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CHAPTER ONE

INNOVATION AND SUSTAINABILITY

Aminah Robinson Fayek, Keith Hampson
Joint Coordinators, CIB Task Group 58: Clients and Construction Innovation

We are pleased to introduce this volume of papers presented at the workshop of the CIB Task Group 58: Clients and Construction Innovation, held on May 18-19, 2009 at the University of Alberta in Edmonton, Canada. The workshop theme, “Leveraging Innovation for Sustainable Construction”, reflects a growing concern among clients for perspectives, approaches, and tools that will secure the practice of construction economically, socially, and environmentally. We believe this collection encompasses some of the most incisive assessments of the challenges facing the construction industry today from a range of researchers and industry practitioners who are leading the way for tomorrow’s innovations. We hope it will be a useful documentation of the ongoing conversation regarding innovation and sustainability issues, and provide a foundation of knowledge for future research and development.

Our sponsors and supporters merit special mention. Our thanks go to event sponsors at the University of Alberta: Office of the Vice-President (Research), Faculty of Engineering, and Department of Civil and Environmental Engineering. We would also like to thank the National Research Council – Institute for Research in Construction, Canada for sponsoring the travel of our speakers and contributors.

CIB, the International Council for Research and Innovation in Building and Construction, was established in 1953 with the support of the United Nations to promote and assist international cooperation and information exchange in technical research in the built environment. This institutional body has now developed into a
global network of over 5,000 experts from as many as 500 member organizations active in research, industry, and education.

CIB comprises over 50 commissions and task groups covering all fields in building and construction research and innovation. Task Group 58: Clients and Construction Innovation engages industry clients and the research community in identifying client needs, determining mechanisms for client engagement, examining the motivations for innovation, improving communication between sectors, and developing feedback processes for construction performance. Since its launch in October 2004, Task Group 58 has been actively identifying leading industry case studies and synthesizing research in public and private sectors globally.

The papers contained in this volume explore the workshop’s overarching theme of how to leverage innovation to increase the sustainability of the construction process and product. Participants sought to generate discussion on the topics of innovation and sustainability within the construction field, to share international examples of innovation from the research community and from industry, and to establish a point of reference for ongoing enquiry. In particular, our contributors have noted the value of learning through practice in order to orient research based on real-world industry experience. Innovation and sustainability in construction are truly global efforts; these papers illustrate how we can draw on international examples and cooperative organizations to address these important issues for the long term benefit of the industry.

Chapters two and three present complementary models of sustainable research programs through the three part collaboration of government, industry, and academia. In his paper “A Sustainable Industry R&D Program,” Dr. Keith Hampson presents the Australian experience of drawing together industry, government and researchers, to improve investment in research and development and increase Australia’s innovation performance among other nations. Dr. Stephen Thomas emphasizes the value of pooling expertise to support innovation in his presentation of “The CII Model for Industry and Academic Collaborative Research.” Sustainability, through this view, takes a holistic approach to the process of planning, constructing, operating, and decommissioning capital projects to meet business objectives while serving current and future human and ecological needs.

Chapters four and five explore new tools and forms of technological innovation as they are deployed to improve construction project management and set the direction for advances in research. In their work on “Using Fuzzy Logic and Simulation Technology to Deliver Innovation to the Canadian Construction Industry,” Dr. Aminah Robinson Fayek and Dr. Simaan AbouRizk address the challenge of creating solutions that are practical for construction problems as they occur, while continuing to advance the state-of-the-art in construction engineering and management practice. A research agenda based around simulation modeling and fuzzy logic is developed to integrate the real world with the simulated one to explore the effects of innovation on construction systems. The sharing of
information as it relates to policy development is discussed by George Gritziotis of the Canadian Construction Sector Council (CSC) in his paper, “Policy/Program Solutions Through Leveraged Innovative Forecasting Techniques.” The CSC’s Labour Market Information (LMI) Program represents an industry-driven effort to collect and deploy information regarding the labour market as relevant to all construction stakeholders. Knowledge in the construction sector must continue to be adaptable, inclusive, and collaborative.

Chapters six, seven, and eight closely study practical examples of innovation in large-scale construction projects, showing with concrete results the impact of applying creative methods and best practices to the field. John Brogly discusses the role of the Construction Owners Association of Alberta (COAA) in his paper “Development and Delivery of Best Practices in the Alberta Construction Scene.” Working to address the needs of owner-members directly, the COAA has provided leadership in safety, workforce development, productivity and contracts, to ensure the effective delivery of construction projects. Innovative approaches to project planning also create opportunity for sustainable construction, as presented by Peter Diedericks in his paper on Petro-Canada’s strategies for “Optimizing Winter Construction.” By focusing on the entire life cycle of a project, Petro-Canada has been successful in adopting novel technology such as construction domes, to better control work environments and secure advantages of the winter window for resource construction. The structure of a project’s management also offers a significant setting for innovation, as Dr. Roger Woodhead discusses in his presentation on “The Canada Line Rapid Transit Project.” The structure of contracting, as with other processes associated with construction, creates communication challenges that can be addressed through fresh strategic approaches. Key partnerships between public institutions and private companies enable purposeful direction and application of knowledge to these large-scale projects.

Other presenters discussed the importance of fostering innovation as part of overall economy- and industry-wide sustainability. Dr. Russ Thomas, Director of New Initiatives for the Institute for Research in Construction (IRC-NRC) in Canada, discussed the role of codes and regulations in creating opportunities for innovation by establishing industry standards, minimizing risks, and raising the level of performance in industry outputs in his presentation on “The Role of Innovation in the Canadian Construction Sector”. Dr. Ric Jackson, Director of FIATECH, discussed the value of sharing of intellectual property, open access, and integration to leverage knowledge for innovation in the construction industry in his presentation on “Technology, Innovation, Wikinomics, and Steroids (or, How to Run Fast).” Through Wikinomics, which employs openness, peer sharing, and acting globally, researchers can leverage their knowledge to identify key standards in the industry and accelerate their development.

The value of supply chain collaboration and knowledge-sharing is critical for the advancement of the construction industry. Clients have significant influence on the
innovative behavior of all parties to the construction process. Historically, the industry has focused on its own segment in the development cycle, limiting the access of other stakeholders to information on project outcomes and lessons learned. This lack of knowledge sharing has, in turn, hindered potential improvements in methods, tools, and policies supporting construction innovation. The expanding reach of construction projects—both in scope and impact—encompasses researchers, public bodies, government, and practitioners. There is therefore a greater need for partnerships and collaboration between these groups and across the industry supply chain and beyond to enhance the innovativeness and sustainability of the industry.

The current global economic downturn provides us with a unique opportunity to re-focus on industry-driven research and development, building more innovative practices for a stronger future. Increasing competitive pressures, both nationally and internationally, provide a stimulus for innovation, which would add greater value to the client and enable organizations to increase their efficiency and effectiveness. During this period, innovative and sustainable developments will help ensure a smooth transition into market recovery, but with improved processes, systems, and skills.

There remains a need to focus on the effective deployment and implementation of innovative practices. In order to reduce the risk to organizations of adopting innovations, we must develop better methods of measuring and benchmarking project performance to demonstrate the benefits of innovation. Validation of innovative practices through practical metrics, case studies, and data is key to industry acceptance and adoption. We have witnessed the value of leveraging innovation through national and international bodies. It is also time to become individual champions, developing and strengthening personal networks for collaboration and communication. In this way, the learning of the past can be captured together with the opportunities of the future. In isolation, a good idea quickly falls silent; but together, our good ideas echo across great distances and reach heights yet unknown.
CHAPTER TWO

A SUSTAINABLE INDUSTRY R&D PROGRAM

Keith Hampson, Ph.D., RPEQ
CEO, Cooperative Research Centre for Construction Innovation, Australia

Abstract

The current global economic climate has focused the attention of construction practitioners on the benefits that applied research can deliver to their business. This paper draws on the history, achievements and lessons of the Australian CRC for Construction Innovation—the first national R&D and implementation centre servicing Australia’s built environment industry. It then explores the model of its planned successor - the Sustainable Built Environment Centre as industry, government and research stakeholders seek a stronger engagement in a more environmentally, socially and economically sustainable future.

1 Introduction

Australia faces major challenges to modernise the environmental, social and economic performance of its infrastructure and buildings to meet increasing demands for more sustainable communities. The nation’s built environment industry has entered a period of unprecedented challenge as it: maximises national returns from infrastructure investment and economic stimulus packages; seeks to reduce carbon pollution and adapt to climate change; and maintains competitive advantage during the global financial crisis and beyond. This industry contributes the greatest value-add to Australia’s GDP of any industry, making it the most
efficient conduit for national economic growth. Government stimulus investments positioning the industry at the forefront of the nation’s recovery strategy must be used effectively, efficiently and sustainably to mitigate long-term underinvestment in national infrastructure. These challenges also increase pressure on the industry’s predominant small-to-medium sized enterprise (SME) base to improve traditionally poor innovation, safety and productivity rates and build new skills and business opportunities in the emerging sustainable built environment economy.

This paper is structured by first providing a background to the Australian built environment industry; followed by a brief examination of the need for applied research and education in this industry. Next, the evolution of Australia’s Cooperative Research Centre (CRC) for Construction Innovation into the Sustainable Built Environment Centre is described in terms of the existing and planned future centre activities and its partner expectations. The paper concludes by proposing a number of observations about a sustainable R&D program based on the Australian experience.

2 Background – Australian Built Environment Industry

The Australian built environment industry (incorporating property, planning, design, construction and facility management) employs around one million people through 365,000 businesses (82% of which are SMEs; ABS 2007), and earns $100 billion annually.

The built environment industry is one of Australia’s most important industries and an integral part of the national economy, contributing significantly to the rest of the Australian economy as an enabler. It is also a key contributor to Australia’s well-being and progress and has a major influence on every citizen. It provides the homes in which we live, the places where we work and play, our schools and hospitals, and the infrastructure essential for day-to-day living such as roads, hospitals, schools, water, electricity and telecommunications. The Australian Bureau of Statistics estimates that from an initial $1 million extra output in the construction sector alone, $2.9 million in output could be generated in the economy as a whole.

Yet there is an acknowledged underinvestment in national infrastructure as evidenced by recent analysis (Coombs and Roberts, 2007) contained in the Australian’s Government’s Budget Strategy and Outlook 2008-09. The average age of Australia’s public sector infrastructure has been rising since the 1970s, providing support for the view that Australia is approaching, or past, the point where much of the public infrastructure delivered in the 1950s and 1960s will need to be renewed or replaced. For example, in 1978 the average age of public infrastructure was 15 years and in 2006 this average age had risen to 20 years. A survey of a wide

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1 The construction industry has the highest number of SMEs compared to other industries. A small business is defined as employing less than 20 people. (ABS, 2007)
range of comparable countries indicates that while Australia is slightly above the OECD average in terms of the perceived ability to support economic activity, it is below the average of leading advanced economies, in part due to its aging infrastructure (World Economic Forum, 2007).

Traditionally, the building and construction industry has been characterised by a culture of being slow to research and innovate. The industry also has a notorious record of adversarial relationships and an identified need to improve its safety and productivity performance and respond more effectively to adapt to climate change. Today’s internationally competitive environment demands a smarter approach. The work of Australia’s CRC for Construction Innovation has addressed these challenges, lead cultural change and delivered real benefits to its partners, the industry and the Australian community. However this Centre’s charter of service will come to a close in 2009.

3 The Need for Applied Research in the Built Environment

The CRC for Construction Innovation was a key outcome of a partnership between the former Australian Government and industry in a collaborative effort that reviewed the challenges to industry competitiveness through the Building and Construction Industries Action Agenda (2000). The subsequent Action Agenda Evaluation Report highlights the winning of this CRC to service the Australian property, design, construction and facility management industry as an outstanding outcome comprising one of only four major outcomes, with the imperative that the CRC continue to service this critical industry. Prior to the formation of Construction Innovation, there was no national research and implementation centre engaging industry, government and universities across the nation. Since the Building and Construction Industries Action Agenda, a further two industry Action Agendas—the Facilities Management Action Agenda (2004) and the Built Environment Design Professions Action Agenda (2008) reinforced the industry’s need for a consolidated national applied research centre.

Independent of these Action Agendas, throughout 2003 and 2004, Construction Innovation facilitated a pioneering foresight exercise involving an extensive series of national industry workshops and interviews with industry leaders and key participants across the built environment supply chain. In this collaborative process with the major industry associations, industry’s views on the future challenges and required research were sought. The subsequent report, Construction 2020: A Vision for Australia’s Property and Construction Industry (Hampson and Brandon, 2004) highlighted the following Construction 2020 Visions for the industry’s future:

1. Environmentally sustainable construction
2. Better meeting client needs
3. Improved business environment
4. Welfare and improvement of the labour force
5. Information and communication technologies for construction
6. Virtual prototyping for design, manufacture and operation
7. Off-site manufacture
8. Improved process of manufacture of constructed products.

Blended with the identified needs of investing partners to the CRC for Construction Innovation, these visions strategically informed the development of the applied research focus of the Centre and served to secure a stronger and more comprehensive base of industry support. This Construction 2020 initiative and the extensive stakeholder engagement activities throughout the two-year process served to consolidate support from the industry associations, especially those forming the Australian Construction Industry Forum (ACIF), comprising 13 organisations representing almost 200,000 individuals across the industry supply chain. This broader and strategically important engagement was considered critical in the industry partnership central to creating a cultural change to embrace research and innovation.

![Outcomes for Industry and the Community](image)

**Sustainable Built Environment Cooperative Research Centre**

*Transforming the Property and Infrastructure Industry*

- **Environmental**
  1. Environmental Impact of Existing and New Facilities
- **Social**
  2. Health and Safety
  3. Skills Development
- **Economic**
  4. Procurement
  5. Productivity

*Through Digital and Process Technology Improvement*

*National Frameworks, Measurement and Reporting*

**Figure 1. The CRC for Construction Innovation**

As an update to this process, Construction Innovation facilitated a fresh National Industry Stakeholder Forum in 2007, bringing 50 industry, government and research leaders together in Sydney. This Forum provided a mandate for Construction Innovation to develop a bid for the upcoming new CRC Program funding round with the triple bottom line research and implementation agenda based on environmental, social and economic sustainability.

On the basis of this affirmation of industry and government research user needs, Construction Innovation sought stakeholder investors across the supply chain and,
together with leading international research agencies as supporting research and innovation partners, developed a comprehensive national bid for the _Sustainable Built Environment_ Centre, and submitted an application to the March 2009 funding round of the Australian Government’s CRC Program.

Coinciding with the industry momentum for this initiative, Australia’s Minister for Innovation, Industry, Science and Research, Senator Kim Carr, highlighted (18 March 2009) the need for Australian research groups to create cooperative networks of teams and individuals and to be active participants in the global knowledge economy and innovation system. One of the new Australian Government’s 10 ambitions for research and innovation was to _double the level of collaboration between Australian businesses, universities and publicly funding research agencies over the next decade_. In particular, Senator Carr promoted the need for forging partnerships with public sector researchers to achieve a 25% increase in the proportion of businesses engaging in innovation over the next decade, and the continuing increase in the number of businesses investing in R&D.

