Reinforcement

An innovative tunnel reinforcement scheme was developed that incorporated 40,000 tonnes of steel (one of the largest cost items of the project) where the reinforcement, set out on a standard 150mm/300mm grid enhanced the use of prefabricated jigs in the casting yard. This design also permitted the use of complex handling equipment with longer bars (up to 21m in length), minimising the need for laps where the reinforcement fabrication was on the non-critical path.

e) Tunnel Foundation

Tunnel foundation consisted of a gravel bed placed in such a manner that eliminated subsequent screeding of the gravel. The foundation was laid by feeding gravel down directly onto the trench floor through a pipe, the lower end of which was fixed a screeding plate that moved slowly across the trench at the correct gravel level in a continuous process.

f) Computer Based Alarm System (Combas)

CCTV system installed in the tunnel and linked to a network of computers at a control centre to enhance automatic monitoring of tunnel traffic and installations for safety of users and for increased efficiency levels of preparedness in the event of an accident.

Innovative Construction Method

Tunnel elements were constructed at a specially built factory without resorting to the use of traditional large excavation, and involved casting of each tunnel segment in 30-hour single concrete pour, full off-line prefabrication of reinforcement cages, and transportation of completed tunnel elements some 300m before immersion in water (Marshall, 1999).

the Baltic sea in addition to inevitable local environmental effects in the Oresund. Thus the governments' stated "zero solution" for water and salt transport through the Oresund and oxygen input to the Baltic implied a continuous optimisation of design to minimise the effect on the environment.

The **project's complexity** permitted numerous collaborative efforts and pre-construction analysis that culminated in several innovative designs which could not have been achieved had ***design been decoupled from construction***. For instance, the blocking of water by the bridge piers and artificial island making the Link were to be compensated for by the dredging of the Oresund sea bed.

The project by its **type and uniqueness** of marine environment had to meet certain **stringent performance and quality requirements** and service levels, with a final design objective aptly summed in the government agreement as to incorporate *"what is ecologically motivated, technically feasible and economically reasonable in order to prevent detrimental impact to the environment"* (Oresundsbro Konsortiet, 2000).

Knowledge and experience from a previous job under similar marine conditions undertaken by one of the joint venture companies was applied in the design and application of the tunnel foundation design and construction method. The array of ***international construction firms*** from across Europe forming the OTC consortium created a pool of unique sources of ideas that enhanced the design and construction processes. European Union (EU) tendering procedures were employed even though Sweden was not a member of the EU in 1994.

The Link's design, operation and maintenance procedures are to minimise the number of accidents. Right from the design phase on, safety has been given the highest possible priority, with cooperation between the Danish and Swedish authorities 7 years before the commissioning of the Link.

The ***complexity, sheer size and scale*** of the tunnel would have required the creation of a huge excavation and subsequent groundwater lowering

Revenue Collection The toll collection mechanism includes both manual and electronic payment procedures. Payment by cash and/or credit card can be made in both local and international denominations including US dollars and the Euro. Frequent users of the Link have BroBize Electronic transponders fixed to windscreens of the vehicles to eliminate delays due to waiting whilst billing is effected electronically. Price per crossing falls as frequency of use increases.	had traditional methods been employed. This would have had adverse impact on the existing groundwater system by causing contaminated groundwater migration and disturbance of existing aquifers. Moreover flooding and dewatering of the excavation would have caused major construction breaks resulting in increased project risk and uneven labour demand. ***(Product and process risks were thus high).*** The requirements ***for broader socio-economic benefits are rather high***. At the country level, the Link provides an effective reliable and comfortable means of transport and hence further economic development between the 2 countries, whilst at the same time connecting Copenhagen to Malmo on a regional scale. The structure is considered as a strategic infrastructure in the transportation system of Europe by connecting Scandinavia, Northern Europe and the Baltic.
Innovation Metric (Benefit)	The benefits of innovation on the Oresund tunnel project are immense. The innovations in design and methods resulted, *in toto,* in the construction of a cheaper immersed tunnel in a shortened construction duration with improved permanent works quality, reduced risks and elimination of well-known dangers traditionally associated with immersed tunnels such as post-construction siltation beneath tunnel elements. Some specific benefits of the various innovations are: Form of Cooperation among project actors • Resulted in optimisation of design and construction to solve some of the most intricate problems. • 7% savings in bid cost in selecting a segmented concrete tunnel when compared to the next cheapest option. Tunnel Joints • The tunnel immersion and segment joints increased quality and durability of the tunnel structure. Tunnel Reinforcement • Produced a final design with about 15% less reinforcement by weight than it is for typical concrete immersed tunnels designed under traditional procurement modes. Tunnel Foundation • Siltation beneath the tunnel structure was eliminated. • Foundation construction was off the critical path for marine works. • Temporary supports in the tunnel trench were also excluded. Construction Method • Artificial cooling in the concrete was eliminated; since early age thermal stresses traditionally associated with concrete immersed tunnels causing through-section exterior cracking and leakage were avoided. • Reduced overall cost of works as a result of reduction in construction time, in spite of the huge capital cost of the special casting facility. • Reduced construction and weather risks.

(Source: Marshal 1999; Oeresundsbron 2003; Oresundsbro Konsortiet 2000; Oresundkonsortiet 2000, 2001.)

Table 3.5 Oresund Tunnel - Factors that act as drivers/inhibitors for innovation

Factors (Drivers/Inhibitors) for Innovation	**Value/ State**	**Product Innovation**	**Process Innovation**	**Revenue Innovation**
Project Type	Tunnel			
Project Scale	DKK 3.98 billion			
Project Complexity/uniqueness	Unique			
Responsibility Integration	Design/Build			
Opportunity for other projects of similar type	Moderate			
Source of Competition	International			
Number of Competitors	4 - 1			
Project performance requirements/thresholds/ constraints	High, Stringent			
Requirements for broader socio-economic benefits	Moderate			
Statement of product solution	Performance Specification			
Statement of process solution	Performance Specification			
Product risks	High Risk			
Process risks	High Risk			
Natural environment risks	Highly complex			
Certainty of economic environment	Highly certain			
Certainty of political environment	Highly certain			
Certainty of regulatory environment	Highly flexible			
Certainty of stakeholder environment	Hostile but engaging, quite uncertain			
Reasonableness of risk assignment	Appropriate/ Balanced			
Penalties for inadequate project performance	Performance-based			
Proposal evaluation criteria & decision and negotiation process	Full evaluation of alternatives			

Key: Primary Importance; Secondary Importance; Little/No Importance

The factors controlling the decision-making process to procure a student housing, Marine Towers, project using a traditional "bespoke" project/construction management mode are discussed in Table 3.6. This model of project procurement at the institutional level, in which the lease agreement excludes the land's market value and where sub-market rates for student user-fees are explicitly circumscribed in an economically self-sustaining manner, appears to be the most suitable and efficient approach for expanding student housing on campus. Although the P3 option projected a 10% savings in design and construction (through stricter control of project scope) coupled with innovative revenue generating mechanisms, the potential savings and efficiencies were not sufficient enough to justify the private sector-led option vis-à-vis the potential risks and consequences of a P3 failure i.e. student dissatisfaction with any hikes in user-fees amidst the public perception of P3s as costly and the university's public image. Market testing and other preliminary procurement processes associated with a P3 option would have delayed the Phase 1A (involving the provision of 600 beds by August 2005) of the project by about 1year. Managing the P3 process would have introduced an additional transaction cost estimated at about 1% of the project's capital cost. The preferred model is strongly underpinned by the universities credibility and seemingly infinite solvency; and recognises and incorporates certain inherent institutional constraints such as a stringent regulatory system, well-established system interrelations/agreements and rigid technical specifications on student housing facilities that leave relatively little room for innovation and efficiency gains by the private sector. Moreover the procurement process is led and driven by a market oriented quasi-private firm on a competitive basis using local resources (designers/constructors/materials/knowledge). Much as the P3 option was not the best fit for the Marine Towers project given the states of the general innovation factors discussed and their influence on the procurement mode selection process, does not make P3s generally undesirable for projects the likes of the Marine Towers. There is significant potential for efficiency from a life-cycle cost perspective, especially when the private sector is allowed to operate and maintain such facilities. Moreover the private sector is able to create diversified and alternative revenue sources leading to revenue maximisation innovations.

The findings perhaps corroborates earlier observations that buildings in general, and student housing in particular, by their unique characteristics and (commercial) functions are not completely amenable to the typical contractual arrangements, agreements and shared responsibilities (risks) characteristic of P3 contracts . There are minimal opportunities for granting a guaranteed minimum return on capital invested commensurate with the risks and cost

of private capital whilst at the same time meeting other stakeholders' requirements, expectations and satisfaction. Unlike other types of civil engineering structures such as roads & highways, bridges, tunnels, etc. the opportunity set and motivations for project innovation in (student) housing projects for all 4 categories of project innovation are limited and constrained.

Table 3.6 Marine Towers Project - Factors influencing the choice of procurement mode

Project:	Marine Towers Project
Description/Location:	4-20-storey high-rise buildings for student housing on behalf of the University of British Columbia (UBC), Canada. The Marine Towers Project is on the main campus of the university and located close to the SW Marine Drive, Vancouver
Project Type:	Student Housing Facility
Completion Date/ Duration:	Construction commenced in May 2004, and the first tower is scheduled for completion by summer of 2005 for student occupancy.
Project Procurement Mode:	The procurement mode employed for the Marine Towers project is a Project/Construction Management approach where UBC Properties Trusts (UBCPT), acting on behalf of the university, sources traditional designers, constructors and related trades and services in direct contracts, and manages the project from scratch to completion to satisfy its functional and quality requirements within budget and schedule.
Project Value:	In excess of $130-million (CDN)

INNOVATION/EFFICIENCY INFLUENCING FACTORS

In spite of the project's size – both in dollar terms and scope, a pure P3 procurement approach was not the most suitable option due to the following issues of concern:

- The university's established institutional regulatory system, which is rather constricting with regards to the magnitude and rate/pace of increase of user fees for the proposed facility. In most P3 contractual arrangements fees paid by end users of a facility constitute a major component of the revenue base, the magnitude and periodic adjustments of which tend to guarantee and justify a reasonable return for private sector investment.
- The enormous debt capacity and high credit rating of the university imply that the university could access capital and borrow funds at relatively cheaper rates to finance such housing projects with more certainty in debt repayment abilities in comparison with the capabilities of a private developer. The private sector financing cost was project to be in the range of 10 – 15pb higher than the university's borrowing rate. Reasonable projections of the cost savings that the private sector might be able to generate, and allowing for the increased costs of the P3 option for project financing, tax payments, and profitability requirements implied that a purely market-based pricing of the residence and service provision would incur rent increases 9% to 17% higher than a UBC managed alternative.
- Technical issues and project complexities that often arise on such arrangements with regards to meeting certain technical specifications, performance measures, and functional requirements can best be handled by the university's own in-house expertise. Student residences are a "customer facing" function – outsourcing operation and housing services can be risky.
- Generally the university's standing agreements with other stakeholders (for example with the custodians of Wreck Beach) as well as the well-structured operational system of the university as an academic/research institution require a level of flexibility and tactfulness in delivery of facility services that are difficult to be reasonably and effectively captured by a private developer.

Innovation Type (Source)
Design The design incorporates familiar and proven concepts, with no significant innovation or use of new ideas (it is not clear at all where design innovation could be achieved in terms of concept). Furthermore, the original design for the 2 towers closest to NW Marine Drive may have to be altered by reducing their heights by 6 floors as a result of their potential adverse effect on littoral activities and beach patronage. The enforcement of a long standing agreement between the university and Wreck Beach managers that effectively prohibits the university from constructing buildings that will overlook the beach and which can be seen from a location in the sea within 500 m from the shoreline during low tides may have necessitated the reduction in the heights of the two towers. Such a solution would perhaps have been more difficult and slower to arrive at had the arrangement been a pure P3 without any form of compensation or altering of design/construction concepts, considering the stage of project development when this issue with wider stakeholders concerning the impact of the project on the existing environment arose. However, energy efficiency and sustainability concepts such as the use of geothermal energy generating systems are being considered in the subsequent designs of 3 of the towers to possibly augment heating from conventional boilers. Such concepts are not restricted to the use of P3.
Construction No new construction methods, techniques or materials will be used in the construction phase (high-rise condo builders in the lower mainland are some of the most proficient in North America). There is nothing exotic in the range of construction technologies to be employed in putting up the structures. However, UBCPT relies on the flexibilities of its construction approaches in building around already existing structures close to the project site to ensure continuous provision of utility services, prevent potential physical and human damage and the associated space constraints in such a sensitive and tight project site for a smooth construction process. Although the project experienced a 4-month delay in negotiations during the development stage, the construction is on schedule. There are no well-structured incentives to the **local** constructor such as shared benefits of early completion or liquidated damages for delay. However the constructor is tasked with the control of general conditions on site to prevent interruptions without any lock-in of the constructor on the completion dates.
Operation & Maintenance UBCPT intends to employ the unionised labour of the university during the operation and maintenance phase of the facility without any novel methods of user-fee collection and adjustments.
Financing The project is being financed through the floatation of bonds to raise the requisite capital using the university's borrowing capacity and credit rating. Periodic debt capital servicing will be made from the university's own funds and receivables. Thus the financing scheme bears some similarities with a traditional mortgage arrangement and is not an off-balance sheet financing.
Benefit An analysis of the tax implications indicates that there will be savings of a third of 700bp in GST taxes using the universities existing tax rebates compared with any tax benefits that would have accrued to a private developer.