Against this backdrop, the global financial crisis has sharply increased pressure on governments as they implement reforms of planning, funding and regulating infrastructure and building construction internationally to counteract the global slowdown. In Australia the Federal Government is introducing a comprehensive national approach to the provision and delivery of infrastructure which has traditionally been the responsibility of the states. The Federal Government has made more efficient delivery of national infrastructure a critical element in its plan to stimulate business and protect jobs in the current global economic downturn.

4 **Construction Innovation** evolves to **Sustainable Built Environment**

*Construction Innovation* has led Australia’s built environment research and helped shape national industry development over the last eight years. During its term, the Centre has grown from 19 partners in 2001–02 to 27 in 2007–08 and doubled its initial partner investment. Its collaborative teams have delivered 70 research projects, and produced over 300 publications, including 25 books, 97 refereed journal articles, 215 refereed conference papers. In education and training, the Centre facilitated _research into practice_ training to more than 10,000 individuals and supported 24 research higher degree graduates, including 18 PhD completions. Highlights of the research and implementation achievements of the CRC for *Construction Innovation* include the examples in the table below.
The newly developed Sustainable Built Environment Centre is a direct response to the urgent need articulated by industry and government for targeted sustainability solutions to address real industry challenges and to follow the national success of the CRC for Construction Innovation. Sustainable Built Environment plans to undertake key activities in sustainability, health and safety, productivity and procurement research and education to underpin the existing momentum for transforming industry culture.

Figure 2. The Sustainable Built Environment CRC

The Centre will bring together leading research teams and individuals across Australia and internationally. It will be a world-leading model for industry-ready R&D, providing the scientific foundations and supply chain collaborations to deliver key research and education outputs of national interest through five Programs and supported across three National Exemplar Projects as illustrated (Figure 2).

<table>
<thead>
<tr>
<th>Research Outputs</th>
<th>Utilisation</th>
<th>Benefits</th>
</tr>
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<tbody>
<tr>
<td><strong>Your Building</strong> provides up-to-date online information on industry best practice in sustainable commercial building design and facility management.</td>
<td>Around 600 registered end-users include Asset Owners, Developers, Designers, Contractors and Facility Managers.</td>
<td>Your Building users have reported significant productivity improvements in using the industry best practice resources.</td>
</tr>
<tr>
<td><strong>LCADesign</strong> is a software tool that can automatically calculate and chart the environmental impact of construction materials and building products.</td>
<td>LCADesign has been trialled in the USA, Europe and Australia to optimise the environmental impact of commercial buildings at the design stage of their life cycle.</td>
<td>LCADesign assists users to reduce greenhouse emissions, air and water pollution, and saves energy through its assessment of building designs.</td>
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<td><strong>The Sydney Opera House Facility Management Exemplar</strong> project showcased digital modelling technologies in one of the world’s busiest performing arts centres.</td>
<td>This project demonstrated that seven existing (and incompatible) IT systems could be consolidated to one 3D digital model, allowing greater security and cost-effective facility maintenance.</td>
<td>The benefit of this work has been valued at $78 million over 10 years in maintenance cost savings on the Sydney Opera House. This project has underpinned a national training program and won national and international industry awards.</td>
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<tr>
<td><strong>This Construction Safety Competency Framework</strong> was designed for safety managers and senior managers to more effectively deliver safety management programs nationally.</td>
<td>Training packages and learning tools are available to VET, industry and other training institutions, better equipping the industry to understand safety culture and improve the industry’s overall safety performance.</td>
<td>Construction Innovation has created an unprecedented national alliance of industry, government and researchers committed to saving lives and preventing injuries on Australia’s construction sites, across state and territory jurisdictions.</td>
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</table>

The proposed Centre’s 36 participants include the nation’s peak industry associations and training groups to provide effective utilisation pathways to industry SMEs and ensure uptake of Centre outputs by end-users. The Centre’s
ability to drive improvements in industry’s sustainability performance will be achieved through reforming public policy, developing industry standards and promoting best practice for ecological modernisation. The Centre intends to coordinate a major cross-sector initiative to deliver global sustainability research outcomes and package them for Australian industry through an innovation exchange network with a particular emphasis on SMEs.

The new Centre’s research, education and utilisation strategies will deliver significant impacts including: increased performance of built assets, reduced greenhouse gas emissions, increased industry productivity, innovation, safety and skills development.

To showcase applied research outputs and facilitate knowledge exchange, the proposed Centre will focus a significant component of its research and development on three high profile capital works and property portfolio projects – in health, education and transport. The Western Australian Princess Margaret Children’s Hospital, Victorian Schools Plan, and Gold Coast Rapid Transit Project in Queensland will serve as National Exemplar Projects for the Centre and facilitate a research-in-action approach across Program activities. A number of smaller demonstrator projects across the country, including the Sydney Opera House and Queensland High Court Building, will also validate technologies and research findings in other real life settings.

5 Conclusions

Around the world, nations are grasping infrastructure and building renewal as well as grants and tax incentives to boost economic activity and maintain jobs. Additionally, the goal of improving productivity and strengthening industry to effectively deliver nation-building assets for long term economic prosperity requires a complementary investment in national research and education. The model of industry, government and research participants collaborating in applied research and education through a cooperative research centre is one such mechanism – and one that can provide long-term national benefits – raising the sea-level of industry performance to better deliver more sustainable communities.

Global market challenges, climate change, new technology and rising client expectations are stimulating a radical rethink of how the Australian built environment industry can be re-engineered to enhance its performance. The Australian CRC for Construction Innovation provides a leading model for change - working at the interface of industry, government and research at a national and international level. The value derived from the CRC initiative is significant—its partners derive value directly from the applied research outcomes, technology diffusion and leadership offered through participation in the CRC; industry benefits through broader technology diffusion and up-skilling especially through strategic activities with industry associations; and the community benefits from economic growth fuelled by innovation in an industry that is shown to be
influential in leading the economy in innovation-stimulated growth. The tripartite collaboration between industry, government and research is developing a robust national research and innovation capability delivering real value to its stakeholders.

The Australian built environment industry is on the cusp of a new era in realising the benefits of a close industry, government and research relationship for stronger national and international performance through improved innovation. The evolution sought for the Australian CRC for Construction Innovation into the Sustainable Built Environment Centre will test stakeholders in their resolve to provide a long term base for this initiative to deliver a more environmentally, socially and economically sustainable future.

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CHAPTER THREE

THE CII MODEL FOR INDUSTRY AND ACADEMIC COLLABORATIVE RESEARCH

Stephen R. Thomas, Ph.D., P.E.
Associate Director, Construction Industry Institute, USA

Abstract

As the Construction Industry Institute (CII) celebrates its 25th anniversary as a major forum for collaborative research for the construction industry, it is appropriate to review some of its major accomplishments and challenges. Dr. Stephen R. Thomas, P.E., CII Associate Director with oversight of the institute’s research process provides an overview of the CII research model based on industry and academic collaboration and includes some assessment of research accomplishments and challenges. In particular, he will address research successes that have lead to breakthroughs in project safety, front-end planning, constructability, and workforce issues. While the impacts of more recent research for enhancing innovative practices and advancing sustainability have yet to be proven, Dr. Thomas will also present CII early research in these areas as potential new breakthroughs for transforming the industry.

1 CII and Research in the Construction Industry

In the late 1970s, The Business Roundtable—the top 200 chief executive officers in the U.S. — took note of the staggering inflation and labor disputes that were
sending the nation’s economy into a deep, downward spiral. Construction, while contributing some eight to ten percent of the gross domestic product, had positioned itself as the top industry in the country at that time. But along with its poor safety record, construction found itself at the forefront of worrisome cost and schedule overruns and in the center of nasty standoffs between management and labor over wage demands.

Given the economic crisis at hand and the overwhelming fragmentation in the industry, The Business Roundtable commissioned a study — the Construction Industry Cost Effectiveness (CICE) Project — and over the next five years garnered the wisdom of 250 industry practitioners from more than 125 top companies. The Roundtable concluded upon completion of the CICE study in 1982 that the construction industry needed massive improvements — improvements that the industry itself could actually bring about. The Roundtable published 23 reports from the CICE Project, each report being printed and distributed over a million times. Over two hundred recommendations were offered, yet one was unique: establish an organization to pursue research in construction management and technology applications.

Construction leaders then compared their R&D efforts with other industries and found construction lagging woefully behind. The aerospace, pharmaceuticals, and automotive industries, for example, were pouring resources into R&D, with their research budgets averaging between three and seven percent of their sales volume. Practically no research in construction could be identified, however, and the very survival of the U.S. engineering and construction industry was brought into question.

Responding to the Roundtable’s recommendation for establishing a research effort, 28 charter members united in 1983 to form the Construction Industry Institute. The purpose of CII was to bring the major participants in the capital facility delivery process — the owners and the contractors — into a cooperative environment to fund and guide research. Academia, a third partner, would perform credible, quantitative studies of topics selected by CII members. The benefits would be shared with the industry at large. On October 28, 1983, at The University of Texas at Austin, CII was officially chartered with a two-fold mission: to perform research to improve the cost effectiveness of the industry, and to address the fragmentation of this huge and important industry. And now as CII reaches its 25th anniversary, it is a good time to review some of its successes and challenges and in particular, issues identified for companies as they attempt to become more innovative and embrace sustainability initiatives (CII, 2008).

1.1 The CII Research Model

CII Research is a unique, cooperative collaboration of owners, contractors, and academics to address and resolve high-priority problems faced by the capital facilities industry. Working together, they develop a mutual understanding of problems of the industry to identify practical and effective solutions.
CII has consistently adhered to highly credible research standards. The close partnership between industry and academia is a hallmark of CII research and differentiates CII research results from those of other professional groups. The research teams (RT), composed of representatives from the owner and contractor organizations and academia, refine the scope for the research effort, develop hypotheses, participate in data gathering and quantitative analyses, and provide the industry with credible research results covering a wide array of topics.

The CICE Project greatly influenced CII in the early days, particularly in the selection of initial research projects. Many topics investigated by the CICE Project were identified as high priority issues for CII, so it is no surprise that early CII research investigated safety, productivity measurements, constructability, contracts, design effectiveness, cost and schedule controls, and materials management. From its beginning with a handful of topics and participating universities, the CII research program has grown into a multi-million dollar effort. As depicted in Figure 1 and Table 1, with more than 115 member companies, most of which are Fortune 500 in size, and 55 universities that have contributed to the program, CII has had a significant impact on the construction industry.

![CII Membership Growth](image)

**Figure 1. CII Membership Growth**

Today, research at CII includes topics that have a large impact on major projects: scope definition, front end planning, risk allocation, and of course, safety. CII also examines related industries for possible
new insights. For example, CII funded research with the primary objective of evaluating practices and processes used by the shipbuilding industry’s global leaders in Asia to identify those practices that have made the greatest impact in enabling those industries to achieve lower costs and shorter delivery schedules. This research into the shipbuilding industry revealed that significant gains can be made through application of a product-oriented approach to construction projects.

Table 1. Participating Universities

<table>
<thead>
<tr>
<th>University of Alabama</th>
<th>University of Houston</th>
<th>University of Pittsburgh</th>
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<tbody>
<tr>
<td>Arizona State University</td>
<td>Idaho State University</td>
<td>Polytechnic University</td>
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<tr>
<td>Auburn University</td>
<td>University of Illinois</td>
<td>Purdue University</td>
</tr>
<tr>
<td>Baylor University</td>
<td>Iowa State University</td>
<td>San Diego State University</td>
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<tr>
<td>Boise State University</td>
<td>University of Kansas</td>
<td>San Jose State University</td>
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<tr>
<td>Bucknell University</td>
<td>University of Kentucky</td>
<td>Southern Illinois University</td>
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<tr>
<td>University of California-Berkeley</td>
<td>Lehigh University</td>
<td>Stanford University</td>
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<td>Carnegie Mellon University</td>
<td>University of Maryland</td>
<td>State University of New York-Albany</td>
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<tr>
<td>Cincinnati University</td>
<td>Mesa State College</td>
<td>The University of Texas at Austin (Founding University and CII Headquarters)</td>
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<tr>
<td>Clemson University</td>
<td>University of Michigan</td>
<td>Texas A&amp;M University</td>
</tr>
<tr>
<td>University of Colorado at Boulder</td>
<td>Mississippi State University</td>
<td>Virginia Tech University</td>
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<tr>
<td>Colorado State University</td>
<td>University of New Mexico</td>
<td>University of Washington</td>
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<tr>
<td>Columbia University</td>
<td>North Carolina Agricultural and Technical State University</td>
<td>Washington State University</td>
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<tr>
<td>Drexel University</td>
<td>North Carolina State University</td>
<td>University of Waterloo (Canada)</td>
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<tr>
<td>East Carolina University</td>
<td>North Dakota State University</td>
<td>University of Wisconsin Madison</td>
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<td>University of Florida</td>
<td>Ohio University</td>
<td>Worcester Polytechnic Institute</td>
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<td>Universidade Federal Fluminense (Brazil)</td>
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While the research topics evolve from year to year, what remains unchanged is the dedicated involvement of industry practitioners from member organizations who direct and guide the research, teamed with the investigative and analytic skills of the academic researchers and their graduate students. As one CII researcher noted, “Having participated in more than a dozen research, education, standing CII committees, and teams over the past 21 years, I have seen and experienced firsthand the truly special collaboration between owners, contractors, and
academics. These efforts have produced new knowledge and useful products positively impacting the industry. But in my opinion the most valuable legacy of CII’s first 25 years has been the outstanding personal and professional development of the thousands of volunteer participants, the strengthening of knowledge and leadership in academia, and particularly the development of leaders through the graduate students involved in the research.” – Dr. G. Edward Gibson Jr., (CII, 2008)

2 Research Value Delivered

CII’s model for research proved practical and quickly garnered significant interest with both industry and the academic community. However, the member companies soon realized that without implementation support and a means to assess the value of the research that sustained participation by its membership was not likely. By 1987, a movement had begun within CII to bring the implementation of research findings to the forefront and by the mid-1990s a formal process was initiated to benchmark research implementation and actual project performance. Oversight of implementation and benchmarking activities was assigned to CII standing committees of the member companies to ensure that value was received for their invested research dollars. The next sections highlight a number of acknowledged successes in CII research and then this paper concludes with discussion of some of the challenges which remain the subject of current research.

2.1 Safety

Construction’s safety record in the late 1970s attracted the attention of The Business Roundtable as it began a five year investigation into improving this fragmented, vital industry. Accidents, incidents, near-misses, and fatalities were at extraordinary levels, yet this “accidents happen” culture was largely accepted across the industry. CII established specific improvement goals early on — goals to improve safety by 25 percent, and to reduce cost and schedule by 20 percent. Within a short time, CII members achieved the 25 percent improvement in safety.

The results from CII’s continued safety research generated significant additional improvement in safety performance over the years as shown in Figure 2, Total Recordable Incidence Rates for CII companies and industry. When CII began benchmarking its member company safety performance, its incidence rate was approximately half that of the widely published rate reported by the government for all of industry. Seventeen years later both data groups have shown improvement, but now CII companies report safety performance more than 10 times better the government published numbers.