3.7. Conclusions

This paper provides insights into assessing the validity of two hypotheses that tend to form the basis of current government decision-making with respect to the procurement of large infrastructure projects. These hypotheses are: (a) Innovation in an infrastructure project is a function of the procurement mode adopted; and (b) Innovation that is realized in projects undertaken as P3 projects is greater than the innovation that would have been achieved using traditional design-bid-build or design-build for the same projects. In assessing support for these hypotheses, we have sought to identify factors or conditions that act as either drivers or inhibitors for innovation. 22 factors have been identified, and they have proven to be of assistance in helping to explain the degree of innovation achieved on actual projects. Realistically, as it is never possible to carry out identical projects using different procurement modes, at best only paper benchmarks exist with which to compare performance. Further, the Canadian history with P3 projects is short, so little real data exist that describe actual long term life cycle performance versus what was forecast. The authors have examined two projects (Confederation Bridge and Oresund Tunnel projects), to identify innovations achieved along with imputed benefits, and the role that procurement mode played in generating them. The factors that controlled the procurement mode selection process for a student housing project (Marine Towers Residence) have been examined. As part of this effort, and in addition to careful scrutiny of the literature and available project documentation, detailed discussions have been held with public and private individuals experienced in the delivery of infrastructure projects under different procurement modes.

Regrettably the literature pertaining to innovations in the context of specific projects and quantification of the benefits derived is quite thin, and where it does exist, it is either very general in nature or focuses at great length on a narrow aspect of the project. Claims made for success, while surely true in many cases, are anecdotal in nature, and seldom are explanations offered that include significant back up documentation to justify these claims.

3.8. References

Anderson, F. and Schaan, S. (2001) *Innovation, Advanced Technologies and Practices in the Construction and Related Industries: National Estimates. Statistics Canada.*

Anonymous (2003) *LaserShell Leads the Way for SCL Tunnels,* Tunnels & Tunneling International, pp 38-42.

Anonymous (2004) *Quality Management System (QMS) of the Millennium Line construction,* Presentation at the Special Course on Private Participation Infrastructure Projects, Civil Engineering Department, UBC. Canada. Sept. – Nov.

Australian Construction Industry Forum (2002) *Innovation in the Australian Building and Construction Industry – Survey Report.* Price Waterhouse Coopers, Australia.

Ball, R., Heafey, M, and King, D., (2000) *Private Finance Initiative – a good deal for the public purse or a drain on future generations.* Policy and Politics, 29(1), 95-108.

Birnie, J. (1998). "Risk allocation to the construction firm within a private finance initiative (PFI) project." *Proc., ARCOM Conf.*, The University of Reading, London, 527–534.

Birnie, J. (1998). "Risk allocation to the construction firm within a private finance initiative (PFI) project." *Proc., ARCOM Conf.*, The University of Reading, London, 527–534.

Bossink, B. A. G. (2004) *Managing Drivers of Innovation in Construction Networks.* Journal of Construction Engineering and Management, 130(3). 337 – 345.

Brochner, J. and Grandison, B. (1992) *R&D cooperation by Swedish contractors.* Journal of Construction Engineering and Management, 118(1), 3 – 16.

Buckland, P. G., Boyd, D. E., Leal, A. J, and J. E. Torrejon, (1997) *The Confederation Bridge: the role of the independent engineer in theory and in practice. Canadian Journal of Civil Engineering*, Vol. 24. 875 – 881.

Carr, R. I. (1983) *Impact of Number of Bidders on Competition.* Journal of Construction Engineering & Management. 109(1), 61 – 73.

Confederation Bridge, http://www.confederationbridge.com (15th Dec. 2003).

Construction Industry Council (2000) *The role of cost saving and innovation in PFI projects,* Thomas Telford Publishing, London, U.K. 128p.

Construction Innovation (2004) *Fraser River Pile & Dredge Ltd. wins Excellence in Innovation Award,* 9(2). http://irc.nrc-cnrc.gc.ca/newsletter/v9no2/award_e.html

Craig, R. (1999) *How innovative is the common law of tendering?* Journal of Construction Procurement, 5(1), 15-26.

Dalpe, R. (1994) *Effects of government procurement on industrial innovation.* Technology in Society, 16(1), pp. 65-83.

Environmental Impacts of the Oresund Tunnel (2000). Oresundkonsortiet.

Evbuomwan, N.F.O., and Anumba, C. J. (1996) *Towards a Concurrent Model for Design-and-Build Projects.* The Structural Engineer, 74(5), 73 – 78.

Fitzgerald, P. (2004). *Review of Partnerships Victoria Provided Infrastructure.* Final Report to the Treasurer of Victoria, Australia. 55p.

Freeman, C. (1982) *The Economics of Industrial Innovation*, 2nd edition Printer, London, UK.

Garvin, M.J. (2003) *Role of Project Delivery Systems in Infrastructure Improvement.* Proceedings of Construction Research Congress, Honolulu, Hawaii.

Glasgow, B. (2003) *A point of Principle.* Global Finance Magazine.

Globe & Mail (2004). July 10 pg. A1, July 24 pg A9, August 11 pg A1, and August 12 pg A4 editions.

Gomez-Ibanez, Jose A. & Meyer, John R. (1993) "*Going Private: The International Experience with Transport Privatization*" The Brookings Institutions, Washington DC, 310p.

Haskins, S., Gale. D. and Kelly, L. Creating and optimizing new forms of public-private partnerships in Seattle. *Water Science and Technology: Water Supply.* 2(4), 211-218.

Hodgson, G. J. and Davies, J. A. (1997). *Can value for money be realised by using private sector finance for the procurement of public service infrastructure?* Int. Council for Building Res. Studies Documentation (CIB) Symposium, Working Comm. W92. Univ. of Montreal, Publication 203, ISBN 0-9682215-0-5.

http://www.oeresundsbron.com (20th Dec. 2003)

Jones, P. (2004) *Bridge Roundtable: Viewpoints on Bridge Design & Construction.* Engineering News-Record (ENR), Special Advertising Edition, November 29 2004. p B6.

Keegan, A. and Turner, J.R. (2002) *The management of innovation in project-based firms.* Long Range Planning, 35, 367-388.

Kumagai-Gumi (1993). "Western Harbour Crossing: Immersed Tube Tunnel Works."

Kumaraswamy, M. M., and Zhang, X. Q. (2001). ''Government role in BOT-led infrastructure development.'' *Int. J. Proj. Mgmt.*, 19(4), 195–205

Leiringer, R. (2003) *Technological innovations in the context of public-private partnership projects.* Doctoral thesis, KTH Industrial economics and management, Stockholm, Sweden.

Lemos, de T., Almeida, L., Betts, M. and Eaton, D. (2003) *An examination on the sustainable competitive advantage of private finance initiative projects*, Construction Innovation, 3: 249–259.

Liddle, B.T. (1997) *Privatization decision and civil engineering projects.* Journal of Management in Engineering, 13(3), 73-78.

Love, P. E. D.; Skitmore, M. and Li, H. (1997). *Towards an innovative procurement process for construction,* Int. Council for Building Res. Studies Documentation (CIB), Working Comm. W92. Procurement – A key to Innovation. Univ. of Montreal, Publication 203, ISBN 0-9682215-0-5.

Marsh, D. (2003) *Does New Zealand have an innovation system for biotechnology?* Technovation, 23, 103-112.

Marshall, C. (1999): "The Oresund Tunnel – Making a Success of Design and Build". Tunnel and Underground Space Technology, 14(3), 355 – 365.

Miller, C. K., Carr, R. I., and Cheung, W. (2001) *Construction Innovation – an Annotated Bibliography,* Journal of Construction Innovation, electronic journal published by the Construction Innovation Forum, Michigan, USA, www.CIF.org, 16pp.

Mitropolous, P., and Tatum, C. B. (2000) *Forces driving adoption of new information technologies.* Journal of Construction Engineering and Management, 126(5), 340 - 348.

Mokyr, J. (2002) *Innovation in an Historical Perspective: Tales of Technology and Evolution* in Steil, B., Victor, D. G. & Nelson, R. R. (eds), Technological Innovations and Economic Performance Princeton, University Press. 476p.

Molenaar, K. and Johnson, D.E. (2003) *Engineering the procurement phase to achieve best value,* Leadership and Management in Engineering, 3 (3), 137-141.

Nam, C. H., and Tatum, C. B. (1992b). *Noncontractual methods of integration on construction projects.* Journal of Construction Engineering and Management, 118(2), 385 - 398.

Nam, C. H & Tatum, C. B. (1997) *Leaders and Champions of Construction Innovation* Construction Management & Economics, 1997, Vol. 15, p259 – 270

National Audit Office (NAO) UK (2003): *PFI Construction Performance.* Report by the Comptroller and Auditor General. HC 371 Session 2002-2003: 5 February.

National Audit Office (NAO) UK (2004)*: London Underground PPP. Were they good deals?* Report by the Comptroller and Auditor General. HC 645 Session 2003-2004.

National Audit Office (NAO) UK (2004): *London Underground. Are the Public Private Partnerships likely to work successfully?* Report by the Comptroller and Auditor General. HC 644 Session 2003-2004.

Oresundsbro Konsortiet (2000) *The Strategic Impacts of Oresund Bridge.*

Oresundsbro Konsortiet (2001) *Two Countries - One Plan*, Joint Danish-Swedish Contingency Plan for the Oresund Fixed Link.

Partnerships British Columbia (2004): *Presentation to Guests from Taiwan.* Special Course on Private Participation Infrastructure Projects, Civil Engineering Department, UBC. Canada. Sept. – Nov.

Partnerships British Columbia (2005) *Project Report: Achieving Value for Money - Abbotsford Regional Hospital and Cancer Centre Project,* February. 34p.

Partnerships British Columbia (2004) *Project Report: Achieving Value for Money for the Sierra-Yoyo-Desan Resource Road Upgrade Project.* November. 20p.

Peters, T.J. and Waterman, R.H. (1982) *In search of excellence: Lessons from America's best-run companies.* Harper & Row, New York.

Pirie, J. D., (1997) *The Confederation Bridge: Project Structure and Risk,* Canadian Journal of Civil Engineering, 24, 867 – 874.

Pirie, J. D. & Giannelia, P. (2004) *Confederation Bridge – A Case Study,* Presentation at the Special Course on Private Participation Infrastructure Projects, Civil Engineering Department, UBC. Canada. Sept. – Nov.

Pratt Contractors v Palmerston North City Council (1995), 1 NZLR pp. 469-472, New Zealand.

Provincial Auditor of Ontario (1996): *Annual Report of the Provincial Auditor*: 234 et seq.

Report By The Comptroller And Auditor General – UK (2001): *Innovation in PFI Financing: The Treasury Building Project*, HC 328 Session 2001-2002.

Report of the Auditor General of Canada (1995): *Public Works and Government Services Canada - Northumberland Strait Crossing Project.*

Roberts, T. (1999). *The funding revolution—New routes to project fundraising*, Falmer Press, London.

Salter, A. & Gann, D. (2003) *Sources of ideas for innovation in engineering design.* Research Policy 32, 1309–1324.

Schumpeter, J.A. (1961) *The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle.* Oxford University Press, NY.

Seadan, G., Guolla, M., Doutriaux, J., and Nash, J. (2001) *Analysis of the survey on innovation, advanced technologies and practices in the construction and related industries.* Statistics Canada.

Slaughter, S.E. (1998) *Models of construction innovation.* Journal of Construction Engineering and Management, 124(3), 226 - 231.

Smith, P. (2004) *Public Finance Initiative.* Project Finance Magazine, April.

Spears, W.M. (1999) *An Overview of Multidimensional Visualization Techniques.* Proceedings Genetic and Evolutionary Computation Conference, Orlando, Florida, July.

Tadros, G. (1997) *The Confederation Bridge: An Overview.* Canadian Journal of Civil Engineers, 24, 850 – 866.

Tatum, C. B. & R. P. Fawcett (1986) *Organisational Alternatives for Large Projects.* Journal of Construction Engineering & Management, 112 (1), 49 – 61.

Tatum, C. B. (1989) *Organising to increase innovation in construction firms.* Journal of Construction Engineering and Management, 115(4), 602 – 17.

Tatum, C.B. (1983) *Innovation in Nuclear Concrete Construction.* Journal of Construction Engineering & Management. 109(2), 131 – 145.

Tatum, C.B. (1983) *Potential Mechanisms for Construction Innovation.* Journal of Construction Engineering and Management, 112(2), 178-191.

Tatum, C.B. (1984) *What prompts construction innovation?* Journal of Construction Engineering and Management, 110(3), 311-323.

Tawiah, P. A. and Russell, A. D. (2005) *The influence of procurement mode on innovation potential in infrastructure project delivery,* Construction Specialty Conference, Canadian Society of Civil Engineers, 2 – 4 June, Toronto, Canada.

The Treasury Taskforce Limited, *Value for Money Drivers in the Private Finance Initiative,* report prepared by Arthur Andersen and Enterprise LSE, HM Treasury, London, UK.

Veshosky, D. (1998) *Managing innovation information in engineering and construction firms.* Journal of Management in Engineering, 14(1), 58 – 66

Waer, M. A., Hayes, T., Quarendon, J., and Mahaffay, D. (2004) *Water Wise in Phoenix,* Civil Engineering, October, pp. 46 – 51.

Widen, K. (2000) *Innovation in the Construction Process – A Theoretical Framework.* Licentiate thesis, Lund University, Lund, Sweden.

Winch, G. M. (2000) *Innovativeness in British and French construction: the evidence from Transmanche-Link,* Construction Management and Economics, 18, 807-817.

CHAPTER 4

Influence of Procurement Mode on Project Innovation Potential in Infrastructure Project Delivery[1]

4.1. Introduction

Within the construction industry, the term procurement system has been defined as "the framework within which construction is brought about, acquired or obtained" (McDermott 1999). In the context of infrastructure development and delivery, procurement from the view point of a client/project owner represents the set of strategic decisions made to acquire capital assets and services to meet certain set project goals. The delivery of infrastructure projects is hampered by a multiplicity of challenges such as budget constraints, programme delays, quality and safety concerns, and an increasingly complex stakeholder environment. The pursuit of innovation has been identified as a means of not only meeting the demands of a wide variety of project performance metrics (e.g. technical, economic, quality, etc.) but also improving upon them and overall project efficiency. While there is general agreement on the critical role of innovation in the procurement process, the strategy for implementing and achieving it by choosing the most appropriate procurement mode has been the subject of much discussion among practitioners, policy makers, researchers and other project stakeholders. Davidson (1998) reports that the relationship (if any) between procurement and innovation was one of key issues at the International Council for Building Research Studies Documentation (CIB) in 1997 and indicated that clients/owners are driven by several motivations (including project scope, urgency, required capacity, project type, project risk transfer, political considerations and capital constraints) when choosing between alternative procurement strategies and that innovation is not always a major consideration during procurement mode selection and structuring. The general observation in practice is that procurement modes adopted for projects often treat project innovation as an incidental product of the procurement process because the motivations for selecting a particular mode are heavily driven by factors (such as risk transfer and budget constraints), which tend to sub-optimise project innovation and efficiency potential because fewer resources are devoted to the design and construction of the underlying physical infrastructure.

[1] This is a paper submitted to the Specialty Conference on Construction, Canadian Society of Civil Engineers (CSCE), 2 – 4 June, 2005, Toronto, Canada.

The objectives of this paper are two-fold: firstly to outline a framework for selecting and structuring the most appropriate procurement mode for maximising innovation and efficiency potential of a project from the perspective of a public sector client and which reflects an understanding of the relationship between project procurement and innovation; and secondly, to provide the project evaluation process with a means of assessing the incremental innovation at the very front end of the process as a function of procurement mode choice.

4.2. Characterisation of Innovation

Innovation can be characterised into several forms depending on the impact on, benefit to and interactions with other existing systems and society as a whole. Based on their impact for bringing about substantive economic change, Pavit (1971) and Freeman (1982) characterised innovations into *incremental (practitioner innovation), radical and revolutionary* types. This classification focuses on the use of innovations to maximise the output/input ratio of process-oriented systems. For the project delivery process, such innovations tend to improve the value/cost ratio or what CIC (2000) describes as an improvement in the average 'unit productivity' (ratio of value of output services to the quantities of inputs used) or reductions in the prices paid for inputs of similar unit productivity. Incremental innovations are a result of small continuous improvements of existing products or processes by practitioners as knowledge and use of the particular innovation become widespread. Sometimes they are simply one-off and are a function of a particular context. Radical innovations on the other hand involve the development of entirely new products or processes and entail major shifts in technical approaches and solutions through research and development activities often affecting the nature and efficiency of a whole industry (e.g. the use of the tower crane in construction). Revolutionary innovations impact a wider economic system through widespread cost reductions and significant improvements in performance characteristics Lowe (1996) e.g. the emergence of the automobile/aircraft/computer at different times in the history of technical change and their incalculable positive impacts on society. Considering the timelines usually associated with the planning, development and delivery of most infrastructure projects, all incremental innovations and some radical innovations will be most applicable to the project development/delivery process. The relatively long gestation periods of revolutionary innovations make their pursuit unattractive in terms of the relatively short time lines allocated to delivering most projects.

Essentially, any innovation-enhancing procurement process should understand these models and recognise the linkages and interactions among innovations (Marquis 1988, Henderson & Clarke 1990; Slaughter & Shimizu, 2000) i.e. the potential for the pursuit of one innovation to spawn other innovations, particularly at the project level.

4.3. Project Innovation

Our primary interest is innovation and efficiency potential at the individual project level and within relatively short time lines. That is, the need exists to assess innovation potential using existing technologies from both within and external to construction, put perhaps in novel ways not seen heretofore. For instance, incremental innovations which are of the most interest in this study can be classified into *cost-saving and product-enhancing innovations* CIC (2000). Most cost-saving innovations are associated with incremental project innovative solutions, the implementation of which leads to reductions in costs (input) while the value (output) of the product/service remains unchanged. Product-enhancing innovations increase quality or are value-increasing novel solutions which attract a value-premium for the product or service provided. Innovation and efficiency improvement can be regarded as two interrelated themes with a common objective of improving upon product or process performance. In assessing the competitive advantage (CA) of Private Finance Initiative (PFI) as a procurement model, Lemos *et al.* (2003) expanded the frontier and indicated that PFI CA consists of 4 closely interrelated building blocks – *innovation, quality, efficiency and responsiveness to customers*. Some project innovations, however, do not always lead to greater process efficiencies (cost-savings) or quality (product-enhancing) in the finished structure. Bowley (1966) introduced the concept of *Ersatz innovations* in a study of British building construction industry, as innovations that act as "perfect" substitutes in the face of scarcity of a particular building component or resource. Such innovations can be the use of a building material substitute that may not necessarily result in either cost-reduction or value-increase.

The different forms of innovation attained at the project level embrace one or more of the aforementioned innovation concepts and models and may be categorised into:

- Innovations emanating from continuous persistent research and development (R&D) work that result in radical approaches such as the use of some novel technology being the result of an extensive and collaborative R&D project often spanning several years and undertaken by

a firm or a group of firms/organisations within or related to the construction industry e.g. High Performance Steel (HPS) in bridge design and construction (Mastaglio, 2004).

- Use of information and communications technology (ICT) and related applications to enhance the construction delivery process. Such ICT tools according to Salter and Gann (2003) can support project processes that enhance the decision-making mechanisms in design engineering, procurement, construction, operation and facilities management e.g. an Online Remote Construction Management (ORCM) on road projects in Australia to improve the project delivery process (Thorpe, 2003).
- Use of new/novel ideas i.e. designs and methods (our primary focus in this paper), project management practices and financing/revenue strategies on projects as a result of responses to specific and unique constraining conditions (drivers) of a project. New does not strictly connote radical ideas, concepts or techniques never used before or originally created for the first time but also embraces incremental innovations and borrowed approaches/concepts that have been successfully employed elsewhere in the industry but may be unique to the particular geographic location of the project/situation under review. Such novel ideas include "Up/Down" construction method (Tatum et. al., 1989) and the segmental pipe placement method (Stewart & Tatum, 1988) which were adopted from another jurisdiction and the petroleum industry, respectively.

The benefits of innovation at the project level manifest themselves in increased efficiency, competitiveness and quality as well as other broader social benefits. Also innovations provide significant intangible benefits to the firm (increased competitiveness) and increase the technical feasibility of construction undertakings (Slaughter, 1998). In terms of the magnitude of its impact on cost reduction, Rosenberg (1982) asserts that the benefit of an innovation on a system is very important in any innovation assessment. This is particularly important in the construction industry and project delivery in particular, where increasing demands on performance to reduce capital and life-cycle costs to meet stringent and ever-increasing quality requirements has led to a setting up of industry-wide performance benchmarks (Egan, 1998). Quantifying the benefits of an innovation, however, on an infrastructure project can sometimes be daunting or practically impossible, depending on the type of innovation and the metric of interest. But estimating the quantum of innovation *a priori* is what is needed in support of the procurement mode decision-making process.

4.4. Sources and Types of Project Innovation

At the project delivery level, innovation can occur at one or more of the project stages/phases of design, construction and operation and maintenance. Innovations appear to be ubiquitous in design and construction (Slaughter, 1998), even at the initial stages of project planning, and may occur in conceptual design, in material selection and construction methods and equipment usage. For project evaluation purposes as well as for the specific objective of assessing and attempting to quantify innovation/efficiency potential as part of the project procurement selection exercise, it is imperative to fully understand the potential sources and types of innovation that apply.

Design concepts and details which Salter and Gann (2003) characterised into *creative* and *operational* designs can act as sources of innovation and greatly influence the innovativeness and competitiveness of project bids and proposals. Creativity or innovation may not be limited to novel designs. Depending on a project and its context, making designs fit safety and environmental standards can engender innovation (e.g. incorporating innovative safety driving features in a highway design such as road alignment). Innovations in construction methods and technologies have centred on the use of advanced equipment and off-site prefabrication/pre-cast factory-style mass production of components. Technology adaptation and input (such as Global Positioning System (GPS) and robotic technologies) from other industries can be a source of construction method innovations. Infrastructure operation & maintenance innovations come from the use of technologies, often adapted from other industries, to maintain durability and safety (e.g. the use of GPS and information & communications technologies in highway operations and safety). The fit of innovative technologies in operation and maintenance programmes depends on the innovations/technologies adopted during the design and construction phases. Innovation can also come from alternative ways of delivering services e.g. for a hospital to contract out meal preparation similar to what is done in the airline industry. Project innovation types can be classified into product, process, organisational/contractual, and financial/revenue innovations as shown in Table 4.1 below. The 4 categories of project innovations identified under this study share some interdependencies. The realisation of an innovation in one class can trigger innovations in one or more of the other classes. The use of an innovative design concept or technology may spawn a major re-engineering of the processes and methods required to realise it, which depending on the type and magnitude of the risks associated with it may call for a re-organisation of contractual relations/obligations and financial recourse. An innovation's risk

profile plays a critical role in its usage and ability to stimulate other types of project innovation. Certain organisational/contractual innovations can lead to direct financial innovations without any re-organisation or re-allocation of risks[2].

Table 4.1 Types of Project Innovation (modified after De Zoysa et al. 2004)

Product Innovations	***Process Innovations***	***Organizational/Contractual Innovations***	***Financial/Revenue Innovations***
- Advanced products (components, materials etc.) and their assemblies - Novel designs and concepts - Use of advanced technology and systems in the operating and maintenance phase	- Measuring, lifting and assembling devices and use advanced technologies during construction - Off-site fabrication and novel construction methods leading to reduced off-site activities - Novel methods of pacing and/or sequencing construction activities leading to compressed project/programme schedules	- Use of information technology tools in project management - New or significantly improved organisational practices e.g. computerised inventory control, inter-firm partnering, novel work certification/approval processes - Negotiation of assignment of risks, development of contractual terms dealing with performance-based revenue or payment mechanism	- More efficient capital/operating costs improvements and programming - Creative project financing strategies and techniques e.g. bond financing etc. - Innovative revenue streams e.g. externalities and third-party revenue, the concept of shadow tolling on some highway projects

4.5. Factors (Drivers and Inhibitors) of Project Innovation

Based on an extensive review of the construction innovation literature and structured interviews held with several individuals experienced in the delivery of infrastructure projects under different procurement modes, a list of 22 factors that act as drivers or inhibitors of innovation have been identified and refined, as shown in Table 4.2. Construction innovation has traditionally been hampered by 2 major concerns – the risk associated with innovation in terms of the consequences of failure with regards to public safety and loss of investment, and the opportunities to appropriate the benefits of innovation in an industry where profit margins have often been described as wafer-thin vis-à-vis who gets the benefits of innovation.

[2] The organisational structure of the Confederation Bridge project, allowed certain unprecedented roles and responsibilities to be performed by an independent engineer. This organisational novelty generated transparency and capital market confidence in the process and thus was one of the primary driving forces for issuing the largest real-rate project bonds in Canada (Pirie and Giannelia, 2004).

Table 4.2 List of Drivers/Inhibitors of Project Innovation (modified after De Zoysa et al 2004)

Project-specific Factors/Characteristics
1. Project Type
2. Project Scale/Scope
3. Project Complexity/Uniqueness

Project Risks
4. Product risks
5. Process risks
6. Natural Environment risks/ Requirements
7. Reasonableness of risk assignment

Socio-Economic & Political Factors
8. Certainty of economic environment
9. Certainty of political environment
10. Certainty of Regulatory System/Environment
11. Certainty of stakeholder environment

Commercial/Business Factors
12. Opportunity for other projects of similar type
13. Responsibility Integration
14. Source of Competition
15. Number of Competitors
16. Nature/Composition of Project Team
17. Proposal evaluation criteria & relative weights, decision and negotiation processes

Project Requirements
18. Project performance requirements/thresholds/constraints
19. Requirements for broader socio-economic benefits
20. Statement of Product Solution
21. Statement of Process Solution
22. Penalties for inadequate project performance

Sexton & Barrett (2004) highlight the issue of appropriation of innovation benefits as an important factor for driving innovation in a competitive project delivery marketplace. It involves a process where a stake holder's rewards are adequately captured and protected to ensure a fair economic return commensurate with the risk and magnitude of investment incurred by that stakeholder to implement an innovation. From the perspective of the project company, the opportunities for further use of a creative idea and the ability to appropriate its benefits on other projects of similar type in the future can drive the pursuit of innovation. However, such pursuit depends on the certainty of the socio-economic and political environments and the overall business case of the project (i.e. competition, proposal evaluation criteria, risk assignment, negotiation processes) to ensure that the benefits of innovation are fully derived. Gann *et al.* (1998), Prior et al. (2004), Sexton & Barrett (2004) emphasise that prescriptive regulations that force organisations to conform to detailed specifications tend to stifle creativity while performance-based building (PBB) regulations and specifications, which stimulate organisations to innovate, are progressive and can be an effective driver of innovation. Conditions such as the capacity and motivation for the stakeholders to innovate are directly linked to the nature of the project's requirements, specifications and constraints (i.e. statements of solutions and the penalties for inadequate performance). Slaughter (1998) argues that in contrast with other industries, especially manufacturing, the construction process and its products are unique, and hence the scale, complexity and durability of these products together with the organizational and

socio-political contexts influence the nature and pursuit of construction innovation. The influence of these factors on innovation is discussed later under Table 4.3.

4.6. Relationship of Factors with Project Procurement Modes

Depending on the state assumed, most of the factors of project innovation identified can either act as drivers or inhibitors of innovation for a specific project context. There are two main objectives and benefits to be derived from understanding and establishing the relationship between these factors as drivers or inhibitors of innovation and the choice of project procurement mode. One of the objectives is establishing conditions that are conducive to innovation, given a particular procurement mode, by exerting some control over the states of the factors, keeping in mind that whilst some factors are within the direct control of project participants others fall outside their influence. The second objective is how to select a project's procurement mode from a list of candidate project modes, given the states of these factors as either drivers or inhibitors of innovations, and their interrelationships for the project of interest. Ideally, the most suitable procurement mode should maximise drivers and minimise inhibitors for maximum project innovation/efficiency potential. Procurement modes considered embrace but are not limited to DBB (traditional design-bid-build and its variants), DBBo (design-bid-build optimized with value engineering, allowance for alternatives, etc.), DB (design-build) and its variants (e.g. novation (Walker & Hampson, 2003)), DBM (design-build-maintain), DBOM (design-build-operate-maintain), FDBOM (finance-design-build-operate-maintain), FDBOMSD (finance-design-build-operate-maintain-service delivery), Project Partnering, and Alliancing. It is worth-emphasising that whereas some types of project innovations can be influenced by the choice of procurement mode, others can be realised irrespective of the procurement mode chosen. For instance the use of specially built mini-cranes occasioned by space constraints on some construction sites may provide construction lifting capabilities in unusually tight areas and may be employed independent of the procurement mode i.e. the drivers of competitiveness and profit provide sufficient motivation to keep abreast with technological innovation. Also certain emerging technologies emanating from extensive and collaborative R&D activities create new construction processes, materials and equipment and can suddenly change the way certain structures and facilities are designed, constructed, operated and maintained. Such innovations usually fall into the radical-type innovation classification and may be employed regardless of a project's procurement mode. For example, ultraviolet (UV) and ozone technologies in waste

water treatment processes have now influenced how such facilities are designed, operated and maintained for maximum efficiency and reliability (Waer, 2004). Orthotropic bridge sections and weathering steel (high-strength, low-carbon alloy) as innovative technologies have also influenced bridge design and construction. High performance steel (HPS) can now allow engineers to design longer, shallower spans and add greater value when replacing traditional simply-supported multi-span structures with continuous-span structures Mastaglio (2004). The savings in capital costs of such innovations can be enormous.