The remarkable reduction in safety statistics reflects CII member organizations’ commitment to the concept of zero injuries as the only acceptable standard for safety on a construction project. The CII research program strongly emphasizes construction safety and since 1985, CII has conducted nearly continuous safety research, with investigations into topics such as: zero accidents, design for safety, making zero accidents a reality, achieving zero injury objective on shutdown
projects, owners’ role in safety, and target safety. Currently CII is researching the project site leader’s role in improving construction safety. The purpose of this research is to investigate the impact of the behavior of the project site leader on his/her employees’ safe behavior, attitudes, and actions that drive safety performance (CII, 2008).

![Figure 2. CII Safety Improvement](image)

### 2.2 Work Force Development

Many CII efforts have addressed the work force, not only in safety as discussed above, but in other areas as well. Now, with the graying of both the field and office work forces, topics in this area maintain an important position in the CII research program.

Early on, CII studied employee effectiveness, project organization, and the construction work force. These efforts were followed by more specific investigations into continuing education for supervisors, workers’ compensation insurance, and project team communications. By the mid-1990s, CII drilled even further into the work force topic by looking at such issues as high performance work teams, attracting and maintaining a skilled work force, craft productivity improvement, and multi-skilling of craft capabilities. By 2003, CII had begun researching programs and techniques to attract and maintain the next generation, those young people now entering the work force, as the Baby Boomer generation begins their exodus. This research included topics such as Addressing the Shortage of Skilled Craft Workers in the U.S., Attract, Recruit, and Retain Construction Leaders, and The Work Force View of Construction Productivity. In 2006, CII developed the Executive Leadership Program. This three-week program which is largely based on CII research is intended to enhance the executive leadership capabilities and strategic business skills of future leaders in the industry. Through a series of lectures, case studies, and simulations from both industry leaders and
professors, students gain important insights into value creation in the capital asset business and build collaborative relationships with peers across the industry (CII, 2008).

2.3 Front End Planning

The Cost Influence Curve provided in Figure 3, has extensively influenced the overall research program. Much of the body of CII research has followed the axiom that cost and schedule are most easily influenced early in project planning. The result has been a wealth of front end planning and constructability research findings, including several CII Best Practices. These stand as testament to the validation of the impact of the Cost Influence Curve itself. In 1994, the Pre-Project Planning Research Team developed CII’s most widely used product to date, the Project Definition Rating Index (PDRI). The initial research developed the concepts based on industrial projects, and a similar product was later developed for general and commercial buildings.

![Opportunity for Influence](image)

**Figure 3. CII Cost-Influence Curves**

The PDRI is a powerful and easy-to-use analytical tool that measures the completeness of project scope definition by identifying and precisely describing each critical element in a scope definition package. The PDRI enables a project team to quickly determine factors that have a high probability of causing undesirable project outcomes. It is intended to evaluate the completeness of scope definition at any point prior to detailed design and construction. The family of PDRI publications are now in their third editions. Related research projects have resulted in such tools as the Owner-Contractor Work Structure and Project Delivery and
Contract Strategies. The benefits of CII’s front end planning research are now well known in the industry (CII, 2008).

2.4 Constructability

Constructability was one of the initial research topics funded by CII. Much was made of the definition of “constructability,” as Webster’s meaning of the word of the same spelling was “the ability to be constructed.” CII and its Constructability Task Force chose a different definition; they preferred to define constructability as “early input of construction expertise to aid design.” A key impetus for research in this area was the issue that designers frequently did not adequately consider construction processes. They created ideas for facilities that could be difficult and therefore costly to construct. In the extreme, some designs literally could not be constructed. For example, cranes may not exist to handle the loads required by the design or the design may not provide sufficient space to accommodate all the required installed equipment. Constructability research proved that the earlier construction expertise was involved in the design of a project and the earlier construction issues were considered in the design decisions, the more cost-effective was the design concept. Decisions made early in a project’s life are much more likely to positively influence cost and schedule. If those same construction problems are raised only much later in the field, the impacts of any resulting changes could be expected to negatively influence cost, schedule and quality, see Figure 3. The constructability concept was compelling and the Constructability Task Force took credit for the new definition of constructability, a concept that greatly enhanced a capital facility project’s “ability to be constructed” within the owner’s cost and schedule envelope.

3 Research Challenges

While we could continue with the discussion of research teams that produced breakthroughs for improving capital facility delivery performance, other teams have taken on topics where the processes are more elusive and the benefits are yet to be proven. Two such CII research teams were RT243 - Enhancing Innovation in the Engineer, Procure, and Construct (EPC) Industry and RT250 - Sustainable Design and Construction. The topics of both of these teams are strategic in the sense that when adequately defined and researched for the industry, they may offer the potential for the industry to reinvent itself and perhaps achieve the productivity gains and cost and schedule benefits experienced by other industries. They may also provide the industry with a longer term focus other than the economic bottom line.
3.1 Innovation in the Construction Industry

A seemingly common perception is that the construction industry lacks the innovation that is more common in other industry groups and that this lack of innovation is partly to blame for a lack of significant improvement in productivity and perhaps project delivery systems. In response to this perception, the CII Research Committee developed a research project to look at innovation within the construction industry and commissioned a team to develop a framework for analyzing, adopting, and fostering innovations to enhance project delivery processes and competitiveness. The team has been chartered to identify attitudes and management practices relating to innovation and to identify ways to increase innovation in the EPC industry. Organizational cultures, staffing, structure, and processes that enable innovation are being examined and an economic decision support model is being sought to assist in the evaluation of alternative innovations.

This research team began its work in October of 2006 and will present its findings to CII in the summer of 2009. Since this work is not yet complete, findings summarized in this paper are based on a white paper submitted in March 2009 and a preliminary report by the research team in 2008, and therefore, should be considered preliminary. The reader can visit the CII website in the fall of 2009 to obtain the final report.

After an extensive literature review, the team adopted a definition of innovation based upon previous research conducted at Oregon State University and funded by the Charles Pankow Foundation (CPF). Of note, the CPF also funded one third of the cost for this CII study as well. The CII definition however, is somewhat more focused and is provided below (RT243, 2009):

“Innovation is the act of introducing a significant improvement in a process, product, or system that is novel to the organization, may cause individuals to view things differently, and results in competitive advantage, increased value for the client or benefit to stockholders.”

The literature search produced a couple of key findings that would influence the research approach. First the team concluded that there were no published works analyzing the relationship between EPC firms’ investment in innovation and their financial performance. In fact, there was little such data available for other industries either and that most findings relating innovation and performance were based upon anecdotal or qualitative information. Another key finding of the team which was discovered through structured interviews, revealed that EPC firms do not measure or track the innovation-related metrics that had been identified in the literature search. This led the team to conclude that it was not possible to empirically demonstrate a relationship between innovation investment and firm success. And perhaps of more importance, the team concluded that having no objective metrics to identify innovative firms within the EPC industry, it would not be possible to identify innovation best practices by studying the activities of these
firms. As a result, the team decided to rely on survey results in which companies self-reported their innovativeness relative to the rest of the EPC industry.

The findings from the survey questions were analyzed by the research team to determine the “Keys to Innovation” based on the industry perspective in combination with the literature base. This analysis provided the following findings categorized in key areas:

1. Management understanding that innovation is critical – An understanding by management is critical for long-term growth and success is an underlying message that emerges in both the literature and the survey responses.

2. The implementation of an innovation culture is the foundation of an innovative organization. Additionally, norms must be in place that encourage and facilitate innovation. These norms should include:
   - A focus on continual creativity,
   - An emphasis on individual initiative,
   - A greater emphasis on risk taking and a stated tolerance for greater risk,
   - An openness to new ideas in all areas of the organization, and
   - A focus on engagement throughout the organization and supply chain.

3. Budget allocations must be made in support of innovation – These budget allocations need to be more than just added contingency on individual projects. Therefore, corporate and/or client budgets should be made available for project innovation. Once an innovation has been proven successful on one project, corporate budgets should be made available to diffuse the innovation to other projects. Corporate budgets should also be allocated to identify innovations from outside the firm (including outside EPC) that could be implemented within the firm.

4. Staff allocations must be made in support of innovation – Specifically, organizations need to task individuals with identifying opportunities for innovation on their projects, with facilitating innovation implementation on individual projects, and with identifying innovations from outside the firm that might be applied within the organization.

5. Processes need to be put in place to support innovation – A key success element of innovation is the existence of repeatable processes that each individual in the organization understands. This element was found to be a key difference between firms that rank high in innovation and those that rank in the lower part of the survey results. Specific components of the process focus include:
   - Repeatable processes need to be established relating to the identification, evaluation and implementation of innovation on project and corporate levels.
   - Promotion and bonus pay should reflect innovation activities, even if innovations are unsuccessful.
Processes should include facilitating creative thinking and decision making.
 Processes should include identifying and meeting customer needs.

6. A new risk perspective needs to be adopted – Specifically, the understanding that innovation involves an additional level of risk is a key to successful innovation implementation. Understanding and managing this risk requires a change in perspective from risk aversion to risk management. Innovation risk can be managed when the perspective is changed from an individual project to multiple projects.

After establishing the “Keys to Innovation”, the research team concluded that many EPC firms faced a significant task in achieving greater innovation. These firms did not value innovation, or failed to see the financial benefit of investing in innovation. Many firms did not understand the organizational commitment required to successfully implement an innovation process. As presented above, issues such as having repeatable innovation processes and changing the organization risk perspective repeatedly emerged as central themes. In response to this finding, the research team determined that two elements were required to assist EPC organizations in advancing innovation; an innovation maturity index and an economic model demonstrating the value of innovation investment. The next paragraph introduces the Innovation Maturity Index (Index) and its capacity to evaluate innovation status and provide recommendations to enhance innovation within the firm.

Upon analysis by the research team, the survey questions were refined and regrouped into eight categories; culture, resources, risk perspective, customer focus, learning, collaboration, leadership, and processes. Each section contains a maximum of ten questions that emphasize the sub-topic and its relationship to enhancing innovation. The questions retain the 5 point Likert scale introduced in the original survey to provide continuity with the original research results.

From the data acquired, it is apparent that not all questions have equal impact in the innovation process. Some can be considered critical to the innovation process, while others are additive in nature and serve to finalize the process. Therefore a significant focus in developing the Index was the establishment of a weighting scheme for the Index and its component sections. The Delphi method was the procedure of choice selected by the research team for establishing the weights. At the conclusion of this repetitive process, each of the 60 questions in the Index was successfully weighted and finalized in the Index.

The Index when completed will provide users with an opportunity to both evaluate their current innovation status as well as obtain a set of recommendations to improve their innovation status. The Index is currently being tested in a series of case studies to obtain final validation and establish the value of the recommendations.
The development of the Innovation Maturity Index provides users with an evaluation and path forward capability in terms of innovation. However, for most organizations an economic justification is required to prompt action on the recommendations. In response to this need, the research team developed an economic model or perhaps framework for an economic model to represent the benefits of innovation. At the core of this model is the concept that organizations need to change their perspective on innovation investment and return. Specifically, innovation is a long-term investment, not a single-project allocation requiring instant return. In the next paragraphs, the model is introduced with the recommendations for changing this perspective in an effort to increase innovation investment and returns.

The current risk perspective held by many organizations is focused on the project manager’s view. In this perspective, the current structure of project implementation does not support innovation investment. Specifically, the probability of a negative result outweighs the potential for positive gain for an individual project manager. From the project manager’s perspective, several negatives are potentially included with innovation including:

- The worst case, although unlikely, is catastrophic.
- Innovation requires learning and multiple iterations.
- The project bears all of the risk and cost, but others stand to capture the gains.

To change the current perspective the research team developed an economic analysis to illustrate the benefit of innovation investment. The cornerstone of this model is the concept that innovation investment must be viewed over multiple projects to receive the full benefit of the investment. A given project can start with a known risk quantity and a known likelihood of meeting an objective such as schedule. When an innovation is introduced, the first generation of project to which it is applied may move the result in a favorable direction reducing cost or schedule, however, the risk of not meeting the objective may be greatly increased. This is a significant negative to an individual project manager. However, the repeated application of the innovation will result in both an increased likelihood of meeting the objective as well as reducing the variability in the risk profile. Therefore, the multiple generations achieve the return on investment in the innovation.

This perspective can be captured by a “casino approach”. In this perspective, the organization should emphasize the spreading of risk over multiple projects to avoid a “break the house” risk. In this perspective, the organization takes many small bets to avoid a major loss from a single bet. This creates a team approach where project managers do not have to feel like individual gamblers. Rather, the team absorbs the investment, the greater risk, and the unknowns in return for greater benefit over the longer term.

Successfully changing the perspective from a project-oriented risk perspective to one that emphasizes a “casino approach” requires a commitment from management as well as buy-in from the individual project managers. To achieve this objective, several key elements are required as follows:
• Shift from “single event” thinking – as discussed above, this is the foundation of the economic model. The organization needs to move away from a “single event” perspective to one that emphasizes a portfolio project perspective.

• Indemnify project managers by creating a “syndicate” – The fundamental difficulty with investment in innovation is the concern by project managers that failure is a greater risk than the potential reward offered by an innovation. To change this perspective, the organization needs to focus on establishing a collaborative environment where project managers believe that an individual result that does not meet expectations will not result in a commensurate penalty. This change to a syndicate perspective will emphasize broad success versus individual achievement.

• Experiment and learn frequently – A key to innovation is experimentation and subsequent learning. Therefore, an organization value must be established that emphasizes an increase in the value of learning and the need to consistently share between project managers. This focus on learning and experimentation will slowly alter the risk perspective and enhance the opportunity for a successful investment.

Although these elements are not the only ones that will contribute to a change in the risk perspective, these elements should be viewed as the building blocks on which an organization can increase its risk tolerance and have a greater opportunity for innovation success.

From the discussion above, it is unrealistic to anticipate that the industry will see significant change in its perspective on innovation in the immediate future. However, it is reasonable for individual organizations to begin to change their perspectives on innovation and to begin to implement the changes required to increase innovation and establish the positions necessary to leverage innovation into competitive advantages. The Innovation Maturity Index introduced by the CII research team provides a first step in evaluating current innovation levels and the framework for economic analyses provides a context for evaluating innovative initiatives (RT243, 2009).

3.2 Sustainable Design and Construction in the Industrial Sector

The increasing importance of sustainability within the global community is making it imperative for organizations in the industrial sector to include environmental and social considerations in the construction of capital projects. After a number of unsuccessful attempts by CII to develop and approve for funding a research topic on sustainable construction for the industrial sector, its Breakthrough Strategy Committee issued a 2006 white paper identifying “Design for Sustainability” as an area where CII could gain traction on the subject. A great deal of literature on sustainability in the buildings sector has been written. And, although many of these principles and ideas can be applied to industrial capital projects, more needs to be
done to define and then implement design and construction strategies in the industrial sector. As follow through to this initiative, CII formed the research team RT250 - CII Sustainable Design and Construction to:

- Investigate trends in sustainability to determine their effects on the capital projects of industrial companies.
- Explore existing and potential approaches to addressing these trends through the design and construction of these projects.
- Inform the industry on this topic and provide resources to assist decision-making.