The ability of a project's procurement mode to deliver or drive innovations depends on how early in the procurement process the concept of project innovation is incorporated into the decision-making process. There is no universal procurement mode that can serve as the panacea for maximizing innovation on an infrastructure project (i.e. there is no direct relationship that can predict the level of innovation to be achieved on a project by merely stating a procurement mode). The suitability of a particular procurement approach for maximum innovation depends on how well it fits the project and its circumstances as well as the states of the project innovation factors as they occur on the project. In switching to an alternate procurement mode, technical and certain socio-economic factors might remain the same; but some aspects of the commercial and project requirement factors and risks might change.

4.7. Definition of States of Drivers/Inhibitors

To drive innovation, the states for each of the factors (e.g. for competition, local versus national versus international) that are most conducive to innovation have been identified and a metric developed to indicate innovation potential. The primary objective is to determine possible states for each factor and assess their relative intensities to drive project innovation/efficiency. Table 4.3 represents possible states for a subset of the factors previously identified (the complete definition for all 22 factors can be found under Appendix A of this document). The intent of the table is to rank the states of each innovation factor in terms of relevance to innovation maximisation. For a factor State 3 represents the highest ability to drive innovation, whilst state 1 implies lowest ability to drive innovation (i.e. an inhibitor of innovation). In practice, each factor can assume variable states in a somehow continuous spectrum. To facilitate ease of use, the spectrum of states has been discretised. The intent has been to "subjectively" characterise each factor into a small number of states to help ensure ease of use of the framework. 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. From table 4.3 a hypothetical project having states 3, 2 and 1 respectively for the factors project type, source of competition, and reasonableness of its risks assignment, *may* have a higher potential for innovation than when for the same project the state for each of the factors is 1. (For a discussion on the interrelationship between factors, see De Zoysa et al. (2004)). It is worth-emphasising that the relative innovation potential as stated by the framework is different from the absolute or real innovation achieved on a project. A $90-million road project may have the same potential for innovation in theory as an industrial project worth $200 million if all the other factors score similarly for both projects, but the actual innovations realised in both cases may be materially different in type as well as in the magnitude of their benefits. The fundamental idea applied in defining the project scale/scope factor is the increasing opportunity offered for investment in repetitive, standardised and/or modularised innovative concepts and methods as project scale/scope, vicariously defined here in monetary terms, increases.

4.8. Measuring Innovation Potential

We seek a way of measuring the presence of drivers/inhibitors of innovation i.e. some kind of an index measure. We use a visual representation, starplot, of drivers and their states (Spears, 1999; Walker & Hampson, 2003) and some basic geometry using a simple non-linear scale for each axis starting from 1 to 3 to correspond to the state definitions in table 3 (an area measure is used for defining the positioning of the 3 states; state 3 corresponds to 3 times the area of state 1). State zero will represent a factor for a procurement mode in which that factor is inapplicable and has no major input in the decision-making process particularly with regards to the pursuit of innovation (e.g. some economic factors in a traditional DBB process). A complete plot of all 22 factors for a real project is shown in Figure 4.1. The visual representation easily highlights factors that should be examined or controlled to create an innovation-driving procurement structure, or conversely in identifying factors that are hindering the innovation effort. Additionally, the area of the starplot can assist in determining how much innovation can be *expected* on a given project, thus providing valuable information to project financial and economic analyses. An implicit assumption in Figure 4.1 is that all factors are accorded the same weight in terms of their contribution potential. If different weights were to be assigned, the geometry of the starplot could be readily adjusted.

Table 4.3 Definition/designation of states of project innovation factors

Factors (Drivers/Inhibitors) of Innovation	**States, Descriptors, Values of Innovation Factors (Relative Ability to drive Project Innovation)**		
	High	**Moderate**	**Low/Insignificant**
	3	**2**	**1**
1. Project Type	Heavy civil infrastructure projects – bridges, tunnels, roads, nuclear plants	Industrial/Commercial facilities, Utilities projects	Residential Projects, Student Housing Projects,
2. Project Scale/Scope (monetary terms)	> $100 million	$ 25 – $100 million	< $25 million
4. Product risks	Totally radical/revolutionary products, background knowledge and specialty of which exist among a few exclusive experts, >80% success rate	Radical/revolutionary products having a broader knowledge base existing among a larger industry audience/experts, success rate 10 – 80%	Totally radical and revolutionary product, never built before whose knowledge base is extremely scanty, success rate < 10% or cannot be determined
7. Reasonableness of risk assignment	Appropriate/balanced allocation of risk among parties	Asymmetrical and/or lopsided risk allocation structure	Complete transfer or off-loading of risks to one party irrespective of their ability to manage the risks assigned
12. Opportunity for other projects of similar type	Opportunities exists even beyond the long term time horizon (> 10 years)	Opportunities exist within the medium term time horizon (5 – 10 years)	Highly uncertain opportunities even within the short to medium term < 5 years
13. Source of Competition	International, competition for project funding, technical competition (based on quality, value, engineering)	National/Regional, competition for project funding, technical competition (based on quality, value, engineering)	Local, no competition for project funding, no technical competition
17. Proposal evaluation criteria & relative weights, decision and negotiation processes	Full evaluation of alternative solutions including unproven technologies/concepts, points allotted to innovation, a whole-of-life approach to proposal evaluation.	Partial evaluation of alternative solutions including unproven methods, technologies & concepts, no points allotted to innovative proposals	No evaluation of alternatives, no points allotted to innovative proposals, only tried and proven technologies and concepts allowed
20. Statement of product solution	Performance or object-based specifications that define the required product output (such as service and availability levels, capacities, rates etc.), use of benchmarks	Functional specifications that only state the set of functions expected to be performed making optimisation difficult to pursue	Technical/prescriptive specifications giving detailed product (physical) description (number, dimensions, colour, material constituents etc.)

4.9. Case Study of Project Innovation

Presented here is a case study of a high profile project for which significant innovation has been claimed. We use it to illustrate application of the concepts described. The authors are currently focusing on compiling a number of such examples. Table 4.4 presents the innovations on the Port of Brisbane Motorway (POBM) project in Queensland, Australia as claimed by Manley (2004). The project alliance structure itself of the POBM project is considered as an innovative project delivery process which in turn facilitated the realisation of other project innovations spawning significant benefits and improvements in project performance metrics. These gains arose in large part from the preparedness to test and implement new technology and methods within the project alliance framework, resulting in a project of greater functionality, quality and aesthetic value than was contractually required (Manley, 2004). Figure 4.1 is a schematic representation of the values or states of project innovation drivers/inhibitors as they occurred on the PBOM project and its plot is based on the designation of the factors in Table 4.3. The area of the shaded region on the plot is 7.64 and it represents a measure of the project's relative innovation/efficiency potential. It can be seen from figure 4.1 that majority of the innovation factors on the POBM project exist at their highest states of driving innovation.

Table 4.4 Case Study of Innovation and Conditions of Port of Brisbane Motorway Project

Project:	Port of Brisbane Motorway (POBM) Project
Description/Location:	Highway project - a 5-km 4-lane motorway project the scope of which includes the construction of 12 new major bridges in Queensland, Australia
Project Duration:	1-year construction program
Project Procurement Mode:	Design & Build Project Alliancing
Client:	Queensland Motorways Limited (QML)
Project Value:	Total Cost Estimate of $112million (AU)

Innovation Type (Source)	**Condition Dimensions**
Product Innovation • Slip-formed reinforced bridge barriers – adopted for the first in the state of Queensland using paving machines instead of form workers. • Water quality design • Elevated tri-level motorway interchange – the first designed and constructed in Queensland involving an innovative structural arrangement. Innovative Construction Method (Process) • A 3-dimensional Global Positioning System (GPS) to control machinery and other construction activities. The first project to adopt the use of GPS in the southern hemisphere. • The use of polystyrene fill to minimise settlement in difficult areas – the first time in Queensland Organizational/contractual Innovation • Third-party certification for safety, quality and environment using integrated management systems to achieve triple-certification for the first time on an Australian road project.	The rather large scope of the project, particularly the number of bridges involved and the potential associated scale economies, gave sufficient incentive to the project team, under a collaborative alliance structure, to undertake tests and analyses to determine the applicability of the contractor-led bridge-barrier technology. The use of custom standards and methods/procedures, in lieu of the generally prescriptive specifications and established construction procedures/practice of the highway agency's in a traditional delivery, allowed for optimisation of design and construction leading to more efficient and effective outcomes. Environmental risks and potential adverse impact of project on an existing floodplain/wetland and excessive noise levels during construction created a hostile but engaging stakeholder environment leading to the setting of high project environmental performance requirements. Project team's commitment to analysis of alternative solutions different from preliminary designs and concepts leading to the use of innovative technologies to meet stringent hydro-ecological objectives and structural design optimisation. Project design team having the technical experience/knowledge and the authority to challenge specifications in design briefs. Win-win environment with a collective ownership of project risks based on a risk/reward arrangement designed to deliver either excellent outcomes or poor performance to all parties. Alliance structure allowed for a strong integration of project functions – integrating design, planning and construction activities. An investment in integrated design, planning and construction creating easy access to and closer interaction among project team members.

Benefits of innovation	• 10% reduction in project cost part of which was delivered as additional project scope including a 30% saving in direct bridge costs, 30% reduction in overall project schedule, 10% reduction in traffic management costs and 40% reduction in lost time injury frequency rate compared to industry averages and cost of delivering similar road projects in South East Queensland.

Source: Manley, K. (2004)

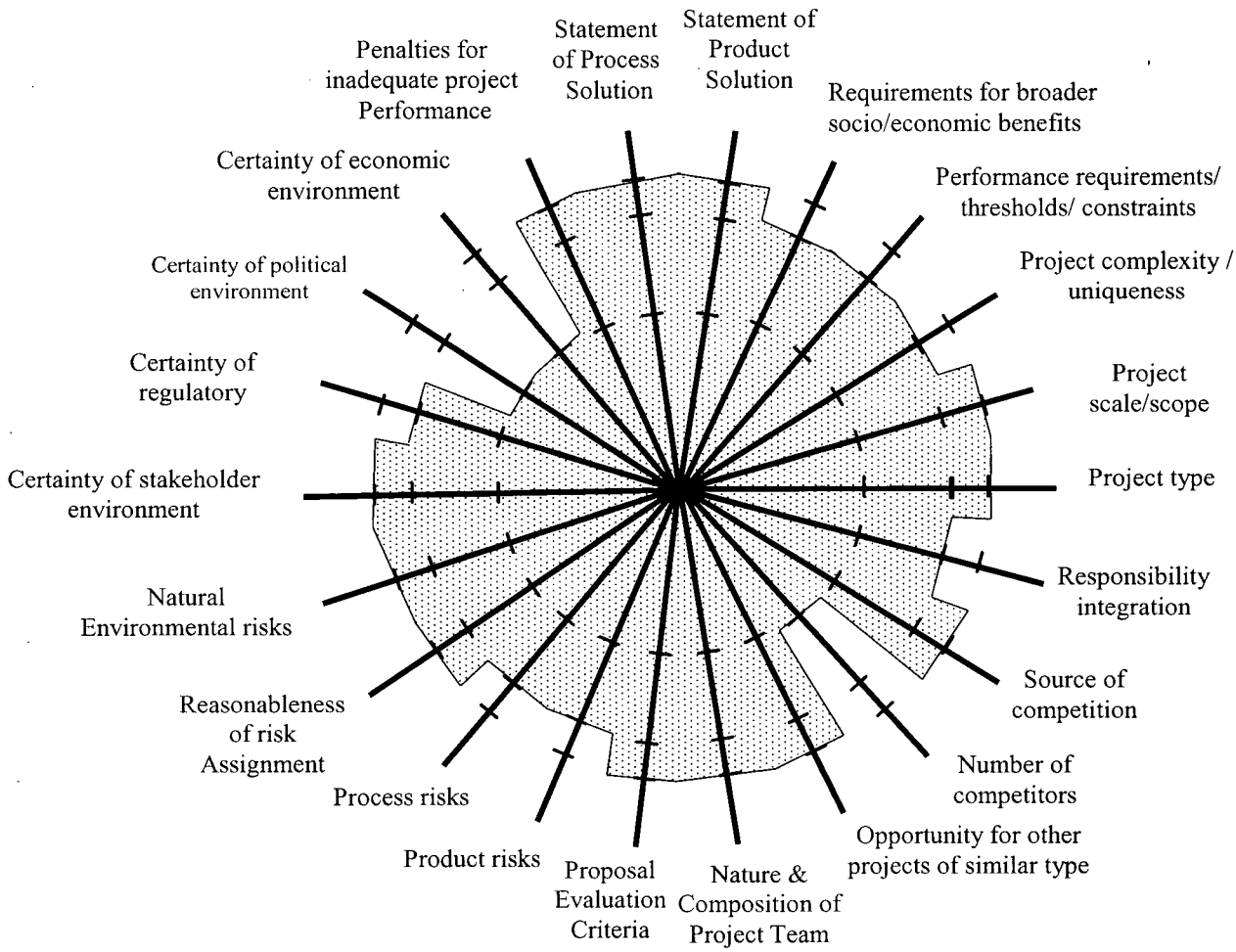

Figure 4.1 Starplot of factors driving innovation on POBM Project

4.10. Project Innovation and Procurement Mode

Conceptually there is a <u>*strong*</u> relationship between project innovation and the most appropriate procurement mode adopted for a project. Innovation and its benefits can only be realised if innovation and efficiency objectives are fully integrated into the procurement process to become one of the central themes of project planning/development, procurement selection and evaluation processes and underpinned by appropriate risk transfer/sharing and incentive/reward schemes for project participants. This project procurement mode–innovation relationship is supported by evidence of the occurrences of significant innovations and efficiencies on some major infrastructure projects and how the procurement mode adopted influenced their realisation. Projects where this appears to be the case include the POBM project (Manley, 2004), City of Phoenix Waste Water Project (Waer *et al.*, 2004), Confederation Bridge (Pirie & Giannelia,