Specific objectives provided to the research team by CII included:

- Define sustainability as it applies to design and construction in the industrial construction sector.
- Identify current and potential sustainable practices in industrial construction.
- Determine benefits and barriers to sustainable practices on industrial construction projects.
- Provide a framework to advance the understanding and implementation of sustainability practices.
- Suggest a metric for the industrial construction industry to use for assessing sustainability practices and to assist in making decisions on the basis of objective, quantifiable data.
- Write a primer on sustainability applicable to the design and construction of capital investment projects in the industrial sector.

In its search for the appropriate definition of sustainability, the research team reviewed many existing definitions and they concluded that all definitions require the simultaneous thinking of the three interrelated aspects—economic, environment and social; concepts put forth by John Elkington as the “triple bottom line”. Eventually they developed their own encapsulation of the concept as:

“Industrial sustainability is the process of planning, construction, operation, and decommissioning of industrial capital projects that meets business objectives while serving current and future human and ecological needs.”

This definition and entire section on sustainability are provided from the research team report, “Sustainable Design and Construction in Industrial Construction” submitted by RT250 (RS250-1, 2008).

To investigate current sustainable practices in use, the team investigated companies with active sustainability efforts and identified the following common characteristics:

- Policy and organizational structure supportive of sustainability,
- Goals and performance objectives of sustainability as applied to their sector and business interests,
- Public reporting of social and environmental performance,
- Involvement in associations or coalitions that promote sustainable outcomes and facilitate peer learning.

At the project level, a variety of concepts were found that contribute to more sustainable practices on projects. Some of these include pollution prevention, waste minimization, material selection for less toxic materials, or to incorporate recycled content, attention to site ecological features, and water conservation.

The team employed a survey to gauge the current state of sustainability understanding and implementation in the industrial construction sector. Thirty companies responded representing the perspectives of the various entities involved in industrial construction: owners, contractors, engineers, design-build firms, architectural firms, and suppliers. Over two-thirds of the respondents perform over $1 billion of work per year and average between 40 and 50 projects per year.

Nearly all the respondents stated that environmental considerations were included in design documents, with about half motivated by “regulatory compliance” and half citing “beyond compliance.” The majority of firms responded that they have a corporate strategy on sustainability, but less than half of the respondents participate in a global reporting initiative. Half of the respondents stated that they did not know if their firms have benefited economically from implementing sustainability practices, and only about one out of four have a standard technique for measuring the benefits of sustainability.

The research team concluded the importance of sustainability is recognized, as most have a strategy, but the majority of responding firms have not succeeded in quantifying the benefits of their approach. Drivers for implementing sustainability as identified by the respondents are shown in Figure 4 below.

Considering that slightly more than 25 percent of the respondents were owners, the first driver listed is no surprise. Public awareness and government drivers are likely to surprise few as well, however, competitive differentiation as a driver is encouraging.

In discerning whether firms were applying sustainability practices to projects, the gap between intention and implementation was clear. Only about a third of respondents include a section on sustainability practices in their project execution plans, and only one in five was aware of a firm’s method of measuring success of sustainability on projects. Firms reported using Energy Star, LEED, and internal company guidelines to evaluate their implementation of sustainability.

Basic environmental practices were somewhat common. Nearly half of respondents said that they consider sustainable materials selection in the design stage and sustainability during constructability reviews. In terms of waste reduction and management, 40 percent indicated they employed methods to reduce the amount of waste generated during construction, and one-third said their construction waste was recycled into other materials or used for other purposes.
The number who reported using renewable energy sources during construction – over 40 percent – was somewhat surprising. However, many of those uses are small, such as photovoltaic-powered signs or gates or biodiesel blends (such as 5 percent “B5” or 20 percent “B20”) in fleet or equipment. Survey results indicated that sustainability has not fully penetrated the supply chain, as only one in five said they prequalify vendors or suppliers on their sustainability or social responsibility practices.

Seventy percent stated that they evaluate social sustainability aspects that could impact project execution. The majority of respondents indicated they addressed local social conditions linked to their projects through the following activities: sweat equity to local organizations; minority-owned business outreach; social impact from noise, traffic, safety, and aesthetics; community development projects; use of local labor; economic impact of projects on business and local communities; actively managing community relations; providing days off on cultural holidays; interaction with the public; building schools; building medical facilities; public health impacts; eliminate high traffic conditions; and impact of the work force on local communities.

In summary, although many firms seem to have a corporate sustainability commitment, benefits and implementation details at the project level are not as well-known throughout the firm as they could be. Responses showed that some practices are being employed, but how to measure, assess, and improve is indeterminate. If CII member firms were more aware of the variety of sustainable options for materials and processes available and the value of the positive impacts, then sustainable practices might be incorporated into more industrial construction projects. The research team expected that the materials and tools discussed here and in Sustainable Design and Construction for Industrial Construction: A Primer (IR 250-2) – if applied by firms on all projects – would help address this gap in the industrial construction industry.
From new and emerging regulations to financial community interest to market demand, finding ways to design, construct, and operate industrial facilities in a more sustainable fashion will be the industry’s challenge for the foreseeable future. Given the breadth, and in some cases depth, of the CII member organizations in pursuit of sustainable solutions, CII is well positioned to build on this initial research and add specificity to the field. As a follow up to this research, CII’s Research Committee in conjunction with its Breakthrough Strategy Committee have developed another sustainability topic: Metrics and Tools for Cost-Effective Sustainable Capital Facilities which will be presented to the CII Board for approval and prioritization at its spring meeting. This research is intended to develop and validate measurement tools to assess the investment performance of sustainability initiatives for capital facilities.

4 Conclusions

CII is fortunate that even in these difficult economic times, its member companies continue to support the collaborative model established 25 years ago to produce credible research for the construction industry. Credit for the success that the institute has achieved is due to the dedication of the many volunteers within its membership, to the professional guidance in the research process provided by its academic participants, and to the forethought of its founding director and board members. CII’s position has always been that industry must lead the process. The issues to be researched are those that its members face daily, so who better to define the research agenda. Within the academic community resides the expertise for conducting this research and also the graduate students that will be the future leaders of this industry. The opportunity to develop these students working with the industry experts which they will later join and to fund this with dollars contributed by industry, not government is what makes CII truly unique.

CII was frequently credited in its early years with many of the industry research success stories that produced some of its more noteworthy products such as its Zero Accidents Techniques, Front End Planning Concepts with PDRI and Constructability. Some tend to attribute the successes to an opportunity to address the “low hanging fruit” and that further achievements are likely to be less profound. Many of the topics that CII researches today such as Innovation and Sustainability are perhaps on a different level and have drivers and implications well beyond the project site. Breakthrough research on these topics may be more elusive, but the benefits to be realized are tremendous; particularly given the interconnectivity of the global world. While CII continues to refresh much of its foundation body of knowledge, much of its research agenda will continue to be forward looking and from it will likely come tomorrow’s breakthroughs.

5 Acknowledgements

The author of this paper would like to acknowledge the many contributors to this work. As the director for CII Research, the author works with the Research
Committee to develop CII’s research agenda and with industry participants and academic researchers to resource the teams that perform the research. It is a pleasure to work with and advise the teams as they conduct and publish their research, but credit for the work and findings belongs to the team members. Virtually all of this paper comes from the work of these teams. Most of the material in sections 1 and 2 was developed by CII’s 25th Anniversary Committee to document its first quarter century of success. Bob Ryan, Jewell Walters, and Kim Allen were instrumental in the development of this material and publication of “Building on 25 Years”. The material in Section 3 comes from RT 243 – Expanding and Enhancing Innovation in the Construction Industry and RT 250 – Sustainable Design and Construction. It was the members of these teams that worked very compressed schedules to perform the research, develop the findings, and produce the publications that enabled this paper. Others such as Dr. G. Edward Gibson from The University of Alabama, and Dr. James O’Connor at The University of Texas at Austin were principal investigators with most of CII’s Front End Planning and Constructability work. While it is not possible to list all of the CII volunteers that contributed to the material that made this paper possible, I would like to thank each of these volunteers for the selfless contributions to the CII process.

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Chapter Four

Using Fuzzy Logic and Simulation Technology to Deliver Innovation to the Canadian Construction Industry: A University-Industry Collaborative Model

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Abstract

The Industrial Research Chair in Construction Engineering and Management (IRC) has developed a number of sophisticated simulation and artificial intelligence modeling tools for industrial applications, comprising both construction synthetic environments (CSE) and fuzzy logic systems. The research carried out through this program focuses on ways of simplifying simulation modeling tools, creating advanced decision support systems that incorporate fuzzy logic and simulation technologies, and integrating simulation with other tools (e.g. visualization, estimating, scheduling) to develop innovative solutions to practical construction problems. This paper will describe the collaborative nature of the IRC program, with the objectives of (1) illustrating the structure of the IRC; (2) discussing how the IRC delivers innovation to the construction industry; and, (3) outlining several examples of successfully deployed innovations.

1 Introduction

In recent years, the Canadian construction industry has faced a period of rapid growth, straining available resources and increasing competition in many market
sectors. The construction industry is highly valuable to the economy of Alberta, and to Canada as a whole. In Canada, construction represents a significant segment of the GDP, totalling over $77.2 billion in 2007. The increase in GDP reported between 1998 and 2007 represented a compound annual growth rate of 5.1% (Industry Canada, 2008). Pressure to respond to rising demand with limited means has affected the overall productivity of the construction industry and threatened the future of investment in construction in Canada. Even in a period of fiscal strain, public spending on infrastructure and construction efforts is regarded as a valuable economic stimulant, as evidenced by the commitments of the 2009 Canadian Budget (Canadian Construction Association, 2009). For the Canadian economy to remain competitive among international markets, the construction sector must take a place of leadership among Canadian industries, and it must be able to compete in global markets. Optimizing construction project planning and control can critically enhance Canada’s economic position by attracting investments to efficient and productive projects, and by promoting Canadian industry as adaptive and forward-looking.

The NSERC Industrial Research Chair in Construction Engineering and Management (IRC) has developed a collaborative research program to bring a new generation of simulation and fuzzy logic tools and processes to the construction industry. The IRC program was established through a partnership between the Natural Sciences and Engineering Research Council of Canada, a consortium of construction companies, and the University of Alberta. At its core, the Senior Chairholder and the Associate Chairholder have focused efforts to undertake industrially relevant research to address problems and to deliver innovation to the Canadian construction industry through technological applications, trained personnel, solid client relationships, and a foundation of theoretical exploration.

The simulation and fuzzy logic theories and tools developed by the IRC program have been implemented in major construction companies active in infrastructure and natural resource development. Investment in construction mega projects and operations in oil sands, coal, and gas is expected to reach $180 billion between 2007 and 2015 (Construction Sector Council, 2007). A significant component of the research program involves the exploration of how such operations are currently conducted. This investigation challenges the principles and technologies upon which current practices reside and forms the basis of the IRC’s mandate to advance the quality and delivery of construction services in an innovative manner with reduced costs and duration. The approaches pursued by the research team will increase efforts to adapt and transfer the powerful modeling techniques developed under the IRC to new construction applications, making the creation of future decision-support systems easier and faster. As such, improvements through the research applications of the IRC and the training of highly qualified personnel (HQP) will have a direct, positive impact on the implementation of these tools within the construction industry. This collaborative relationship of the IRC will also provide a gateway for the expertise developed in building simulation modelling into construction operations within Alberta to be exported to international markets.
The objectives of this paper include: (1) illustrating the structure of the IRC; (2) discussing how the IRC delivers innovation to the construction industry through technology transfer, education, and training; and (3) outlining several examples of successfully deployed innovations. The IRC engages in high-level theoretical research into simulation and fuzzy logic processes, which often produces tools that can be used within the industry, such as fuzzy decision support systems used for evaluating contractors for bonding (SuretyAssist) used by AON Reed Stenhouse and AXA Pacific, or tunnelling applications based on simulation templates used by the City of Edmonton. The IRC also carries out industry-driven projects, such as the Construction Owners Association of Alberta (COAA) Foremen Skills Development Tool, and using simulation for the management of module assembly yards at PCL. This paper will present case studies of both types of projects, and the authors will discuss how such project interaction is key to the mandate of the IRC program.

2 Building Collaboration with Industry

Since its establishment through a partnership between the Natural Sciences and Engineering Research Council of Canada (NSERC), a consortium of construction companies, and the University of Alberta in 1997, the IRC program has greatly emphasized the connection between high level research activity and tangible outputs as a means of driving relationships with industry. The first term of the IRC (1997-2001) enabled the research team to build the critical mass required for a major endeavour in the area of computer simulation in construction, and to develop new technologies for enhancing construction productivity. The second term (2002-2007) enabled the team to extend research activity, solidifying the group’s role as a leader in construction research and establishing the foundations for a new generation of modeling and simulation techniques. Already renowned for its work in the convergence of simulation technologies with construction practices, the next stage of the IRC program, through to 2011, involves an unprecedented level of theoretical and practical exploration.

The IRC program is characterized by the close involvement of partner companies within the life of the research institute as collaborators, advisors, and venues for testing. Under the current structure of the IRC, research teams undertake process and production improvement studies with partner companies to assess performance, enhance operations and identify areas of potential improvement. Industry partners contribute to the program’s success not only through their financial support, but by enabling researchers to perform hands-on research related to issues they are facing in real construction projects. The IRC is able to accomplish its mandate of transferring knowledge from the academic realm of research to the actual construction site because of the close relationship researchers enjoy with participating construction companies and organizations.

Although research directions are set by the Senior and Associate Chairholders with other faculty, the strategic operations of the IRC are undertaken in conjunction with an advisory Consortium Board, composed of representatives from each senior
partner company, the Chairholders, and other faculty. The Board members are valuable assets to the program, acting to enhance the industrial scope of the research undertaken. These individuals are chosen to be ‘champions’ for the program within their respective organizations; as such, they must occupy a position of influence within the company, while still remaining connected to operational activities (i.e. vice presidents, general managers). As champions, the members are enthusiastic about dealing with the University, researchers, and students; as the IRC program has grown, many former students have risen within construction and engineering firms to the management level and have returned to the program as partners and supports. To a certain extent, the role of champion also has a personal component, based on interaction with the Chairholders. Board members must be trustworthy, reliable, and innovative in outlook in order to form a lasting and productive relationship with the IRC program.

Industry partners and Board members are active within the IRC in several areas. As the program expands and takes on new member companies, recruitment has been made easier by the program’s ability to show industrial relevance and success. At the end of each term, the IRC is subject to a renewal process; again, to show relevance and the potential outlets of the research, the program benefits from finding synergetic partner companies who will support the proposed areas of research. During the program term, Board members act more as a sounding board, helping to identify strategic decisions on organizing the work of the IRC and services that are provided to the partner companies. Lastly, Board members are effective individually, as members become conduits through whom the Chairholders contact their respective companies. They report on overall issues of the company, giving a sense of the company’s internal works and the “problem of the moment.” With this background, these representatives are in the best position to link the company’s needs to the research endeavours of the IRC, finding what tools and applications would be useful to them.

Researchers work closely with industry partners to place both graduate student Highly Qualified Personnel (HQP) and undergraduate students within shared research and development projects. Because the IRC is a research program with an emphasis on training, partner companies are given the opportunity of employing the student researchers with whom they have been working throughout the duration of the project. This ensures the continuity of the work and provides a viable medium for technology transfer between the research and application aspects of the program. This relationship also offers a valuable resource for training company staff in state-of-the-art topics in construction through training seminars and on-site project assistance. More informal training often occurs for both existing staff of a company and student researchers during the day-to-day interactions that take place on the project site.

Construction engineering remains a fairly functional discipline overall; getting people involved with industry remains a fundamental anchor for building partnerships. The main vehicles for transfer of the IRC’s research program into industry are as follows:
• Joint projects focus on implementing prior research findings within specific companies. In general this takes on two forms: simulation and decision support systems deployment, and process analysis and improvement. They are carried out by teams from the IRC program and the involved companies. In many cases, research findings are issued as joint publications and presentations with industry partners.
• Students trained in the program are typically hired into the Canadian construction industry upon graduation, especially by partner companies. Those same students have become sponsors of new collaborative research projects, acting as champions within their own organizations.
• The annual Canadian Construction Research Forum (established by the Senior Chairholder in 1995) provides a conduit whereby the IRC’s research results are disseminated to the public at large and the collaborating companies in particular. The Forum includes joint presentations with industry partners and students working on their projects, and typically draws more than 100 industry participants from across Western Canada as well as illustrious speakers from the construction industry.
• The IRC works with national organizations such as the Construction Sector Council on a number of collaborative research initiatives to disseminate research findings across a wider body.

The IRC research program has a dual focus on both fundamental, theoretical research and applied research tools. In terms of fundamental research, the IRC’s flagship project, the Simphony simulation modeling program developed by the Senior Chairholder, is in wide use by researchers and practitioners worldwide. This platform is used for building simulation tools and/or for using the tools to build models of real-world construction systems. As will be discussed, these advanced simulation-based planning methods have become the standard for planning tunnel projects in the City of Edmonton, improving reliability of project delivery and productivity. The work of the Associate Chairholder incorporates fuzzy logic into simulation theories, producing new methods of incorporating the context and subjective variables involved with construction, as well as producing fuzzy decision support systems. The examples that will be discussed include the SuretyAssist program developed to integrate the many factors considered by surety firms when bonding contractors.

With respect to applied research, a number of technology applications designed by IRC researchers have been implemented by partner companies for planning, scheduling, and tracking activities in the fabrication shop and on the job site, leading to savings and competitive advantages. As an example of a simulation-based productivity tool, the scheduling of module yard assembly at PCL will be discussed. Applied research focused on client-related issues is another key support in the implementation of tangible, usable products emerging from the group’s research efforts. Here, the Foremen Skills Development Tool developed by the Associate Chairholder with the COAA is strongly industry-driven in terms of identifying problems and creating tools to solve those problems. By working
alongside project managers, addressing problems and needs as they are encountered, and providing the latest in research and technology, the IRC research program is able to give construction companies the advantage of significant technical support.

3 Working with Industry: Solutions

The first aspect of the IRC’s research work occurs when ongoing fundamental research evolves into an application. In these scenarios, researchers consider how findings could best be applied to industrial issues, and then investigate partner companies for problems best suited for such applications.

Based on the simulation toolkits developed by the Senior Chairholder for the Simphony platform, a number of templates and system models have been developed for partner companies. An example of this process can be seen in the IRC researchers’ work with the City of Edmonton on tunnel construction, particularly the use of analytical methods for forecasting productivity and predicting risk.

Tunnel construction projects are very high-risk projects. Because of the high levels of uncertainty involved in tunnel construction operations and an overall lack of data, industry practitioners make various assumptions before construction commences. Special purpose simulation has been used by the City of Edmonton’s Drainage Design and Construction Section for project planning and bidding analysis (Ruwanpura et al. 2001). Though the linear, repetitive nature of tunnel construction is especially well-suited for simulation, the progress of the overall tunnelling project is dependent upon the progress of individual activities involved in excavation, dirt removal, and tunnel support. Any planning exercise that attempts to optimize the overall operation must examine the system as a whole. Improvement in one activity, such as tunnel excavation, must be balanced with improvements in related activities, such as dirt transportation. The system is optimized when all activities are synchronized to minimize the waiting or idling time and the resources are 100% utilized. It is, therefore, important to evaluate improvement to an activity that impacts the waiting times and the utilization of resources leading to a minimum unit cost. The tunnel advance rate is perhaps the most important measure of efficiency for tunnelling projects, determined in part by soil conditions along the excavation site.

Through simulation templates, IRC researchers applied analytical methods for predicting the soil types along the tunnel alignment during simulation, enabling City engineers to reduce the uncertainty of the project during the planning stage. The prediction of soil types and the combinations of soils from the surface soil layer to the bottommost soil layer along the tunnel path was successfully validated by applying the modeling concepts of the analytical method during the planning of the NEST tunnel project in Edmonton. The outcome of this research also assists in reducing the uncertainty between boreholes, thereby allowing prediction of the
transitions of soils in the tunnel alignment that are then implemented within a special purpose simulation template for tunnel construction operations to improve the accuracy of construction productivity assessments.

To elaborate, the NEST tunnel involved excavating 1.6 km of tunnel through mixed soil types, 2.9 m in diameter and 14 m deep, with a budget of $8.8 million and a very tight timeline of less than a year. With respect to the uncertain risk factors of the project, uncertainty modelling was undertaken in Simphony to determine variability in production rates, impact on schedule, different crew structures, shift lengths, and workforce deployment. Following this, planners were able to establish mitigating actions to meet the target completion date by conducting schedule, cost, and productivity analyses using simulation modeling. Productivity analysis was based on the following “base case” inputs: which were then modified to generate six different possible production scenarios:

- One way tunneling
- 1 undercut + 1 removal shaft
- soil segments:
  - 100 m low penetration rate
  - 544 m good soil
  - 200 m wet soil
  - 758 m hard soil
- 8 hr shift
- 2 trains (each has 3 muck cars, 1 material car)
- 3.2 m diameter TBM
- Crane hoisting one car at a time

The inputs were modified to generate six different possible production scenarios, as shown in Table 1.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10-hour shift</td>
</tr>
<tr>
<td>2</td>
<td>One train + reduced dirt removal time (2-3.5 min)</td>
</tr>
<tr>
<td>3</td>
<td>Two trains + dirt removal time (3-5 min)+ Material loading time (4-7 min)</td>
</tr>
<tr>
<td>4</td>
<td>Constant dirt removal (i.e. conveyor belt)</td>
</tr>
<tr>
<td>5</td>
<td>No delays due to surveying (surveying removed)</td>
</tr>
<tr>
<td>6</td>
<td>No delays due to TBM breakdown (breakdown removed)</td>
</tr>
</tbody>
</table>

Each scenario was modelled in Simphony (Figure 1) for purposes of comparison.

Following this, the simulation outputs were compared (Figure 2), showing potential areas of improvement to the construction method. Ultimately, Scenario 5 (removal of surveying delay) was selected as the target area, based on budget, schedule, and personnel issues. Surveying delays were minimized by working with the survey crew yielding good production rates. Actual costs were within budget, and the schedule was within required delivery date.
An example of how advanced techniques such as fuzzy logic and expert systems can be applied to solve a practical problem in the construction industry is the development of SuretyAssist. SuretyAssist is a decision support system to help surety brokers and surety underwriting firms to systematically evaluate contractors in order to qualify them for bonding. Owners require contractors to obtain bonding to undertake construction projects as a way to mitigate the risk of contractor default. Surety brokers act on behalf of the contractor to obtain bonding for them from surety underwriters. Since surety underwriters bond contractors with the expectation that the contractor will not default, they need a thorough, systematic, and consistent method of evaluating contractors prior to providing them with construction bonds. The initial assessment of a contractor determines their performance in a number of areas, capital (financial stability), character, and capacity, and determines whether or not the contractor will be considered for bonding. If they are accepted by the surety underwriter, then they apply for bonds for specific projects, at which time the project risk and contractual risk of the project are evaluated. SuretyAssist was developed to address the initial contractor evaluation (Marsh and Fayek, 2009), although project specific assessment is currently being researched.
Figure 2. Comparison of alternate scenarios for NEST tunnel project

The theoretical basis of SuretyAssist is fuzzy expert systems, which is a method of representing expert assessments in the form of if-then rules. The use of fuzzy logic enables experts to express themselves either linguistically or using known numerical values to evaluate a contractor against a set of criteria, and to combine their rules of thumb and know-how into an overall assessment of the contractor. Many of the criteria involved in assessing a contractor’s qualification are subjective in nature, and best expressed linguistically. Even for objective criteria, such as financial indicators, there is range of values that are acceptable, and the transition from acceptable to unacceptable performance is gradual rather than abrupt. Examples of subjective criteria used in contractor assessment are: contractor’s reputation, relationship with owner, management capability, resource quality, and financial statement quality. Examples of objective criteria are: contractor’s current ratio, gross profit trend, debt to equity ratio trend, working capital trend, and accounts payable and receivable. Fuzzy logic enables us to capture both linguistic and numerical variables in the form of membership functions that capture their meaning, and allows for gradual transitions between states of variables.

The need for SuretyAssist was identified by the Associate Chairholder in consultation with AON Reed Stenhouse, a surety broker, and AXA Pacific, a surety underwriting firm. These firms felt that although good measures were in place to
evaluate contractors based on the objective (largely financial) criteria, the remainder of the contractor assessment was subjective, based on gut feel, variable depending on the underwriter’s experience, and not well documented. The use of a fuzzy expert system to model the decision was very well received by the participating firms. As such, these firms committed significant resources in terms of their personnel’s time and access to their data to help the researchers (a) understand the criteria used in evaluating contractors and the decision-making process involved, (b) capture the expert judgment required to develop the components of the fuzzy expert system, including the membership functions to model the criteria and the rule base to capture their decision-making, and (c) collect data with which to validate the developed system.

SuretyAssist has been implemented in software form and is currently being used by both AON Reed Stenhouse and AXA Pacific to evaluate new contractors as they apply for bonding. Although the system was developed using a fuzzy logic inference engine, FuzzyTech®, the interface is in the form of Excel® spreadsheets for ease of use. SuretyAssist provides a systematic approach to explicitly account for the numerous factors that are considered by surety firms in evaluating contractors to quality them for bonding, some of which were previously ill-defined due to their subjective nature. Use of the system over time will help surety firms to document their decision-making process, and to improve the quality of their decisions leading to fewer contractor defaults. The system is also beneficial as a training tool to help underwriters new to the industry learn about the methods of evaluating contractors for bonding. Surety Assist can also be useful to contractors applying for bonding to better understand their areas of strength and areas of weakness so that they may improve on them and increase their chances of obtaining bonding, particularly in challenging economic times with significant competition for projects.

4 Working with Industry: Applications

The second aspect of the IRC’s research work occurs when the Chairholders are approached by industry partners with a specific problem that cannot be solved by another outlet. In these scenarios, research is initiated by partners, through the conduit of Board members, who have developed a relationship with the program and who possess a level of comfort with the research work that is carried out. IRC researchers — usually a faculty member and assigned graduate students — work with the company to identify problems that can be solved with the program’s knowledge base, and then work to develop a tool or application custom-built for this purpose.

An example of this applied form of research is in the Senior Chairholder’s work on developing artificial neural networks (ANN) for use at PCL Constructors Inc., to enable accurate estimation of labour production for industrial construction tasks such as welding and pipe installation. Detailed estimation of construction costs involves determining the quantity of work to be completed and the costs associated
Researchers developed a method of ANN to allow estimators to adjust the average productivity value of the project examined to accurately reflect specific project conditions in an accurate manner (AbouRizk et al. 2001). In practice, this process tends to be highly subjective with inconsistent results among estimators and projects. The developed model produces a set of artificial neural networks utilizing a two-stage process for predicting an efficiency multiplier that an estimator can use to adjust the average productivity and reflect specific job conditions anticipated on the project.

Neural networks are used to learn patterns and relationships in data (this process is known as “training”). Once trained, the neural network can be used to solve problems similar to the ones it was trained on (a process referred to as “recall”). Neural networks can be used for classification or prediction. In this case, the network was trained to solve problems of productivity to improve the overall consistency of estimation. Factors affecting productivity rate fall into nine categories: general project characteristics, site, labour, equipment, overall project difficulty, general activity conditions, quantity, design, and activity difficulty. These factors, 33 in total, were correlated against data collected from the company’s database and from interviews. Correlation showed that the most significant factors are the ones related to activity difficulty and detail. This correlated data set formed the material for training the neural network before turning it to the prediction of future projects.

The developed ANN model was based on a limited data set from 27 projects. Although its testing was successful at PCL (AbouRizk et al. 2001), efforts continue to date to increase the database and enhance the software. The model was fully automated to enable faster data collection and to allow its inclusion in future training of the network—a requirement for its successful application in industry. In particular, the ANN model proved to be primarily useful in reducing the subjectivity of estimators between estimates, hence improving the estimation ability for new projects. This accuracy is an asset to PCL when bidding on new projects, increasing the likelihood of winning bids and maintaining project budgets. The most significant (and demanding) aspects of applying ANN within an industrial setting such as this one are defining input factors and collecting sufficient relevant data for training. Because this study was carried out in conjunction with a partner company, with a Board member even acting as co-lead and co-author on subsequent reports and papers stemming from the findings, researchers were able to access vast repositories of company data and process information that might not otherwise have been available.

The Construction Owners Association of Alberta (COAA), a leading group of owners representing many sectors of the Alberta industrial construction community, is a long term research partner of the Associate Chairholder and a member of the IRC. Over the past decade, the Associate Chairholder has developed a number of solutions to practical problems facing the industry, as identified by the COAA, including improving apprenticeship training and development, reducing construction field rework, and, most recently, developing an absenteeism tracking tool. Another example of an industry-driven application is the Foreman Skills
LEVERAGING INNOVATION FOR SUSTAINABLE CONSTRUCTION

Development Tool, which was developed for the COAA to address a need identified by the industrial construction community. At the time of its development, the Alberta construction industry was facing a significant shortage of skilled tradespeople and construction supervisors, particularly in the industrial construction sector. Construction tradespeople were being promoted into supervisory positions, often based on their skill as tradespeople and often with little or no supervisory training or experience. In an effort to address the lack of a formal qualification for construction foremen, the COAA developed a construction trades foreman position description for the industrial sector, and as a result needed a method with which to assess a foreman against this position description, identify gaps in skills, determine appropriate training and mentoring to fill those gaps, and monitor improvements over time.