2004), and Oresund Tunnel (Marshall, 1999). Although such projects form a minority in relation to the population of infrastructure projects executed globally, their very existence lends credence to such a relationship. However, considering the paucity of evidence from other case studies, reports and interviews, this relationship appears *tenuous* under present practices for the following reasons:

a) Project innovation has often been perceived by most practitioners and infrastructure procurement personnel as a "by-product" of the best-fit procurement mode whose structure and provisions effectively ensure that important project performance metrics (such as time/schedule, cost/budget, quality and safety) are sufficiently met. In actual fact, project innovation, under the most appropriate procurement mode and context, has the potential to serve as a conduit through which these cardinal project performance metrics will not only be met but also improved through increased efficiencies and economies. In the UK's PFI/PPP experience, CIC (2000) indicates that the focus has been on such issues as commercial (e.g. contract standardisation), political (e.g. public sector balance sheet treatment), financial (the actual impact of higher private sector cost of borrowing) and organisational (e.g. role of government finance agencies) to the neglect of quality, cost of service operation and design and construction of the underlying physical assets.

b) As a result of significant effort and time being expended on such contractual and organisational issues, pre-construction phases of the procurement cycle are sometimes accelerated creating shorter planning periods. This often leaves procurement personnel and project proponents with relatively little time while preparing responses to an RFP or call for bids for effective and thorough analysis of novel concepts which can be adapted or adopted from other jurisdictions by scouting and tapping into a global pool of innovative ideas and best practices.

c) Innovations can be inherently risky – their use to solve a problem and/or improve upon the performance of a system/process or to simply mitigate the effects of other risk(s) can sometimes introduce new risks and uncertainties. The search for innovation in design and construction has been hampered by the concerns for public and environmental safety. A risk-seeking and innovation-savvy client is more likely to make specific commitments towards the search for novel ideas in design concepts and methods of project delivery. Such project actors, referred to as innovation champions (Tatum et. al., 1989) must provide leadership and apply new knowledge in driving the project procurement and delivery processes. Someone from the project team must stick their neck out to share or take risk with regards to the use of

innovative/novel ideas and concepts. In a design-build contract of a rail embankment stabilisation project, the client (London Underground Ltd., UK) was prepared to take risks and hence told design & construct contractors to be radical in their solutions. The result was a revolutionary railway embankment design involving bored pile walls and vegetated slopes generating a 65% cut in stabilisation cost (Fitch, 2000).

An analysis and design of procurement modes should address impediments of the foregoing type so that a better understanding of the linkage between procurement mode and innovation potential can be obtained.

4.11. Conclusions and Recommendations

We conclude with the following observations. First, clearly defined project objectives and functional requirements with the right balance between technical/prescriptive and functional/performance requirements based on the type and nature of project can drive innovation. The POBM project employed custom standards, methods and procedures allowing for optimisation in design and construction processes, thus leading to the realisation of innovations and efficiencies.

Second, the choice of a procurement mode with innovation as one of its primary objectives should be based on a sound business case which includes an analysis of the broad spectrum of factors/drivers of innovation identified. The innovative project Alliancing procurement mode adopted for the POBM reflected the various project-specific technical challenges and risks of constructing a largely-scoped highway project. The procurement structure allowed for an optimum risk/reward structure in a fully integrated delivery process that had a technically-skilled project team with a commitment to implementing innovation. The procurement mode selected along with associated terms should recognise the states of the innovation factors and any likely interplay among them with the aim of maximising drivers and minimising inhibitors of project innovation. Its structure must, however, fit existing market structures to ensure project viability and encourage competition, industry interest, and an appropriate reward and risk transfer/sharing among project participants to reflect the risk(s) inherent with innovative solutions.

We recommend that innovation should be institutionalised within the procurement process (Miller 1997) and potential costs and benefits of a particular innovation should be treated

explicitly in project metrics such as NPV, time, cost, quality, and safety. Project proposal evaluation criteria that specifically reward or recognise the positive contribution of innovative proposals are rare to come by. This situation is a reflection of the ambivalence and challenges facing procurement agencies desiring "innovation" but wanting to accept only tried and proven design concepts and construction methods and technologies due to the risk factor. State Route (SR) 57, SR125 and SR91 toll highway projects in California, USA were identified and proposed by private developers that exposed them to more developmental risks with a greater flexibility and incentive to develop new ideas. The bid evaluation criteria set out by the government procuring agency also included, among others "the degree to which the project incorporated innovative ideas" (Gomez-Ibanez & Meyer, 1993). The evaluation criteria allocated 10 points out of a 110-point maximum to the degree of technical innovation displayed in the project proposals (Levy, 1996), which led to substantial innovations in pavement alignments and construction techniques, toll collection (congestion pricing on a toll road was introduced for the first time in the US); and financial innovations particularly on the SR125 project (Innovative Finance, 2003; Gomez-Ibanez & Meyer, 1993). To encourage and recognise project innovations, and in concurrence with findings of CIC (2000) and Gomez-Ibanez & Meyer (1993), proposal evaluation criteria, apart from giving prominence to specific project objectives, needs and requirements to fully reflect government's procurement strategies, should also award points directly, however modest, to novelty/innovations in proposals, as well as treating innovation directly in traditional performance metrics like NPV.

4.12. References

Bowley, M. (1966) *British Building Industry.* Cambridge University Press, Cambridge, 488p.

Construction Industry Council (2000) *The role of cost saving and innovation in PFI projects*, Thomas Telford Publishing, London, U.K.

Davidson, C. H. (1998) *Procurement – the way forward:* Proceedings of CIB W92 Symposium, University of Montreal, Montreal, CIB publication 203. ISBN 0-9682215-0-5.

De Zoysa, S., Russell, A. D. and Tawiah, P. (2004) Innovation Potential of the Private Sector and its Relation to the Project Delivery Mode, 1st International Conference, World of Construction Project Management, Toronto, Canada.

Egan, T. (1998)). *Rethinking Construction, 'The Egan Report'* Department of Transport and the Regions (DETR), London, UK.

Fitch, T. (2000) *65% cut in rail embankment stabilisation cost, Project 55.* Movement for Innovation, UK.

Freeman, C. (1982) *The Economics of Industrial Innovation*, 2nd edition Printer, London, UK.

Gann, D. M. (2000) *Building Innovation - complex constructs in a changing world.* Thomas Telford Publishing, Thomas Telford, UK.

Gann, D. M., Wang, Y. and Hawkins, R. (1998) *Do regulations encourage innovation? The case of energy efficiency in housing.* Building Research and Information. 26(1), 72 – 78.

Henderson, R.M. and Clarke, K.B. (1990) *Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms,* Administrative Science Quarterly, 35, 9 – 30.

Innovative Finance, Quarterly Journal from the US Federal Highway Administration (FHWA). 2003 9 (2).

Lemos, de T., Almeida, L., Betts, M. and Eaton, D. (2003) *An examination of the sustainable competitive advantage of Private Finance Initiative (PFI) projects.* Construction Innovation, 3(4), 249 – 259.

Levy, S. M. (1996). *Build, operate, transfer*, Wiley, New York.

Lowe, J. (1996) *Technological Change and Construction.* Journal of Financial Management of Property and Construction. 1(2), 65 – 94.

Manley, K. (2004) *Motorway Alliance Drives Performance Improvement,* CRC for Construction Innovation.

Marquis, D. G. (1988) *Anatomy of successful innovations, in* Readings in the Management of Innovation, M.L. Tushman and W.L. More (eds), Ballinger, Boston, MA, 79 – 87.

Marshall, C. (1999): "The Oresund Tunnel – Making a Success of Design and Build". Tunnel and Underground Space Technology, 14(3), 355 – 365.

Mastaglio, L. (2004) *Leading Infrastructure Innovation,* Engineering News-Record, Special Advertising Section, November 29, B1 – B2.

McDermott, P. (1999) *Strategic Issues in Construction Procurement.* Procurement Systems – A Guide to Best Practice in Construction. Rowlinson, S. and McDermott, P. (eds), London, E&FN Spon: 3 – 26.

Miller, J. B. (1997) *Procurement Strategies which encourage Innovation: The Fundamental Element of Sustainable Public Infrastructure Systems?* Int. Council for Building Res. Studies Documentation (CIB) Symposium, Working Comm. W92. Univ. of Montreal, Publication 203, ISBN 0-9682215-0-5.

Pavitt, K.L.R. (1971). *The Conditions for Success in Technological Innovation*, Paris, OECD.

Pirie, J. D. & Giannelia, P. (2004) *Confederation Bridge – A Case Study,* Presentation at the Special Course on Private Participation Infrastructure Projects, Civil Engineering Department, UBC. Canada. Sept. – Nov.

Prior, J., Szigeti, F. & Oostinga D. (2004) *Compendium of PB Statements of Requirements SOR.* Proceedings of CIB 2004 (#539) World Building Congress, 2 – 7 May 2004. Toronto, Canada.

Rosenberg, N (1982) *Inside the Black Box – Technology and Economics.* Cambridge University Press.

Salter, A. and Gann, D. (2003) *Sources of ideas for innovation in engineering design.* Research Policy, 32, 1309–1324.

Sexton, M. & Barrett, P. (2004). *Performance-based building and Innovation: Closing the loop.* Proceedings of CIB 2004 World Building Congress, 2 – 7 May 2004. Toronto, Ontario, Canada

Slaughter, E. S. (1998) *Models of Construction Innovation.* J. Constr. Engrg. & Mgmt., 124(3), 226 – 231.

Slaughter, E. S. and Shimizu, H. (2000) 'Clusters' of innovation in recent long span and multi-segmental bridges Construction Management and Economics (2000). 18, 269 – 280.

Spears, W. M. (1999) *An Overview of Multidimensional Visualization Techniques.* Proceedings Genetic and Evolutionary Computation Conference, Orlando, Florida, July 1999.

Stewart, W. S. & Tatum, C. B. (1988) *Segmental Placement of Renton Outfall: Construction Innovation.* J. Constr. Engrg. & Mgmt. 114(3), 390 – 407.

Tatum, C.B.; Bauer, M. F. & A. W. Meade (1989). *Process of Innovation for Up/Down Construction at Rowes Wharf,* J. Construction Engrg. & Mgmt. 115(2),179 – 195.

Thorpe, D. (2003) *Online Remote Construction Management trials in Queensland Department of Main Roads: a participant's perspective.* Construction Innovation, 3(2), 65 – 79.

Waer, M. A., Hayes, T., Quarendon, J., and Mahaffay, D. (2004) *Water Wise in Phoenix,* Civil Engineering, October, 46 – 51.

Walker, D. & Hampson, K. (2003) "Procurement Strategies – A Relationship-based Approach", Blackwell Publishing.

CHAPTER 5

5.1. Conclusions and Recommendations

This thesis has provided a way of thinking about the factors that influence innovation at the project level. The research study has proposed a framework for assessing innovation potential as part of the procurement mode selection/structuring process for infrastructure projects through an extensive analysis of instances of innovation occurrence/non-occurrence, the controlling factors and their relationship with the procurement mode adopted. The first paper is the product of an initial exploratory research into innovation occurrence and procurement. In its skeletal form it served as the guiding framework for conducting more detailed research and for providing significant fore-knowledge about the objectives and substance of the research to interviewees prior to meeting them. Most of its ideas and concepts expressed were generally accepted to be valid in practice by all the interviewees. The second paper bears some semblance with the first. It is a refinement and extension of the first paper based on a definitive literature review and structured interviews with industry experts for the purposes of providing a picture of the (current) state of knowledge on innovation as it relates to procurement mode, what the real issues are in any attempt to postulate innovation as a function of procurement mode and specific examples of innovation and related drivers. The third paper expands the investigation and research to include a detailed study of innovation and presents a definition of the states for the factors identified in the two preceding papers. Thus the mechanism for selecting and/or structuring a procurement process to maximise project innovation/efficiency potential should be reflective of the states of the factors for a particular project. In trying to forge a link between degree of innovation and procurement mode, it is observed that hard evidence is difficult to find, the pool of evidence is scanty – particularly instances where specific innovations have occurred on infrastructure projects and are directly attributable to the particular procurement mode adopted. Hence at the conceptual level, the procurement mode-innovation relationship is considered strong, but tenuous in practice. It is difficult to establish on an empirical basis whether P3/PFI project procurement routes yield more innovations, as the results across different sectors and regions/countries are mixed, despite their theoretical appeal for project cost-saving and innovation potential. We believe that there has not been sufficient documentation of real evidence and instances by practitioners to lend strong support to such a relationship. Any assertion to that effect should be comprehensively and objectively analysed in comparison with the performance of existing public procurement in the particular sub-sector of a geographic

jurisdiction. The implication of the findings from the Partnerships Victoria review (Fitzgerald, 2004) is that efficiency gains from private sector-led delivery processes can at best be modest, if an efficient and competitive public-sector procurement process already exists. The issue of investigation, subsequent then, is: Given that a whole-of-life approach including value engineering, alternates and optimisation are incorporated into a competitive public sector-led procurement, will there be substantive opportunities for incremental innovation and efficiency under such an integrated[1] procurement system? This issue is worth further research to identify instances of such procurement approaches and strategies.