The Associate Chairholder’s research team worked with the COAA Supervisory Training and Qualifications Subcommittee to develop the Foreman Skills Development Tool, which has been implemented in software form (Fayek and Poveda, 2008). The tool consists of a comprehensive questionnaire to gather an assessment of a foreman’s skills in each task identified in the foreman position description, as well as other relevant tasks gathered from the literature, in six areas of responsibility: safety, planning and scheduling, leadership and supervision, employee relations, quality assurance/quality control, and administration. The questionnaire is used to elicit assessments for a given foreman from his or her crew members, supervisors and peers (i.e., other foremen), and the foreman himself or herself, thus yielding a 360 degree review. The assessments are then combined, analyzed statistically, and presented graphically to provide an organization with a detailed evaluation of the skills of each of their foremen. A sample of the results is shown in Figure 3 and 4. Figure 3 shows a radar diagram representing the overall assessment (on a scale of 1 to 7) of an individual foreman relative the group of foremen in the organization. Each category of assessment on the radar diagram (e.g., administration) is calculated based on the assessment of individual tasks under that category. The overall assessment is based on a combined assessment from each of the three perspectives (crew members, supervisors and peers, and foreman). The individual assessments based on each of the three perspectives are also available in the form of a radar diagram. Figure 4 shows a box plot representing the foreman’s overall assessment relative to the statistical distribution of the group of foreman surveyed, according to each category of assessment. The Foreman Skills Development Tool also collects objective project performance measures for a given foreman (e.g., productivity factors, schedule and cost performance factors, crew absenteeism and turnover rates, rework rates, and safety statistics). It attempts to correlate these measures to the foreman’s overall assessment, demonstrating a relationship between a good assessment and good objective performance on the work supervised.

The Foreman Skills Development Tool was validated with Ledcor Industrial, one of the IRC partner companies, in their pipe and module fabrication facility. Seventeen foremen, 140 crew members, five superintendents, eight general foremen, three QA/QC personnel, two safety personnel, and four materials management
personnel participated in the study. These personnel completed the questionnaires, providing data with which to test the Tool. They also provided feedback on the completeness of the tool in capturing a foreman’s responsibilities, the appropriateness of the data analysis and presentation techniques, and the usefulness of the feedback provided to foremen on their performance. The company’s senior management provided similar feedback to help enhance the Tool. Following validation with Ledcor Industrial, a workshop was held with 16 contractors and labour providers, who are potential users of the Tool, to obtain their feedback, all of which was positive particularly because of the software implementation.

The Foreman Skills Development Tool can be used by organizations in a number of ways:

1. To provide foremen with feedback on their skills, and to measure improvements over time.
2. To identify training and mentoring required for foremen to improve their skills in the core competencies.
3. To measure the impact of training or mentoring on the skills of foremen and to monitor improvements over time.
4. To provide foremen with the opportunity to gain recognition for their skills based on their assessment as a basis for promotion.
5. To help the organization to identify site-wide or project-wide issues that may be affecting the ability of their foremen to carry out their responsibilities.
6. To help in identifying company- or industry-wide areas that require further training or mentoring of foremen.
7. To help in establishing an on-the-job component of a formal qualification for a construction trades foreman.
8. To help foreman become more effective in their job, and to develop better trained and skilled foremen, leading to better project outcomes.
Figure 3. Radar diagram showing foreman’s overall mean assessment relative to company’s overall mean assessment (Fayek and Poveda, 2008)

Figure 4. Box plot showing foreman’s overall mean assessment relative to distribution of company’s overall mean assessment (Fayek and Poveda, 2008)
The COAA Supervisory Training and Qualifications Subcommittee is now working on a strategy to market the widespread use of the Foreman Skills Development Tool in the construction industry. This strategy will include promotional material, instructional workshops, and technical support for organizations wishing to use the Tool to assess the skills of their foremen. Central data warehousing and analysis, to provide industry wide data for comparison purposes, is being considered. The IRC continues to support the COAA in these efforts.

This study not only led to a practical and useful solution for the construction industry, but it is also a good example of training of HQP. The graduate student who worked on the research project was hired upon graduation by Ledcor Fabrication as their Facility Process Manager.

5 Future Research

The Senior Chairholder’s ongoing research will focus on the development of a scenario-based planning simulation tool based on the FIATECH Roadmap (2004). Current simulation environments are powerful for single-user issues, but they fail when the problem requires input from a number of users at the same time or at varying locations. The FIATECH Roadmap has articulated a complete vision to aid in the timely, automated, and effective completion of projects, which can only be implemented through a new simulation environment designed to support collaboration among users within the construction industry using high-level architecture (HLA). The next stage of simulation research within the IRC will be based on HLA and construction synthetic environments (COSYE), producing portable, flexible, and reusable modelling components.

FIATECH has emphasized planning in the capital projects industry, as a crucial part of the construction industry that provides infrastructure to the economy, but these principles are valid for any large-scale undertaking. The roadmap proposes a highly automated integrated project planning process using advanced technologies in all phases of the project and its life cycle. Project information will be available on demand for all project stakeholders at any phase. In this integrated environment, all users will be able to interact with each other. This automation of the system and its processes will reduce the time and cost of planning. Scenario-based planning systems will help in selecting the best method of project completion by accurately assessing all options available. The roadmap consists of nine elements as follows (FIATECH 2004):

- Scenario-based project planning
- Automated design
- Integrated, automated procurement and supply network
- Intelligent and automated construction job site
- Integrated self-maintaining and repairing operational facility
- Real-time project and facility management, coordination and control
- New materials, methods, products, and equipment
The focus of the Associate IRC’s ongoing research is on developing hybrid systems for improved decision-making and project planning and control. These hybrid systems will see fuzzy logic concepts integrated with discrete event simulation systems to enhance their ability to capture subjective and linguistic variables and to model different types of uncertainty. Another application of hybrid systems is incorporating neural network training techniques to optimize fuzzy decision-support systems to improve their knowledge representation and rule bases. Improved methods of expert knowledge elicitation and representation will be the cornerstones of the next phase of the Associate IRC research. We will explore methods of extracting data from past cases, historical databases, and expert knowledge to develop more accurate and robust intelligent decision support systems for construction.

6 References


CHAPTER FIVE

CONSTRUCTION INDUSTRY – LABOUR MARKET INFORMATION PROGRAM

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Abstract

The presentation will focus on how the Construction Sector Council leveraged innovative forecasting techniques that today produces data used by industry to develop targeted labour supply solutions and by governments for labour market policy and program development. Mr. Gritziotis will also explain the use of a stakeholder regional network to bring labour market information to life. He will elaborate on the understanding that in order for LMI to be a valuable planning and decision making tool, it must have the benefit of local stakeholder knowledge of both supply and demand.

1 Why an LMI Program for Construction

The main feature of the Construction Sector Council (CSC) LMI Program is the industry’s leadership and support in making LMI a reality for all construction stakeholders. It is an industry driven effort to provide the information needed to make informed human resource development decisions, and labour market policy.

The CSC provides the venue as a central location to collect labour market information and distribute this information to regional stakeholders for analysis and validation. The main objective is to increase construction industry productivity levels on a long-term basis by:
• maintaining the experienced workforce in the construction industry;
• attracting experienced workers back to the industry;
• adjusting the flow of new apprentices so that it corresponds to industry needs, and so that fewer apprentices leave; and
• recruiting qualified new apprentices by offering stable employment to candidates.

To achieve these objectives, construction industry stakeholders need a well-structured LMI program that will enable them to make the right human resource decisions at the right times. These stakeholders include contractors, buyers of construction, labour groups, industry associations, and governments.

1.1 Unique Industry Characteristics

The construction industry represents one of the most important economic forces in the developed world today. In Canada alone, capital expenditures for construction in 2006 exceeded $200 billion. The industry employs one million people, accounting for 6 per cent of total Canadian employment, and makes up more than 12 per cent of our total Gross Domestic Product. Looked at another way, one out of every seventeen workers is involved in construction.

One of the most distinctive features of the industry is the relationship between workers and their employers. In many industries, employers hire workers to meet the demands of the business cycle, usually on a long-term basis. However, in the construction industry, employers are continuously hiring, even during a downturn in the economy. This is due to the temporary nature of construction work itself, and the fact that construction is a very cyclical and seasonal activity.

The construction industry is also a flexible one. In any given year, roughly one-third of construction workers are employed by more than one employer. This captures only part of the mobility of the workforce because even the workers who stay with one employer may still work outside their region of residence or outside their province. The higher construction workforce flexibility also creates a higher turnover rate which increases the hiring requirements of construction firms. Globally, these factors generate a workforce mobility rate that is twice as high as the average for all other industries. After manufacturing and retail, it is the construction industry that hires the most workers in a given year.

If the construction industry was dominated by a few firms, workers looking for employment would only have to contact these firms, and the labour market for construction would function efficiently. But the construction industry is highly fragmented, and many, many firms are operating in the residential and non-residential marketplace. A typical firm hires an average of only four workers, when we count the actual months that the firm is doing construction work. This makes it difficult for unemployed workers to know which firms may be hiring, or the kinds of skills upgrading he or she might need to secure work in the future.

Recruitment is also difficult because the industry’s level of activity is closely linked to investments, the most volatile component of Gross Domestic Product (GDP). Over a downturn of the business cycle, construction activity may be halved and
then doubled again over the next growth period. During the downturn, employment opportunities decline dramatically, even for the experienced worker.

When hiring starts to pick up with the next business cycle, young people may be reluctant to enter the field. This is a critical issue because it takes roughly five years to train a journeyperson. Three to four years of strong growth will have drained the pool of potential experienced workers but the skills of first or second year apprentices won’t be sufficient to meet industry requirements. The call goes out for more apprentices who now enroll in larger numbers in vocational schools during the peak of construction activity. But the shortage of skilled workers remains. Despite an increase in apprentices signed on to meet the rapid growth of the industry, it will still take five years for these apprentices to be properly trained.

These features make the construction industry a challenging environment for any kind of LMI intervention. Managing these peaks and valleys to ensure the construction industry has the skilled labour it requires is the driving force behind the CSC LMI Program. For any LMI program to work, it must take into account the unique features of the industry.

2 How We Did It

At its founding Board meeting, CSC Board members agreed that the industry needed an objective scientific approach to better understanding the supply and demand for labour. CSC staff was instructed to research previous construction labour studies and approaches, consult with industry and governments, and identify best practices with a view to developing an ongoing labour market information capability for the industry. This Board directive led to the early foundation for a construction LMI Program through the following activities:

2.1 Construction Labour Market Studies

As far back as the early 1990s, the federal government, through Human Resources and Social Development Canada (HRSDC), supported several trade specific labour market studies. These studies began to articulate the unique challenges inherent in the construction industry and their impact on the industry’s ability to manage the supply and demand for skilled labour.

2.2 Industry Government Consultations

To update and add to this body of understanding, shortly after the launch of the Construction Sector Council, the council crossed the country facilitating a series of focus groups to identify labour market issues facing the industry. This process also uncovered the need for labour market information and articulated the issues behind the need for solid LMI and a system for anticipating labour supply and demand issues well in advance. It also led to the genesis of industry led Provincial Labour Market Information Committees and the CSC Regional LMI Network.
2.3 Best Practices

The Construction Owners Association of Alberta and the Commission de la construction du Québec had developed their own labour market information and forecasting capabilities. The CCQ LMI capability served the needs of the residential and non-residential sectors in Quebec, while the COAA served the needs of the heavy industrial construction sector in Alberta. Both organizations provided the CSC with the early foundation that led to the design and development of the CSC LMI program that serves the needs of all construction sectors in all provinces / territories in Canada.

This groundwork was an important step on the road to labour market forecasting. It not only helped to build a broader understanding of the issues amongst the key stakeholders but it also provided venues for a variety of groups to come to a common vision of what was needed. Armed with this information and industry support for LMI, the CSC was then able to move forward to develop a comprehensive LMI Program.

3 Key Elements of the CSC Forecasting Tool

In response to the above, the CSC developed a planning and decision making tool in the form of a labour market forecast. The elements of the forecasting tool are:

Provincial/regional approach – matches the provincial/regional structure of the construction labour market.

Regional Network of LMI – committees comprised of key industry and government stakeholders tasked with bringing regional realities to the forecast.

Mid-term and long-term forecast – facilitates planning and the development of supply side solutions.

Macro economic outlook – the construction forecast is grounded in the context of a broader economic forecast.

Construction investment outlook - derived from provincial/regional major project information vetted by provincial/regional stakeholders.

Supply side tracking – builds on the data provided through traditional data sources bringing a greater degree of accuracy and detail.

Labour requirement assessment – provides a quantitative and qualitative analysis of labour requirements for 32 trades/occupations.

4 Success Factors

There are many factors that have contributed to the success of CSC’s LMI Program and our analysis of the program indicates that all of the following must be present:

• Recognition that it is industry and its stakeholders brings life to LMI.
• Ground-swell of industry support for a comprehensive labour market information program.
• LMI Program must respond to an industry identified need.
• All segments of the industry at the regional and national levels must participate in the development of the forecast.
• Governments (all levels) and other key stakeholders must be involved in developing the forecast.
• Forecast must be built from the regional level and then rolled up to present a national picture.
• Key elements of the forecast need to be built in an iterative manner increasing the capability over time.
• Forecast models must be tailored to reflect the unique characteristics and structure of the specific industry.
• Industry leaders must champion the LMI Program within their constituencies.
• Methodology must be, and be seen to be credible and state-of-the-art.
• Forecast must be used for decision making and planning by stakeholders.
• Forecasts must be released publicly at the provincial and regional levels to raise awareness and promote the use of the information.
• Existence of industry infrastructure (e.g. owners, associations, unions, contractor groups, construction education and training community) representing the diversity of the industry that enabled the CSC to tap into a broad cross section of key stakeholders as developer and end users.

5 Components of the Forecasting Program

There are four key components to the CSC forecasting program:

1. Forecast Development Process
2. Macro Economic Outlook
3. Construction Investment/Employment
4. Supply Side Tracking

5.1 Forecast Development Process

The forecasting process involves a number of steps to create the forecast and publish the results. These steps include:

• Establishing a Regional Network of Committees to bring regional realities to the forecast
• Educating the committees on their role and the forecast methodology
• Working with the committees (meet approximately 3-4 times in a forecasting cycle) to gather and vet elements of the forecast and the final report including:
  o Agreeing on key economic assumptions
  o Collecting major projects information
  o Vetting results of macroeconomic forecast
  o Vetting employment and labour force forecasts
  o Agreeing on labour market assessments
  o Reviewing preliminary publication
  o Signing off on final publication
• Working with the committees to jointly release the provincial forecast reports
  o Media and industry events

The CSC can and will share all aspects of this process with any economic sector that is interested in developing an LMI process.

5.2 Macro Economic Outlook

There are three models used to produce the labour demand and supply forecasts. Only one of these models, the macroeconomic model, can be used directly to assist with the production of forecasts of occupations other than construction trades.

The main determinants of future labour supply and demand are those associated with the performance of the provincial economies. In the case of construction trades, for example, the amount of investment in the economy is the key determinant of the level of construction activity and the demand for construction trades. Population and overall labour force growth are important factors behind the supply of labour available to the construction industry as well as other industries.

These determinants are embedded in the macroeconomic model, one for each of Canada’s provincial economies. This model was developed, and is owned and supported by an external firm. It contains a description of the workings of the provincial economies, including the key determinants of provincial economic performance.

This model is not specific to the construction sector. It produces information that can be used in forecasts of the demand and supply for any of the occupations or trades in the economy.

While the macroeconomic model can be used directly in other sectors’ occupation forecasting it may not be desirable to use the CSC outlook produced by the models. The reason for this is that CSC forecast is set with assumptions that mainly drive construction activity such as major project announcements against construction trade labour availability.

Other sectors could use the CSC macro economic outlook or they could contract to develop an outlook based on a different set of assumptions to produce an industry specific forecast. These assumptions would reflect the views of that sector’s LMI committee members thereby leading to a different macroeconomic forecast.

The CSC annually prepares a macro economic outlook. This approach could be shared and adapted by other industry groups (or sector councils). A significant part of the macroeconomic modeling system is setting up a base case forecast.
5.3 Construction Investment / Employment

This model determines employment and labour force for each trade in the construction industry and all other industries in the economy\(^3\). The equations that determine labour force are the same for both the construction and other industries. The equations for employment differ between the construction industry and other industries. The latter equations are similar to those used in the COPS model, while those for the construction industry are driven by construction investment expenditures and seasonal factors.

None of the equations in the CSC system can be used directly for other sector occupation models, since they are calibrated using data on construction occupations. Nevertheless, the structure of these equations – except for employment in the construction industry – can be adopted and calibrated using data on a particular sectors occupational category.

The CSC could share this modeling with other industry groups (or sector councils) that could then adapt it for their sectors’ occupation categories.

5.4 Supply Side Tracking

The supply side tracking model used by the CSC is applicable as a format to other sectors with significant adapting. This includes the method of assessing the labour market. The CSC can share the supply side model with other sectors who can then contract with someone to adapt the model to meet that particular sector’s needs. This model requires adjusting by someone who understands the specific industry and its labour market dynamics.

6 Who Uses the CSC LMI

Although only four years old, CSC’s LMI Program is well-known and highly-regarded within the Canadian construction industry, and is used by thousands of construction industry stakeholders, including businesses, contractors, governments, industry associations, labour organizations and educational institutions. It is regarded as being very applicable, relevant and representative of the industry by an overwhelming majority of industry stakeholders and users.

The CSC examined the use, value and impact of the LMI Program by way of an industry stakeholder survey and focus-group discussions. In total, 350 survey responses and 43 focus group participants contributed to the findings.

\(^3\) Currently, the model determines labour demand and supply of workers in two industry groups “in construction” and “out of construction.”
7 How is CSC LMI Used?

In what capacity do you use CSC’s LMI forecasting tool? (Please select all that apply) (N=132)

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Count</th>
<th>Percent of N=132</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy and decision making</td>
<td>81</td>
<td>61%</td>
</tr>
<tr>
<td>Training/Apprenticeship program planning</td>
<td>79</td>
<td>60%</td>
</tr>
<tr>
<td>Construction project planning</td>
<td>32</td>
<td>24%</td>
</tr>
<tr>
<td>Staffing (employee requirements)</td>
<td>29</td>
<td>22%</td>
</tr>
</tbody>
</table>

For what specific purpose(s) do you use the CSC LMI forecasting tool? (Please select all that apply) (N=131)

| Purpose                                                        | Count | Percent of N=131 |
|                                                               |       |                 |
| Identify and evaluate human resources challenges              | 102   | 78%             |
| General information                                           | 90    | 69%             |
| Make or support policy changes                                 | 68    | 52%             |
| Overcome human resources challenges                           | 55    | 42%             |
| Make sound budgeting and planning decisions                   | 35    | 27%             |
| Help minimize business risks                                  | 27    | 21%             |
| Identify and evaluate business opportunities                   | 21    | 16%             |
7.1 Value of the CSC LMI

The general consensus is that LMI forecasts are very applicable, relevant, and representative of industry. Responses ranged from valuable to very valuable. None of the respondents found that the CSC LMI program was not valuable.

8 Benefits Realized by Users

The respondents identified a number of benefits emerging from the application of LMI forecasts in their organizations, particularly when developing facilities and managing human resources. The LMI forecasts provided the rationale (based on reliable statistical information) for the development of a significant facility and program expansion in order to meet increased apprenticeship and certificate training at the provincial level. They have served as support criteria in determining the need to open up a training center for heavy equipment operators in central Alberta. The CSC LMI have been useful in recruiting students to construction programs at one college and has also helped to validate the recent expenditures in this discipline at the college resulting in new lab space, renovations, and equipment. The data provided served as a catalyst to engage contractors and the community college system in New Brunswick to offer training courses for heavy equipment operators. Similarly, the LMI have given the plumbing industry much needed data to assist its training providers in becoming more proactive with its training needs and have helped focus the training program needed for a major $1.5 billion hydro development project.

The LMI forecasts have also been valuable sources of economic and political information across Canada. They have assisted in evaluating general economic forecasts in British Columbia by providing an independent assessment of the trends in the construction sector. When B.C. first decided to make drastic changes to the carpentry trade to suit residential construction needs, policy-makers had no empirical data upon which to base what those in the industry knew anecdotally to be true. CSC’s inclusion of residential reporting has now provided the tool needed to substantiate our reports with timely geographical data. In the past, empirical data, from Statistics Canada was usually not specific to B.C. in these ways. CSC has changed the use of these resources, and trade leaders now send copies of CSC LMI reports to all Ministers and MLAs. The LMI forecasts have also been used to analyze potential migration to Alberta from other provinces for a multi-billion dollar oil sands project; these were subsequently used to develop and prioritize supply mitigation strategies for an industry association. This data has provided a real source of labour market information to the New Brunswick construction association. The reports are referred to in briefs to politicians, used a data source in presentations to educators, quoted in media releases, and provided to contractors for project purposes. Clients want information to minimize their risks and the CSC LMI Forecasting Tool is becoming the best tool to provide information on labour availability in the country.
8.1 Training and Apprenticeship Benefits

The LMI forecasts developed by the CSC have begun to change the construction industry from the ground level by standardizing and improving training and apprenticeship. Forecast data helped to identify where money should be invested in trades training over the long term and shaping promotional efforts and information to youth and the public regarding career decisions. The facts and projections have been employed in explaining the state of the industry to media and the public. In job centres, patrons have been encouraged to explore expanding job markets and anticipated regional demands and focus on making informed career/training decisions.

In terms of recruitment, the LMI forecasts provide a basis for promoting careers in construction to high school students while explaining the cyclical nature of the work. It has been helpful in bringing awareness to the local school district about the need to increase vocational training. It helped to stress the urgency of skill shortages in the industry and the need for quick response and provided information as to which trades are/will be in demand, thereby giving direction to youth considering the trades as a career. The reliable data assists clients in making sound decisions before committing to a new training program for the longevity of their career and financial situations. The different regional reports also aid them by showing where work might be in the near future.

At the college and apprentice training level, the LMI forecasts have assisted with research on apprentice intakes and apprentice training curriculum. This includes determining future program offerings, defining proper allocation of resources, determining the challenges associated with recruiting faculty, and providing tools for marketing and promotion. Further, they have aided in scheduling training programs to meet the forecasted related work. The forecast data have been used to assist colleges in deciding what areas of instruction need an increase in capacity and to re-evaluate apprenticeship training models.

The LMI reports have assisted in better understanding and planning for the growing training demands within individual provinces. They have been used to support decision making around which trades training provinces should be investing in to assist with skills shortages. For example, the forecasts have been a catalyst in prompting the need to engage contractors and the community college system in training courses for heavy equipment operators in the province of New Brunswick. The LMI have provided support to the decision to expand trades training facilities in Saskatchewan. They have also been applied in modifying training centers to handle the wave of upcoming apprentices and have served as support criteria for the intention of opening a training center in the central area of Alberta, dedicated to the training of heavy equipment operators.

At the industry level, the LMI forecasts have been used to recognize the need to solicit and train apprentices. Retirement rates and industry activity prove we need to "build" more tradesmen, and this data has alerted the contractors and various associations within construction of the need to train. In planning ahead, the LMI
have helped to evaluate apprenticeship requirements for present and future projects and assisted trades in making decisions on ratios. In one instance, trade leaders were able to use the LMI to help predict the required number of apprentices at the optimum ratio for maintaining a sufficient size of workforce to satisfy the needs out to 2014. The forecasts assist in motivating trade organizations to explore new ways to develop the delivery of apprentice training programs and plan for an increase in the numbers of apprentices they are prepared to train in terms of finances, instructors, facilities and equipment. They are used within organizations to ensure that we keep good training levels, specifically in supervisor training and apprenticeships, based on predicted future needs within particular trade areas. For example, the forecasts have been used as part of an analysis of the labour and skill shortages and training challenges for the heating, ventilation and air conditioning industry. They have also provided the plumbing industry with much-needed data to assist its training providers to be proactive with training needs both in rural and urban areas and changing curriculum and training techniques to meet industry needs.

8.2 Policy Benefits

The CSC LMI forecasts provide the kind of accurate, trackable data needed by provincial governments to make effective policy decisions. They have supported policy positions and statements made on issues such as apprenticeship training, the need to develop domestic labour market pools before looking to quick fix solutions (i.e. temporary foreign workers), the need to support policies that build in stability for the industry (e.g. project labour agreements, prevailing wage rate legislation, stronger qualification assessment, standards and certification requirements, stronger OH & S regulations and compliance measures). In doing so, this data has helped make the case for more investment in apprenticeship and trades-related policy. As outlined above, the reports provide an overview of labour trends that assist in policy decisions regarding education and training as well as targeting industry promotion.

Within individual provinces, LMI data has been used during policy making discussions for a Provincial Nominee program, has guided decisions to invest in and enter into longer term collective agreements, has been used to plan apprenticeship funding, and has provided guidelines for other funding decisions for EI clients. Generally, industry association public policy positions can be more strongly reinforced by the labour data, such as the Alberta report providing context for policy positions regarding the development and promotion of a skilled workforce, and when changes were implemented to the outdated, un-enforced and unattainable trade ratio requirements in Saskatchewan.

8.3 Information Benefits

By collecting and analyzing data from a range of sources across the construction trades, the LMI forecast reports provide a wealth of information for different stakeholders in the construction industry. These provide a good measure of future
activity, training needs, and demographics of the industry generally and for specific trades. Research information can be used for writing standard occupational profiles for the construction industry, used as part of an economic background information package, and to offer concrete, well-sourced figures for industry and government reports.

In terms of planning, the LMI forecasts provide industry-specific data about the skills in demand within the construction sector, the nature of this demand, and trends in the industry that can be passed on, with confidence, to workers, potential workers, and to employers. These are used to increase the overall understanding of labour strains in the sector and to assist with planning for skilled worker requirements over the next five years.

Within labour organizations, communications personnel are better equipped to provide members with information on what work is available, and where that work is located. Organizations are encouraged to provide information from the LMI to their membership. The reports can be used to put together an economic position and labour market conditions-overview for members. This data can also have strategic impact, aided in decisions to target business owners when undertaking LMI for particular sectors, such as residential construction.

Regionally, The LMI forecast data have also had significant impact, providing a good overview of economic activity in the area. They have assisted in evaluating general economic forecasts for B.C. by providing an independent assessment of the trends in the pace-setting construction sector. The reports have also been used as a source of information when preparing the Greater Toronto Area labour market quarterly bulletins. The data provides useful information for planning regarding apprenticeship training proposed projects and labour requirements for the future in Atlantic Canada and other areas in Canada. As well, the LMI have informed and justified the requirement for, and mutual benefit of, a CHBA-Alberta/Alberta Employment, Immigration and Industry partnership.

8.4 Occupational Forecast Benefits

The LMI forecast reports have been very useful for provided information for client(s) in occupational goal setting/preparation. Used with other sources, they can often identify trends, issues, and even areas where there are conflicting messages. This synthesis aids in developing long-term strategies based on future labour source demographics. LMI data have aided in projecting manpower supply that will be needed in certain provinces and where there may be resources that can be utilized from slower regions in the country. For example, the reports helped policy makers in understanding demand/supply imbalances in the trades sector. This information was used as a source (with other sources) in determining occupational trends, which are described in Manitoba Job Futures (http://mb.jobfutures.org/). The LMI provided quality analysis for the occupational profiles of 203 Occupational (NOC) groups in Manitoba, helping particularly with employment requirements and, in some cases, training. When working with industry sub-sectors on the development of retention and
recruitment strategies, the labour supply and demand and retirement statistics from the CSC forecasting tool are invaluable.

8.5 Foreign Worker Benefits

In considering total resources and demands within the construction industry, LMI forecasts have helped in the analysis of the need for a Foreign Worker program within the construction trades. The reports aided in determining the requirements for foreign workers for major upcoming construction projects and assisted in the development of the LMO submission for the Temporary Foreign Worker (TFW) program through Service Canada.

8.6 Aboriginal Worker Benefits

Regional and demographic data presented in the LMI forecasts have aided in aboriginal labour projects, employment equity programs, and the development of attenuated training programs. These have positively impacted on program planning/development in the area of Aboriginal apprenticeships within Ontario.

9 Conclusion

In conclusion, our experience over the past four years in the development of an LMI Program has taught us that this type of LMI approach must be industry specific and can only be successful if it is developed in response to an industry identified need. It is too labour intensive and too comprehensive to be embarked upon without significant industry support and input, and existing expertise.

The program must be built in the context of the specific industry, reflecting those realities and incorporating the factors that drive and in all ways affect the structure and functioning of the industry. This is not a one size fits all exercise.
CHAPTER SIX

DEVELOPMENT AND DELIVERY OF BEST PRACTICES IN THE ALBERTA CONSTRUCTION SCENE

John Brogly
Chair, Best Practices, Construction Owners Association of Alberta

Abstract

The Construction Owners Association of Alberta (COAA) has developed 23 Construction Best Practices to date in the areas of Safety, Workforce Development, Productivity and Contracts. A brief description of each best practice is provided along with an assessment of factors that impact the success or failure of best practice development and deployment.

1 Introduction

The Construction Owners Association of Alberta (COAA) is the principal industry association for heavy industrial construction in Alberta, providing leadership to enable our owner members to be successful in their drive for safe, effective and productive project execution. One of the primary means of achieving this mission is through creating and promoting industry best practices. The COAA was founded in 1973, but efforts to develop industry best practices didn’t begin in earnest for 20 years with the inaugural COAA Best Practices conference in 1993. The first published COAA Best Practice, an Owners Guide to Contractor Health and Safety which addressed owner requirements for contractors’ health and safety management systems and included a standard pre-qualification process, was
completed in Feb. 1997. In the last 12 years, the pace of best practice development increased significantly. Today, a total of 23 Best Practices have been developed and implemented with several more in progress in four strategic areas: Safety, Workforce Development, Productivity and Contracts. While there are many factors determining the potential success or failure of these best practice initiatives, two factors predominate:

- Owner leadership and collaboration
- Effective means of best practice deployment

This paper provides a short overview of each of the 23 Best Practices completed to date and explores the impact of the two factors noted above in both the development and deployment of construction best practices. A brief overview of best practices under development is also provided.

2 Synopsis of COAA Best Practices

COAA Best Practices are developed by committees composed of owners, construction contractors, engineering firms (EPCM, EPC), labour providers, government, other industry associations and other vested stakeholders including universities and other research groups that may be involved in pilot work. While there are standing committees for each of the four strategic best practice areas and for best practices like the Supply-Demand Forecast which produce deliverables each year, the majority are formed based on an agreed objective and set of deliverables and sunset once the work is completed.