The most suitable procurement process adopted for a project for maximum innovation and efficiency should incorporate the following considerations in addition to other specific recommendations made elsewhere in the three manuscripts presented in this thesis:

- To press for an effective definition of the project (in this case the project scope, requirements, constraints etc.) to drive or encourage incremental innovation development and implementation which are within the power/capabilities of the project proponent/developer/constructor and a relaxation of non-essential project constraints. It is noted that some of the constraints however are a function of procurement mode – for instance capital budget constraints and frequent project scope changes become highly important issues in some publicly-led procurement modes.
- To allow for a process of getting behind the code system and exploiting approximations to actual system behaviours from which optimisation and creativity can reap significant benefits and savings – i.e. in defining specifications, the procurement process should allow for the use of alternative provisions of the code that will permit say, the engineer through sound analysis not to strictly follow the standard approaches prescribed by the code. For example the switch from traditional sloping webs to perpendicular webs of box girders in steel bridge design and construction led to significant reduction in fabrication time and cost (Azizinamini et al. 2004). Gann *et al.* (1998) propose that the strategic design of regulations and standards can create positive innovation outcomes through system flexibilities and increase in demand for new practices and technologies.
- To employ a two-prong approach or what is referred to in industry as a two-envelope system where demonstrable and deliverable ideas, concepts, technology are proposed and backed by

[1] Integrated is being used loosely here to imply a whole-of-life procurement approach that includes life-cycle cost analysis in addition to the usual capital budgeting of the proposed infrastructure.

experienced project organisations and teams. From the study it is becoming increasingly clear that innovation realisation on infrastructure projects is by and large hugely dependent on getting the project team right. By this we mean the selection of organisations and individuals within the organisation that have a track record of working well together and who are focused on a proactive approach to problem solving. Subsequent to that is the use of evaluation methods which are responsive to the project budget i.e. technical quality and value should precede price. In the context of P3 projects, this approach implies streamlining the project risk profile and emphasising on concept and solution reliability before price determination. Inappropriate risk transfer can attract a huge premium from concessionaires due to the magnitude of work responsibilities and shortage of resources, particularly the ability to evaluate or price risk which often leads to ultra conservative behaviour by concessionaires, contractors and their financial partners.

- To encourage, where possible, the active involvement of a technically competent client with the requisite technical knowledge, background and experience to understand and take on project risk to encourage the use of innovative concepts and solutions. Engineering and construction should not be treated as commodities that can simply be bought, but should form a topmost component of the procurement process and project objectives along side the project pricing and financing.

5.2. Future Research Work

The limitations of the research and findings lie in the lack of a sufficiently large number of projects of interests to form a truly representative pool of case studies from which conclusions can be drawn. More work is required in assembling and analysing project case studies and specific instances of innovation and how they came about.

5.3. References

Azizinamini, A. Fallaha, S., Foud, J. and Farimani, R. (2004) *Outside the Box Girder,* Civil Engineering, September, 58 – 61.

Fitzgerald, P. (2004). *Review of Partnerships Victoria Provided Infrastructure.* Final Report to the Treasurer of Victoria, Australia. 55p.

Gann, D. M., Wang, Y. and Hawkins, R. (1998) *Do regulations encourage innovation? The case of energy efficiency in housing.* Building Research and Information. 26(1), 72 – 78.

APPENDICES

APPENDIX A: Definition of States for the Innovation Factors

Factors (Drivers/Inhibitors) of Innovation	States, Descriptors, Values of Innovation Factors (Relative Ability To Drive Project Innovation)		
	High	**Moderate**	**Low/Insignificant**
	3	**2**	**1**
1. Project Type	Heavy civil infrastructure projects – bridges, tunnels, roads, nuclear plants	Industrial/Commercial facilities, Utilities projects	Residential Projects, Student Housing Projects,
2. Project Scale/Scope (monetary terms)	> $100 million	$ 25 – $100 million	< $25 million
3. Project Complexity/uniqueness	Large resource requirements (>10,000 activities, 10^6 mhrs/yr), high precision & stringent tolerance limits, >1000 interactions/interfaces of elements, one-off project	Moderate resource requirements (5,000 – 10,000 activities, <200,000 mhrs/yr), moderate precision & tolerance limits, 100 – 1000 interactions & interfaces,	Low resource requirements (<5,000 activities, <100,000 mhrs/yr), low precision & tolerances, <100 interactions/interfaces, commonly recurring project
4. Responsibility Integration	Complete integration of all project functions e.g. Finance-Design-Build-Operate-Maintain-full Service Delivery	Integration of two or more major project functions/roles with value engineering	Fragmented process – sequential project phases/sections contracted out to distinct and different parties, with no value engineering
5. Opportunity for other projects of similar type	Opportunities exists even beyond the long term time horizon (> 10 years)	Opportunities exist within the medium term time horizon (5 – 10 years)	Highly uncertain opportunities even within the short to medium term < 5 years
6. Source of Competition	International, competition for project funding, technical competition (based on quality, value, engineering)	National/Regional, competition for project funding, technical competition (based on quality, value, engineering)	Local, no competition for project funding, no technical competition
7. Number of Competitors	3 (represents a certain optimum number of competitors)	4 - 6	Less than 3 or greater than 6
8. Nature/Composition of Project Team	Innovation champions in project team with broad technical	Some innovation champions, moderate technical knowledge,	No innovation champions, little technical competence, little or no

Factors (Drivers/Inhibitors) of Innovation	States, Descriptors, Values of Innovation Factors (Relative Ability To Drive Project Innovation)		
	High	**Moderate**	**Low/Insignificant**
	3	**2**	**1**
	knowledge, long track record or experience (> 10years) of project excellence with a high absorptive capacity.	track record or experience (5 – 10years) of project excellence	track record or experience (<5 years) of project excellence, little or no absorptive capacity
9. Proposal evaluation criteria & relative weights, decision and negotiation processes	Full evaluation of alternative solutions including unproven technologies/concepts, points allotted to innovation, a whole-of-life approach to proposal evaluation.	Partial evaluation of alternative solutions including unproven methods, technologies & concepts, no points allotted to innovative proposals	No evaluation of alternatives, no points allotted to innovative proposals, only tried and proven technologies and concepts allowed
10. Project performance requirements/ thresholds/ constraints	Stringent performance requirements (≥75-yr service life, emphasis on a balance between capital and life-cycle costs using a whole-of-life approach, minimal schedule constraints at all project phases	Moderately stringent performance requirements (50 – 75-yr service life, less emphasis on whole-of-life approach, significant schedule constraints especially at design phase)	Code-based performance requirements (< 50-yr service life, no emphasis on whole-of-life approach, very tight schedule constraints at the design phase) or overly stringent performance requirements at levels practically impossible to achieve or work with in reality.
11. Requirements for broader socio-economic benefits	Compliance requirements that allow a limitless blend of local and "foreign" resources and expertise for maximum dual benefits to both project team and peripheral project stakeholders	Compliance clauses that guarantee maximum use of local resources and expertise, and a cap on the use of "foreign" resources and expertise	Stringent compliance conditions/clauses that ensure the engagement of only local resources and expertise
12. Statement of product solution	Performance or object-based specifications that define the required product output (such as service and availability levels, capacities, rates etc.), use of benchmarks	Functional specifications that only state the set of functions expected to be performed making optimisation difficult to pursue	Technical/prescriptive specifications giving detailed product (physical) description (number, dimensions, colour, material constituents etc.)
13. Statement of process solution	Performance specifications that define the required process output	Functional specifications that only state the set of functions	Technical/prescriptive specifications giving detailed

Factors (Drivers/Inhibitors) of Innovation	States, Descriptors, Values of Innovation Factors (Relative Ability To Drive Project Innovation)		
	High	**Moderate**	**Low/Insignificant**
	3	**2**	**1**
	and rates (set using key project milestones), benchmarks	expected to be performed making optimisation difficult	process description
14. Penalties for inadequate project performance	Performance-based payment and reward schemes based on prudence and fairness in a win-win arrangement	Performance-based payment and reward schemes that reward all parties for over-performance but selectively punish a party for under-performance	Draconian or extremely punitive schemes based on unconscionable contracts
15. Product risks	Totally radical/revolutionary products, background knowledge and specialty of which exist among a few exclusive experts, >80% success rate	Radical/revolutionary products having a broader knowledge base existing among a larger industry audience/experts, success rate 10 – 80%	Totally radical and revolutionary product, never built before whose knowledge base is extremely scanty, success rate < 10% cannot be determined
16. Process risks	Totally radical/revolutionary solutions/processes, background knowledge and specialty of which exist among a few exclusive experts	Radical/revolutionary processes with a broader knowledge base existing among a larger industry audience/experts	Totally radical and revolutionary product, never built before whose knowledge base is extremely scanty, success rate cannot be determined
17. Natural environment risks/requirements	High adverse project impact in a complex bio-diversity consisting of one or more of the following components over an extensive area of the project site – (1) endangered species, (2) hazardous & contaminated substances, (3) archaeological & historical sites, (4) difficult terrain: hydrologically or topographically - with slope stability problems, (5) high noise levels	Adverse project impact in a complex bio-diversity consisting of one or more of the 5 main high risk components which occur as isolated patches over small areas.	Project has potentially little or no adverse impact on the environmental components none which fall within the 5 main high risk groups.
18. Reasonableness of risk assignment	Appropriate/balanced allocation of risk among parties	Asymmetrical and/or lopsided risk allocation structure	Complete transfer or off-loading of risks to one party irrespective of their ability to manage the

Factors (Drivers/Inhibitors) of Innovation	States, Descriptors, Values of Innovation Factors (Relative Ability To Drive Project Innovation)		
	High	**Moderate**	**Low/Insignificant**
	3	**2**	**1**
			risks assigned
19. Certainty of economic environment	Very stable labour & material availabilities, interest rate, currency exchange rate regimes, predictable over their respective individual cycles with high certainties (> 80%), high market availability/demand and interest in product or service to be delivered	Moderately stable labour & material availabilities, interest rate, exchange rate regimes, predictable over their respective individual cycles within 50% – 80% certainties	Highly volatile labour & material availabilities, interest rate and currency exchange rate regimes, predictable over their individual cycles with low certainties (< 50%), high market availability/demand and interest in product or service to be delivered
20. Certainty of political environment	Demonstration of strongest political commitment/will to project, consistency in the actions of government; certainty, enforceability and legality of project agreements over longer political time-horizons 20 years and beyond	Demonstration of some political commitment/will and consistency by government; certainty and enforceability of project agreements over medium term political time horizons (5 – 20 years)	Demonstration of weak political commitment/will and inconsistency by government; certainty and enforceability of project agreements over short political time horizons less than 5 years
21. Certainty of regulatory system/ environment	Highly flexible standards and codes allowing room for trying new concepts; stable statutes - certainty and enforceability of specific regulatory provisions of project agreements over the longer term > 20 years	Moderately flexible standards and codes ensuring partial adherence to existing system; fairly stable statutes - specific regulatory provisions of project agreements certain and enforceable over the medium term; 5 – 20 years	Fixed or rigid standards and codes ensuring strict adherence to existing system; unstable statutes -certainty and enforceability of specific regulatory provisions of project agreements only over the short term < 5 years
22. Certainty of stakeholder environment (i.e actions of environmentalists, unions, social groupings/benefactors, general public)	Hostile but cautionary and engaging, high certainty	Moderate resistance and engagement	Hostile and very resistant, highly uncertain

APPENDIX B: Interview with Expert 1 - CH2M Hill Ltd.

CH2M Hill in Canada is a fully integrated project-delivery firm providing planning, financing, designing, construction, operations and maintenance services in water (clean & waste water, utilities), environmental clean-up (site/waste management) and transportation (bridges & highways, ports & intermodal, transit, aviation) projects. The firm has delivered services in wastewater and transportation projects under different project procurement modes including traditional design-bid-build (DBB) and design-build-finance-operate (DBFO) as a member of either the project client's or proponent's team at separate instances. In its pursuit of excellence and application of innovative services on different projects, certain general factors and conditions have been identified as critical to achieving project innovation and improving efficiency. The factors/conditions have variable impacts on project innovation depending on the project type and may either be present or absent in moving from one project to another; often having a multiplying effect when jointly present on a particular project. The factors/conditions are discussed below:

- **Objective Function**

Most engineering projects exhibit a multivariate objective function—i.e. their effectiveness depends on a number of independent variables which may also exhibit correlation with each other. These variables almost always exhibit significant variation in the time domain. Traditional DBB procurement limits the number of these variables which can be explicitly varied by any one party, and typically limits the consideration of time domain effects (i.e. project life cycle effects) in a focus on capital cost. By structuring project delivery models to transfer more of these variables to the marketplace for competitive optimization, greater innovation is to be anticipated. However it is tough to set and transfer fully the objective function when a piecemeal approach is adopted for infrastructure procurement. A whole-of-life approach to the procurement process where the (private) developer is incentivised to consider operation and maintenance costs earlier in the project design phase is important for achieving project innovation and efficiency.

- **Capital Availability**

Seemingly limitless (private) capital can support an often costly resource (capital and assets) optimisation process by assessing several infrastructure investment alternatives whereas public sector fiscal constraints often preclude implementation of proposed infrastructure investments, no matter how attractive. Capital rationing by the public sector in its selection of infrastructure projects for implementation often leads to a piecemeal approach of infrastructure delivery and distorts the objective of optimising investment and achieving economies of scale which are some of the prerequisites for investments in technology and innovation. Abundant capital can facilitate implementation of a more optimal (in the economic sense) suite of capital investments and hence contribute to overall system efficiency.

- **Scope Definition**

The quest for an optimum solution or innovation on a project is strongly linked to how effective and appropriate the project scope and brief are defined i.e. project requirements, functions, service/capacity and availability levels. Thus the optimisation of any solution or concept depends on how succinctly the project's deliverables are expressed. However in practice project scope definitions are often blurred by non-technical issues (jurisdictional, environmental, social etc.) and constraints which are non-conforming and difficult to determine or express cognitively. Some procurement modes have been effective in pushing and controlling such constraints – design/build procurement mode is one example, even better is the use of a life-cycle cost approach to the procurement process. Specification of outcomes (e.g. "move 10,000 people" between A and B) vs. functions (build a highway to move 8000 vehicles between A and B) vs. end product (build me a 4 lane road and two

interchanges in this area) vs. procedures (use 30 MPa concrete and 15 M rebar at 150 mm o/c). Choosing the right level of specificity of requirements is critical!

- **System Complexity**

Project innovation is also hampered by the inability of project grantors to effectively describe a model in objective terms for optimisation by another party unknown to the system within the project's timeframe. Such system complexity is characterised by factors such as political, technical and environmental considerations and greatly influence project relationships and parameters which change with time during the procurement process and/or get loosely defined causing a lack of their proper understanding by project teams.

- **Economic/Market Conditions**

Sustained markets and opportunities for future work can contribute to innovation-seeking behaviour by project proponents through continuous training and investment in new technology. Mobility and availability of skill sets and professionals can negatively impact innovation development and implementation.

- **Mindset of Project Teams**

Legal liability concerns and professional responsibility for public safety of project teams have often engendered conservative behaviour in design concepts, construction methodologies and technologies employed in infrastructure project delivery. To drive project innovation, engineers, designers and constructors should assess critically as part of project objectives the efficient use of resources whilst at the same time taking responsibility for the impact of their activities on society. Engineering should not be decoupled from economics to achieve system optimisation and efficiency.

- **Standards and Codes**

The nature of standards and codes (being flexible or rigid) can either serve as a driving or inhibiting force for project innovation. Prescriptive standards and codes induce conservatism in design and construction and influence the behaviour/mindset of project teams. Safety standards and codes usage as against the use of the experiences of users/stakeholders has often narrowed the definition and scope of alternative solutions and concepts. There must be a balance between output and prescriptive specifications. However such a balance depends on the type of project – contrast the safety and environmental concerns of the construction of a highway in a green field terrain with that of an urban highway and how prescriptive the standards and codes should be to reflect the unique challenges of the respective projects.

- **Incentive/Reward Mechanisms**

Performance-based specifications and payments do drive efficiency. For instance on major highway projects minimum benchmarks based on performance-driven specifications can be set for mobility, safety and environment upon which design concepts and construction methodologies can be optimised within project budget to reap shared benefits and savings. Traditionally, incentive and reward schemes have not rewarded innovative behaviour by designers and contractors. Instead some punitive and liability clauses in contracts have prevented team work within project teams and have demotivated designers to take risks. Integrated procurement systems such as design/build, DBFO, DBFOM etc. can reduce the incidence of the needless adversarial culture and ultra-conservatism on projects to drive innovation and efficiency. However the compartmentalised system of the P3 process may not necessarily solve the problem. Much depends on the level of (technical) sophistication and experience of clients and proponent teams who are better able to understand innovation and its associated risks to drive creativity and project excellence.

Methods to encourage project innovation

On the bases of experience and practice in delivering different projects in different jurisdictions under varying procurement modes, the most suitable procurement process adopted for a project for maximum innovation and efficiency should:

- Press for an effective definition of the system (in this case the project scope, requirements, constraints etc) to allow for innovation which is within the power of the project proponent and a relaxation of the project's constraints. The constraints however are a function of procurement mode – for instance budgetary constraints become highly important in project procurement modes that involve the use of private capital.
- Allow for a process of getting behind the code system and exploiting approximations to understand the variation between the real/actual system behaviours and their approximations from which optimisation and creativity can reap significant benefits and savings.

Innovative Project Case Study

A) Sea-to-Sky Highway Project: Upgrade and Expansion of Highway 99, B.C.

Project Type/Cost	A 100-km improvement of the section of Highway 99 between Horse Shoe bay and Whistler. Improvements will include highway widening and straightening, improved sightlines, additional passing lanes and other design innovations and measures to reduce hazards, shorten travel times and increase capacity of the Sea-to-Sky Highway at a cost of $600million using a design-build-finance-operate-maintain (DBFOM) procurement mode. In order to minimize the risk to the project's schedule and to minimize the disruption to traffic flow construction is currently underway in advance of the main project in two sections of the corridor (Culliton Creek to Cheakamus Canyon and Sunset Beach to Lions Bay).
Procurement Mode	Design-build
Innovation(s)	• Construction method involves the building of retaining wall at some sections on the side of the road corridor closer to the sea and a fill-up of the resulting space to the level of existing road instead of a traditional approach that would have involved massive rock-cutting on the opposite side of the corridor. • Optimisation of budget and other performance-based (mobility, safety, environment) benchmarks
Driving Conditions	• An analysis of alternative solutions (incorporating 3 future demand/usage scenarios) and use of different systems that allowed prototyping to obtain various productivity data under the different solutions. • Budgetary constraints that forced project proponents to assess creative solutions in a $600-million range. • Concerns about the impact of the traditional rock-cutting methods on traffic safety/flow and the environment.
Benefits	• Significant cost savings in traffic management during construction • Project proposals based on the most optimum solution arrived at from the analysis of alternatives indicated a total cost which was $20million below the initial project budget.

Source: http://www.partnershipsbc.ca/files_2/seatosky.html, www.seatoskyimprovements.ca

B) Delta Port Container Terminal Project, B.C.

Project Type/Cost	Port Terminal Project at an estimated cost of $110 million
Procurement Mode	DBB with aspects of Construction Management
Innovation(s)	• Moved project from 1998 to 1996 completion date
Driving Conditions	• Schedule constraints influenced by market-timing • Micro-packaging that allowed for simultaneous construction activities • Taking of interface risk by construction manager to ensure on-time market delivery. • Impressing upon client to violate some of the principles for revenue optimisation and capital cost.
Benefits	• Savings in design and construction costs. • Ability to capture early revenue and market opportunities for operators. • This concept (empties storage) is being studied by the port for their present generation of investment and relates to their partnership with the Tsawwassen First Nation, not the original project.

APPENDIX C: Interview with Expert 2 - Westmar Engineering Ltd.

Westmar Ltd. provides a complete range of engineering and consulting services globally and across many disciplines and project types including heavy industrial facilities (port & terminal planning, bulk material handling, industrial structures), bridges & civil structures as well as unique maritime and offshore structures. Most of its projects can be classified as private sector works which often have roots in public sector clients and large industrial clients. In its pursuit of excellence and application of innovation and creativity on projects, certain general factors and conditions have been identified in the process as critical to achieving project innovation and efficiency improvement, and are discussed under the following sub headings:

- **Role of Client/Owner**

From the design perspective, project innovation and creativity require "unique" clients who are prepared to take on risk. Risk attitude depends on the client type – private clients are more risk averse apparently due to their susceptibilities to legal suits and obligations to project financiers who only accept tried and proven concepts and methods in a litigious project contracting environment. Contrary to the historical norm in the consulting industry where project innovation had been encouraged due to owners' willingness to share design risk with their consultants and thus were willing to pay for reasonable efforts and reasonable mistakes, the past 30 years, and in particular the last 15 or so, have seen a shift in the attitude/perception of project owners and their advisors (legal, finance/business) to one that attempts to buy perfection even though the conventional consulting contracts state reasonable efforts. Consequently reasonable efforts have become a defence rather than an expectation, and as a result innovation in design and contracting is being reduced.

- **Complexity**

Project uniqueness and complexity in terms of technical, schedule and budget do drive innovation. The more complex the site or the problem the more unique the solution.

- **Project Type**

The opportunities for innovation depend on the project type and/or constraints (contrast a hospital project with a transportation project where the former is controlled by strict health delivery standards, regulations and specifications or green field projects versus brown projects).

- **Competition**

Competition originating from strategies and plans to create unique and better solutions leading to product/process differentiation can drive innovation. However price-based competition can restrict innovation because of the consequences of failure and potential damages associated with creating and implementing an innovation. This inherent risk component of innovation development has led to the phenomenon of non-acceptance of consequential risk or end-product risk in EPC contracts often creating "negative innovation" i.e. an attempt to minimise the inputs of what is to be delivered while still being seen to meet the requirements. Technical competition which focuses more on design and solution concepts to drive value and reliability has resulted in significant innovation but is a process which is rarely used on its own. This can in practice lead to a greater use of relationship-based contracting by working with an owner over time to examine a range of alternatives, in comparison with competition-based contracting.

- **Organisational Structure / Project Team**

Process rigidity increases with firm size and the more rigid the work procedures the lower the proclivity to create an organisational/work culture that promotes creativity and innovation.

Diversity (in the form of intellectual, cultural and experiential) and the ability of team members to feed on one another can drive innovation. The blending of project teams with different personalities including innovation champions and engineering "geniuses" who are ready to think outside the box is very important for realising project innovation.

The benefits of integrated teams manifested through diversity of knowledge (technical, financial and experiential) can spawn innovation. The application of known processes in a unique way based on broader knowledge base (knowing more technology) and experience (from work on different projects across the globe) can result in significant savings from what others have proposed by analysing that solution's faults and then generating new or alternative concepts. The benefits of contractor construction knowledge are often over-rated. Experienced design firms by building a variety of projects in a variety of jurisdictions, often have broader experience base than some (local) contractors. Usually contractors optimise project plans and concepts based on their experience; and innovation based on an alternative design may not be well understood by a local contractor with a narrow experience/knowledge. Hence local knowledge and standard practice can inhibit the implementation of innovation (for e.g. $13million savings were accrued on a California project where a steel pile foundation designed to allow displacement instead of traditional rigid concrete pile foundation was proposed by an experienced design firm).

On the bases of experience and practice in delivering different projects under different jurisdictions the most suitable procurement process adopted for a project for maximum innovation and efficiency should recognise and incorporate two main objectives:

1) A two-prong approach or what is referred to in industry as a 2-envelope system where demonstrable and deliverable ideas, concepts, technology are proposed and backed by experienced project organisations and teams and using an evaluation method which is also responsive to the project budget i.e. technical quality/value should precede price. In the context of P3 projects, this approach implies streamlining the project risk profile and emphasising on concept and solution reliability before price determination. Risk transfer can attract a huge premium from concessionaires due to the magnitude of work responsibilities and shortage of resources, particularly the ability to evaluate or price risk which often leads to ultra conservative behaviour by concessionaires and contractors.
2) Technical competence of a client with the requisite technical knowledge, background and experience to understand and take on project risk to encourage the use of innovative concepts and solutions. Engineering & construction should not be treated as commodities that can simply be bought, but should form a topmost component of the procurement process and project objectives along side the project pricing and financing.

Pacific Coast Terminals Project - Upgrade of Bulk Loading and Berth Facilities. (Innovative Project Case Study)

This project sited in Port Moody B.C. highlights an example of project innovation which often encapsulates technical innovation. Thus the creativity or novelty on this project is one relating to business process or operational re-engineering and innovation which may not necessarily be highly technical in nature. The project was environmental in nature and involved the replacement of 2 old ship loading machines (shiploaders) having spillage and associated environmental

problems with the construction of a new 5,000 tonne/hr shiploader operating on a pile supported pre-cast quadrant beam.

Procurement Mode

The procurement mode adopted was one of the variants of the **traditional procurement process** - an initial Value Engineering (VE) and later a negotiated contract on engineering and construction management.

Westmar Consultants Inc. was retained by Pacific Coast Terminals Co. Ltd. (the project owner/client) to conduct a peer review of a proposed solution to contain the spillage from the two existing machines. The proposed solution consisted of constructing a new sheet pile wall in front of the marine berths and then backfilling under the existing ship loaders behind the wall so that all spillage could be contained. The proposed remediation design was estimated to cost in the order of $6 Million.

Innovation

The project innovation was the design and construction of a new ship loader that replaced two travelling shiploaders at Berth 1 and 2 and allowed the construction of a new dedicated liquids loading station at Berth 1. To facilitate the new shiploader, four new high capacity berthing dolphins and a new 550 ft. long by 70 ft. high feed conveyor were constructed. The new one-machine shiploader had greater loading rate and capacity than the two original machines and complied with environmental regulatory requirements whilst at the same time freeing the space originally used by the second shiploader for expanded operations.

Benefits

Although the capital cost of approximately $20million was more than double the estimates based on the initial design, the innovative solution has generated significant savings in operation and maintenance costs, with a good return on capital and a positive and significant return on the invested capital. The new shiploader complies with all environmental regulations, contains all spillage and is equipped with an automated clean-up system. The original proposed containment solution while requiring a lower capital investment provided no return to the owner.

There has been increased quality and improvement on operational performance and productivity. The new process is less labour-intensive and has greater loading rate.

Driving Conditions

The project innovation has come from adopting a whole-of-life approach to the process achieved through a trade-off between capital and life-cycle costs and walking the client through the innovative solution to adopt a different mindset or thinking with regards to the risk associated with innovation implementation. This is however driven by bringing different knowledge bases and experiences to bear on the process as a creative solution proposer and having the technical competence and authority to focus on the business/ operational perspective rather than on a narrow technical view.

Methods to improve traditional delivery modes to encourage project innovation

- Value Engineering (VE) – can be a good tool to force critical thinking and comprehensive work. Even if VE is not a requirement of the main procurement process, its application

internally by project teams as a check on completeness and appropriateness of project bids can drive value and innovation.

- Alternates – encouraging the inclusion of alternate approaches and concepts in bid documents can drive innovation in a traditional delivery mode. Clients must however be prepared to pay for the cost to evaluate alternatives critically in order to meet project requirements and constraints and not be restrained by budgets.

APPENDIX D: Interview with Expert 3 - Stantec Program & Project Management

Stantec Program and Project Management provides professional project management, design, and engineering solutions/services for all types of facilities and infrastructure projects to both public and private sector clients undertaking capital project programmes. In its pursuit of technical excellence and creativity in managing projects, Stantec has identified certain key factors and conditions (drivers) critical to achieving project success, innovation and efficiency improvement, and are discussed briefly, at a higher level, under the following subheadings:

- **Project Objectives**

The setting of project objectives should be expanded beyond just specifying the usual project costs and schedule targets, to include the definition of hard tangible and clear deliverables on what is being built and/or achieved vis-à-vis the proposed structure's functionality to incorporate the expectations of not only the client, but also the input of potential end-users of the facility. Often times project objectives are not effectively and comprehensively defined at the outset, creating a situation where the putative on-time, on-budget objectives drive the process unequally at different project phases. This can then lead to mushiness of the design and construction processes. Also the interests/objectives of various project parties must be fully aligned to a set of clearly defined project objectives.

- **Project Planning**

Much time is often spent on the "what" of the project (i.e. concept design drawings, outline specifications, cost estimates) leading to a near-neglect, inadvertently, of the "how" of the project (i.e. the implementation of the "what") – the project structure, how it will be done, who takes the decisions, the procurement strategies etc. Unfortunately most projects lack proper project plans. "A client through their project manager must have the discipline to plan the project".

- **Project Risk Management/Mitigation**

Risk management from the client's perspective should be about reducing and mitigating risks inherent in the project, and not a complete transfer of them to another party (usually a general contractor) who in turn sees risk as a premium charged back to clients. There must be a change in client perception of certain risks not as contractor responsibility but rather as a project responsibility. Unmitigable risk should then be placed with the party or parties best able to manage it. The risks usually inherent in innovative concepts and methods can be managed through the holding of formal risk management processes and meetings involving all parties for a greater understanding of the risks, the challenges and their implications.

- **Value-Based Team Selection**

Project team selection must be based firstly, on value before fees and price. In the selection of design consultants and contractors, fees and prices must be set against the experience, credentials and track record of the firm as an organisation capable of delivering projects. "The goal must be to select the right team members, at the design stage, with the right experience and capabilities, and at an appropriate fee, to reduce the overall life-cycle cost of the project", i.e. creating the right incentives and rewards to drive and maintain a high team motivation necessary for creativity.

- **Integrated Team**

In most construction undertakings, unlike in other industries, design is separated from production, limiting the potential for cross-learning and interactions among the different project teams. Early involvement of builders and suppliers in the design process can create value-based design decisions and concepts in an ambience of partnership. Early lock-in of sub-trades and suppliers can avoid or abate the impacts of labour and material shortages – a major component of the causes of recent project cost escalations.

Case Study: BC Cancer Research Centre

Project Background

The BC Cancer Research Centre (shown in Figure 1 on the next page), located in Vancouver, British Columbia, is a $95-million facility which provides 230,000ft^2 of new research and clean room laboratory space for leading-edge cancer research. The project client is BC Cancer Foundation, with Ledcor Ltd., a local construction firm, acting as construction manager/general contractor. Stantec provided full project management services to the client. Project was completed in December 2004 in a 32-month construction schedule for a spring 2005 opening.

Decision-Making and Procurement Processes

The project took off with an initial 6-month project planning phase during which design and structural consultants where hired. Other key activities in this phase included a review of an original programme constituting the initial project concept and the development of a project implementation plan (i.e. what the project is, what is to be achieved, schedule/budget programme as well as funding and other approval processes) to produce the overall project document. Part of that process also included conducting risk management and organising full discussion sessions with the client and other project stakeholders (BC Cancer Agency, Canada Foundation for Innovation (CFI), and Provincial House Services Authority) to satisfy every one of their requirements. Being the first major project of its type and size in the province, the complexity (in terms of its technical systems) of the BC Cancer Research building project limited the use of the traditional sequential design-bid-build procurement process. The constructor and mechanical/electrical trades were initially brought on-board at the design phase to provide preconstruction services at negotiated fees on competitive selection bases. The role of the constructor was initially that of a construction manager (CM) – though not a pure CM contract - until all the CM structures were in place at which point it was converted to that of a General Contractor (GC) using a modified CCDC2 for a negotiated fee and allowances all with the objective of mitigating project risks. An open-book tender approach and subsequent negotiation adopted for contracts with the trades led to a final contract in a far more transparent process than the traditional tendering process.

Specific Innovations and Technical Excellence

The project had simple clear objectives to build one of the world's most advanced state-of-the-art cancer research facilities and create an environment that will be a research home for scientists. The building's functional objectives included, *inter alia*, an adaptability of lab space to serve multiple functions and research types through its lifecycles as well as having the flexibility to meet changing lab use requirements as funding and researchers change with time.

1) Design (Product) Innovations:

The product innovations can be described as the results of incremental smart engineering (particularly in the Mechanical/Electrical aspects) and use of LEED rating system for sustainable

building design. Spatial innovations incorporated a concept that partitioned the building into a respective 1/3:2/3 layout for offices and laboratory and in effect having two buildings in one. The idea was initially driven, in part, by limitations of the building's footprint from a regulatory perspective and identified during the initial project planning process. The structure has reduced floor to floor heights for office areas allowing 2 office levels for each laboratory/interstitial floor and novel open-plan labs (see Figure 2) representing a philosophical shift in the way the building's end-users will interact with one another when working. Physical component innovations include the following mechanical air conditioning systems among others:

- Use of variable fume hoods instead of conventional constant volume fume hoods to assist in reduction of outside air required leading to less energy to cool/heat intake air
- Use of operable windows in offices for natural ventilation (see Figure 3) and a helix staircase using motorised operable window for natural ventilation
- Use of low-flow toilets and waterless urinals in washrooms
- Installation of bifurcated strobic fans instead of conventional fans on the roof ensure air exhausted 30' above roof top leading to a reduction in stack height requirement and enhanced visual aesthetics.

2) Construction (Process) Innovations:

The project schedule drove the innovations realised in the construction methodologies adopted.

- The interstitial spaces (floor-to-floor heights) were such that the use of traditional formwork would have prolonged the project by 6months and this condition drove the contractor to come up with an innovative way of doing formwork leading to a flexibility in the length of the formwork employed.
- Construction process included a change from a one-crane system to a 2-crane anti-collision system in a controlled tight construction environment using computer simulations.
- Use of offsite pre-fabrication techniques/methods, where applicable, leading to a reduction in the number of work trades in a controlled environment.

3) Organisational/Contractual Innovations:

- Collapsed the supply-chain such that key suppliers and trades had a fundamental involvement in the design process, using a partnership approach to tap the expertise of trades and suppliers.
- Periodic review of the delivery process to encourage team work, similar to a partnering agreement.
- Implementation of an integrated risk and change control system to manage issues as they came up, e.g. monthly risk management meetings involving all project participants.

Benefits of Innovation

- Substantial project completion achieved 1 day ahead of schedule.
- 8% under the initial $95-million budget.
- Smooth construction process and relationships achieved among parties, thus avoiding the sometimes complex and challenging contractual discord associated with constructing high-rise concrete buildings.
- The first building in Canada to place GLP animal facility, a barrier facility and Cesium treatment all under one roof.

Figure 1: SE Elevation

Figure 2: Lab Detail

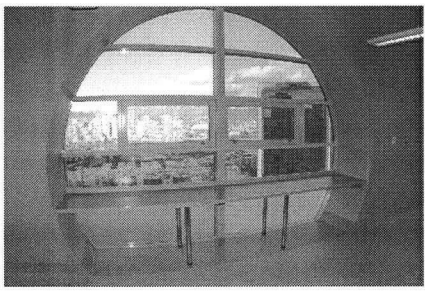

Figure 3: "Petri dish"-shaped Lab Window

Other References:

Kennedy, M. *Head: On Budget, On Schedule,* Design Quarterly, spring 2005, Architects in B.C.

Stantec Consulting, Keen Engineering, The RADA Group and Glotman Simpson. *BC Cancer Research Centre,* Document submitted to Consulting Engineers of British Columbia (CEBC) - 2005 Awards for Engineering Excellence. January 2005, 11p.

APPENDIX E: Interview with Expert 4 – Ledcor Ltd.

Ledcor ltd. provides professional project management, design, and engineering solutions/services for all types of facilities and infrastructure projects to both public and private sector clients undertaking capital project programmes. The role of Ledcor on an institutional building project as well as the innovations/efficiencies achieved and the controlling factors on the project are discussed below.

Case Study: UBC Life Sciences Building Project

Project Background

The UBC Life Sciences Building (shown in Figure A), located on the Point Grey Campus of the University of British Columbia (UBC), Vancouver Canada, is a new university medical teaching and research facility which includes a variety of laboratories, lecture theatres, classrooms, seminar and reading rooms, administration offices and a major vivarium. The project client is University of British Columbia, with Ledcor Ltd. acting as **design-assist Construction Manager** to fast-track the design and construction activities.

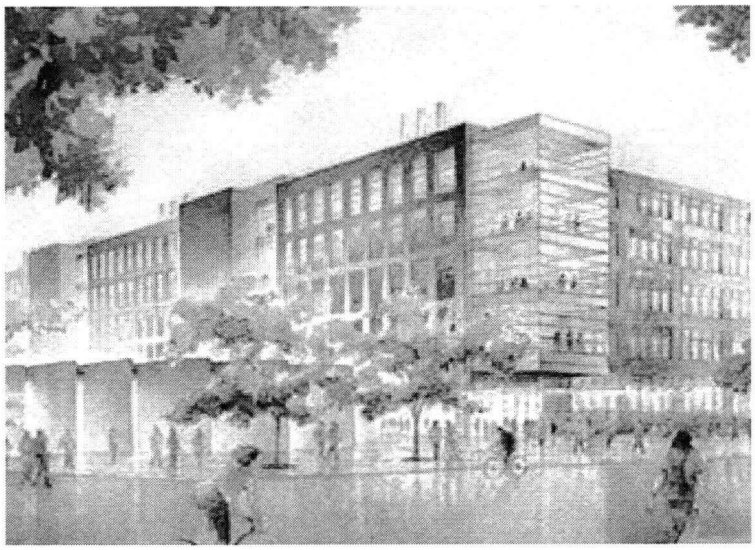

Figure A: An architect's rendering of the UBC Life Sciences Building (Source: www.ledcor.com)

Decision-Making and Procurement Processes

Ledcor Ltd. was brought on board within a week of the architect selection and participated, along side the architect in the selection of consultants. Building design started in March 2002 and Construction commenced 4 months after. One of the major drivers of innovation and efficiency was the early involvement of a contractor to provide pre-construction input and services during the design phase.

Specific Innovations

Design (Product) Innovations

Structural Systems:

Imposed structural system rules that allowed columns to start from the foundation and run to the roof with workings around them and no transfers. Achieved a lateral load resistance system from the foundation to the roof and was well-distributed through out the building. This was meant to avoid the occurrence of any eccentricities or the payment of a premium to have the centre of resistance of the building located differently from its centre of mass. Structural proceeded well in advance of the architectural process. Devised a way of fitting lab modules into floors by making the floors a bit wider (still achieving maximum illumination), and thus saving almost a storey. The modularised labs created repetitive work and significant cost savings. The design of the atriums – from a sustainability perspective – created more usable space in a more economical manner by minimising ratio of surface area to enclosed area to minimise energy loses to achieve cost savings. For the typical floor spaces, long-span functions were outside of the short span functions.

Mechanical/Electrical (M/E) Systems:

Well-distributed M/E distribution systems - mechanical rooms were placed in the basement for easier access through big shafts, in order to avoid building the structure to the roof before starting mechanicals systems whose activities were on the critical path. This led to a better control of the total project schedule and created lots of room for working. The air-handling system was broken down into 34 independent air handling units to provide flexibilities of their installation and workings. Different units served different uses – separated air systems for the offices and for the labs. The integrated mechanical and structural systems in the lab spaces with the help of the structural design resulted in an optimum floor to floor height with minimal interferences.

The building envelope consisted of simple details with good quality materials which made it cheaper and most economical to maintain from a life-cycle point of view the most.

Organisational/Contractual Innovations

Unlike other institutional clients having a bureaucracy of small groups of designers controlling the project design process with no ties to the budget or the facility's long term performance, the process for the Life Sciences building adopted more of a private-sector approach where the most efficient and effective solutions from the life-cycle cost perspective (e.g. the selection of mechanical equipments) were adopted.

The project adopted an innovative contracting method - breaking up contracts to have smaller private sector contractors building the facility and not large institutional firms who often demand a premium for their services. This contracting approach was adopted to increase competition, which also enhanced the design team's work, e.g. contracting separately for several of the various mechanical and electrical works.

Benefits of Innovation

- Facility was built at about $75/sq ft which less than the industry average.

Table A: Influence or relevance of factors in driving/inhibiting innovation

Factor	Impact/Influence on Innovation	Comments
Source of Competition	Little impact	Local team of designers, and constructors, although Ledcor is international in its outlook.
No. of Competitors	No impact	Ledcor got the job first, based on its team of people
Opportunities for other projects of similar type	No impact on the process	Architectural and structural components are project-specific, as conditions and market change with time
Project Scale	Driver	More scale gives time to think about alternatives solutions to problems. Building was a large one.
Project Type	Driver	Dealt with the client only, user input, with a broad spectrum of people
Proposal Evaluation Criteria	Driver - very important	Budget , schedule and utility drove the process, and outweighed aesthetics,
Penalties for inadequate performance	Little significance	Project built through lump sum competitively acquired trade contracts with a schedule that came with them, contracts had clear certainty on schedule with a month or two of contingency estimate, no liquidated damages for delay clauses, as the owner's agent Ledcor had no contract with trades, no penalties
Reasonableness of risk assignment	Driver	Appropriate risk transfer with the right incentives to encourage risk taking.
Certainty of stakeholder environment	Driver	Senior people from UBCPT involved and empowered CM to sometimes challenge design and construction propositions, particularly on their cost implications
Certainty of Regulatory Environment	Inhibitor	Challenged UBC's bureaucracy, standards and codes, used competitive national standards
Certainty of Political Environment	Driver	Comfortable with the client, sure to get the project built before any possible change in government
Certainty of Economic Environment	Driver	Stable economic environment, very important

Natural Environment Risks	Little significance	Benign risks - nice site, without much contamination, relatively unconstrained site with good soils
Process risk	Driver	Good environment – construction, procurement processes, brought in a lot discipline as to the way the building was organised.
Project team	Major Driver	Closer interaction among team members in finding the best solution for a problem, not big institutional players
Requirement for broader socio-economic benefits	Driver	Helping to create more doctors and that made a difference from the perspective of the public
Performance requirements	Driver	Strict technical, schedule and budget requirements that were initially perceived to be unachievable