2.1 Safety Best Practices

The COAA Safety Committee’s goal and strategic development areas are noted below:

“Leadership in safety ..... no one gets hurt in heavy industrial construction”.

- Identify and facilitate resolution of emerging safety issues.
- Ensure safety best practices lead industry best practices and legislation
- Lead implementation of the Canadian Model Alcohol and Drug Guidelines.
- Establish common safety training tools and practices.
- Promote COAA's position on safety and make it readily available on the COAA website.
<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>OVERVIEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behaviour-Based Safety</td>
<td>Based on the ABC (Antecedents-Behaviour-Consequences) model for behaviour management. Critical safe behaviours are identified, behaviour audits conducted, data analyzed and interventions applied using the ABC model.</td>
</tr>
<tr>
<td>Canadian Model for Providing a Safe Workplace</td>
<td>Alcohol and Drug Guideline and Work Rule including testing protocols for pre-access, post-incident and for-cause testing aimed at reducing safety risks due to alcohol and drug use and effects in the workplace. Includes requirements for education, training and post-test interventions.</td>
</tr>
<tr>
<td>Construction Safety Training System (CSTS)</td>
<td>Comprehensive computer-based construction safety training required by all COAA members as a pre-requisite to site access. Provides common safety training, reducing the requirements for site indoctrinations.</td>
</tr>
<tr>
<td>Contractor EH&amp;S Management</td>
<td>Owner requirements for contractor EH&amp;S systems including pre-qualification, contractor selection, contractor mobilization and contractor performance evaluation.</td>
</tr>
<tr>
<td>Cranes and Hoisting</td>
<td>Owner requirements for cranes and hoisting including training, competency, maintenance, inspections and procedures for lift planning.</td>
</tr>
<tr>
<td>Field Level Risk Assessment</td>
<td>Risk identification and mitigation system designed for use by workers at the work face. Includes training and implementation guidelines.</td>
</tr>
<tr>
<td>Leading Indicators</td>
<td>Owner and contractor best practice identifying the optimal leading indicators (measurements) for an effective safety management system.</td>
</tr>
<tr>
<td>Modified Work Programs</td>
<td>Contractor best practices for early return to work following a workplace injury.</td>
</tr>
<tr>
<td>Workers at Risk – Mentoring</td>
<td>Safe work practices and mentoring for workers under 25 years of age</td>
</tr>
</tbody>
</table>
2.2 Workforce Development

The Workforce Development Committee’s goal and strategic development areas are:

“The right skills in the right place at the right time.”

- Collect, analyze and/or disseminate construction workforce supply and demand information.
- Develop strategies to influence key decision makers in order to increase the availability of construction workforce in Alberta.
- Identify and develop best practices that positively affect supply and effectiveness of the construction workforce.
- Influence and collaborate with others (including associations, governments and educational institutions) to achieve COAA’s goals.

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>OVERVIEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alberta Industrial Projects Workforce Graph</td>
<td>User-friendly database developed jointly with the Construction Sector Council (CSC) where owners input trade worker requirements for large projects (&gt; $100 million). Enhancements include turn-around demand.</td>
</tr>
<tr>
<td>Apprentice Best Practice Booklet</td>
<td>A training booklet for apprentices to document on-the-job training and skill development, helping ensure both apprentices and journey persons have positive learning experiences.</td>
</tr>
<tr>
<td>Apprentice Mentoring</td>
<td>Comprehensive program for developing apprentices, including choosing and training mentors, mentoring agreements and action plans and an owner / contractor implementation guide.</td>
</tr>
<tr>
<td>Trade Up - Careers in Construction CD-ROM</td>
<td>Developed jointly with CAREERS: the Next Generation. An interactive CD-ROM with information on construction careers and targeted at junior high school students to increase interest in construction trades apprenticeships.</td>
</tr>
<tr>
<td>Essential Skills Toolkit</td>
<td>Developed for workers who are skilled at their trade but require upgrades to their skills in reading, writing and math. Includes a comprehensive list of training resources available in the province.</td>
</tr>
</tbody>
</table>
2.3 Construction Productivity

The Workforce Development Committee’s goal and strategic development areas are:

“World-class productivity in heavy industrial construction.”

- Promote adoption of Workface Planning and Rework Reduction.
- Produce the Alberta Benchmarking Report.
- Develop a long-term strategy for benchmarking.
- Identify the next opportunities in productivity.

The COAA Productivity Best practices fall into three distinct areas: Re-work Reduction, Benchmarking and Work Face Planning.

Rework Reduction best practice development started in 2000 and, along with a standard definition of Field Re-work, a series of tools were developed primarily aimed at Owners and engineering companies to help collect data on and reduce the causes of re-work at various project development stages. The tools include:

- Construction Execution Plan Checklist (spreadsheet)
- Engineering and Reviews Checklist (spreadsheet)
- Field Re-work Data Collection
- Measuring and Classifying Construction Re-work
- Project Rework Reduction Tool (interactive CD)

Benchmarking committee activities started in 2003. By 2005 a formal relationship was established with the Construction Industries Institute (CII) at the University of Texas in Austin which lead to the development of a web-based benchmarking survey / questionnaire based on a CII model and modified to meet the specific requirements of the COAA.
needs of the COAA Benchmarking Committee. Training on the questionnaire was conducted in 2006 and 2007, followed by data input and culminating in the production of the Alberta Report in 2009. A total of 78 Alberta projects were initiated in the benchmarking system and of these 37 completed the data input prior to the report cut off August 2008. Project performance metrics included cost, schedule, safety, change and re-work. Productivity metrics assessed both engineering and construction productivity, overall and in specific disciplines. The effectiveness of 14 project Best Practices were assessed for their impact on performance metrics. Eighteen COAA-specific metrics were included such as comparison for direct and indirect costs, use of modularization, overtime, peak workforce and overtime. Finally a comparison was made between Alberta projects and comparable projects in the CII database for the United States.

Work Face Planning committee activities also started in 2003. The goal of workface planning is to ensure that the materials, tools, people, equipment and information are all at the workface when needed to maximize tool time and productivity. The committee developed fourteen “rules” for successful workface planning along with planning tools, audits, Field Installation Work Package templates and examples and a complete implementation guide. In addition, it became clear that workface planning would not be implemented successfully if the activities were expected to be completed by the construction foreman, so a new construction job description was developed: the Workface Planner. In 2006 a partnership with the Southern Alberta Institute of Technology (SAIT) helped create a training course for Workface Planners.

2.4 Contracts

The Contracts Committee was formed in 1998 to attempt to standard construction contracts in Alberta, reducing the contract development effort required by owners and contractors and ensuring there was a balance in risk sharing. Standard contracts also enables the other best practice committees to include (where feasible) the requirements for their best practices in the construction contract. To date, contracting philosophy and standard documents have been developed for Stipulated Price Contracts, EPCM Contracts and EPC Contracts.

3 Construction Owner Leadership and Collaboration

In some construction sectors, owner organizations don’t exist or aren’t very active, so contractor associations are the prime drivers of industry-wide improvement. However, in the heavy industrial sector, it became clear early in the COAA’s best practices journey that successful development and implementation of industry best practices required not only direct owner involvement, but owner leadership. The reasons for this are easy to elucidate, particularly in the area of safety where there are direct benefits in both safety performance and cost that accrue to the owner.

Heavy industrial construction is characterized by large projects on sites where the owner often has large staff workforce or for green-fields projects, certainly will
have one upon completion of the project. Operation of heavy industrial complexes is inherently risky to people, the environment and assets, so owners usually have very well-developed safety, health, environmental and loss management programs. In years past, these programs were developed primarily for operations and often owners were less concerned about the performance of contractors on their sites, particularly construction contractors. This double-standard wasn’t likely to last, particularly when large projects require construction work forces that can dwarf the staff numbers.

As a result, times have certainly changed with most owners now having aggressive safety goals for both staff and contractors. Often there are dozens or even hundreds of contractors executing the work, with hundreds or thousands or workers, so without proactive owner requirements and involvement (and often even with it) contractor performance will be highly variable and will likely not meet owner goals.

While improved safety performance for construction contractors will invariably result in better overall performance, in the short run, it costs more than it saves. Contractors are unlikely to take these costs on unless they are a requirement of the owner. Needless to say, if most or all owners in the sector require a particularly safety program, compliance for construction contractors is a matter of survival. Furthermore, there can be significant cost savings for all owners to develop common industry safety programs.

There are a couple of excellent examples of how owners have benefited in both lower cost and improved safety performance: Construction Safety Training System (CSTS) and the Canadian Model – Alcohol and Drug Guidelines and Work Rule.

CSTS is a computer-based construction safety training program with content that covers both legislative and owner minimum requirements for safety training and site indoctrination. Before the use of CSTS, heavy industrial owners had long site indoctrination programs, often two full days, which all workers were required to take in spite of the fact that the most workers may have been at other owners’ sites within the last year that had almost identical site indoctrinations. Owner’s paid for the workers time during indoctrinations, so the cost to the industry was quite high. Development of CSTS required owners to standardize many of their safety requirements; the computer-based delivery meant that workers could take the training off-site. The result was that site indoctrinations would take a few hours rather than a couple of days with consistent content and the computer-based delivery offered the potential for workers to take the training on their own time.

However, when the program was first released, contractors were reluctant to make it a pre-employment requirement for their workforce since not all owners required CSTS before accessing their sites. Because of this, owners often allowed workers to start work on site without CSTS certification to avoid delays in mobilization with a requirement that they get CSTS-certified within 3-6 months. Needless to say, this partially defeated the purpose of CSTS and certainly wasn’t easy to manage.
About three years after CSTS was released, all owners in COAA finally agreed to make it mandatory for accessing their sites. This required all workers in the sector to ensure they had CSTS certification as a condition of work in the industry and made it easy for contractors to insist on it as a condition of employment. Ultimately, owners benefit with improved safety training and consistently and lower indoctrination costs. To date, over 100,000 workers have taken CSTS and contractor organization in other sectors (Calgary Home Builders Association for one) have made CSTS certification a requirement. A conservative estimate of the cost benefit to the heavy industrial sector is over $30M per year.

The Canadian Model was an attempt to reduce the risk of safety incidents in heavy-industrial construction by reducing the risks associated with the use and impact of alcohol and drugs in the workplace. The Model was first published in 1999 and has undergone two revisions, one in 2001 and again in 2005. The current model addresses for-cause testing and has provisions for pre-access and random testing along with a fully-developed protocol for dealing with failed tests or refusal to test. While all owners generally agreed that this was a worthwhile endeavour, some owners were much more proactive than others in requiring compliance to the model. As a result, support for the Canadian Model including the provision for pre-access testing built slowly over a few years. In this case, owners that delayed implementation the program came to the realization that workers who couldn’t pass the pre-access tests at other owner sites were likely to migrate to owners that had no such requirement with potential dire implications on safety performance. This inherent self-interest drove the balance of owners to implement the program.

Much like safety, owners have historically left the area of construction workforce development in the hands of construction contractors. When there is an ample supply of workers, this makes some sense. However when demand for workers approaches or exceeds supply, the resultant increases in costs are invariably borne by the owner.

As already mentioned, heavy industrial projects are often large enough to have profound impact on the availability of workers. In Alberta, large projects can have peak workforces that approach 10,000 workers. To make matters worse, construction contractors are in competition with each other to attract workers, so there may be little or no incentive to cooperate with each other. For instance, during the construction peaks in 2001/02, contractors provided worker incentives which resulted in workers moving from employer-to employer, often on the same owner site. In this case, lack of direct owner involvement and leadership is a recipe for disaster. The exact role of the owner in workforce development depends on the goal of the best practice.

The following examples serve to illustrate how owners have either a participatory or leadership role in construction workforce development: Essential Skills, Supply-Demand forecasts and best practices or other initiatives that impact the supply of workers.
The Essential Skills program was developed to improve the literacy and numeracy skills of older workers who may not have participated in formal education to become journeyman in their trade. Improving their literacy and numeracy skills makes them safer and more productive workers. COAA owner members have participated by simply providing facilities on their sites for Essential Skills training organizations who conduct the courses in the evenings, a strategy that is particularly effective if the majority of workers are in camp during work cycles.

On the other hand, Supply-Demand Forecasts clearly require owner leadership as contractors are not in a position to forecast project demand. COAA owner members have collaborated in providing demand data for large projects in Alberta and in a Supply-Demand annual forecast since 1996. Initially done on a simple spreadsheet, a collaborative effort in 2004 and 2005 with the Construction Sector Council, a national federally-funded association resulted in a user-friendly database where owners could input data directly. In fact, until the fall of 2008 where economic uncertainty made project forecasts almost untenable, owners allowed the project data they supplied to the database to be displayed on the demand graph as individual projects. This demand data is in turn used in the annual Supply-Demand forecast. The fact that owners provide the data directly to the database lends credibility to the forecast, in spite of the fact that owners have historically been over-optimistic about their ability to fund and execute projects.

The forecasts provide ample motivation to both owners and contractors to collaborate on best practices and other initiatives that improve the supply of workers to the industry. Some examples are:

- Trade-Up CD ROM to increase interest in apprenticeships
- Initiative in 2001 to train welders for the industry using a compressed curriculum to increase the supply of journeyman welders.
- Work with Apprenticeship and Industry Training and Government of Alberta to increase the training capacity of apprentices. Apprenticeships in Alberta have doubled since 2001 - from 35,000 to over 70,000
- Stream line the process of obtaining foreign workers. Collaboration with the provincial and federal governments in 2004/5 resulted in a Memorandum of Understanding on the importation process.

One final note on owner involvement and leadership in the construction sector: often, owners are unable or unwilling to collaborate, particularly in areas where they are in direct competition with each other. As a result, the COAA’s best practice efforts focused initially on safety and workforce development, areas where collective efforts produce results much greater than the sum of the parts. This track record of success has built trust and enabled collaboration in areas that might have been considered a competitive advantage in years past. This includes the best practices in areas of reducing re-work, standard contracts and construction productivity.
4 Effective Means of Best Practice Deployment

Some best practices of the COAA have become standard practice in the industry while others have struggled to find traction. One of the significant determinants of where a best practice will end up on this continuum is the robustness of the delivery system.

When the COAA best practices efforts started, it was generally assumed that committees would collaborate to create a best practice document, provide a simple implementation guide and share it at the annual Best Practices Conference and expect (or hope) that the practice would gain acceptance in the industry. The COAA didn’t have a web site (if you can believe that!) until 2001, so the annual conference was the main communication tool.

While this doesn’t appear to embody a robust delivery system, for best practices like Field Level Risk Assessment, this was all that was required. Both owners and contractors recognized early on that this simple tool was an excellent means to effectively engage construction workers in actively managing their own safety and the safety of their co-workers each day. As a result, virtually every owner and contractor in the heavy industrial sector uses some form of Field Level Risk Assessment.

For best practices where the main deliverable is information, like the Alberta Industrial Projects Workforce Graph and the Supply-Demand Forecast, the simple model of sharing at the annual Best Practices Conference and making these available on the website has resulted in extensive use of these tools by industry. As already noted, some best practices are adopted quickly with a simple deployment system due to other factors like not wanting to be the last company to implement the Canadian Model.

Some best practices by their nature require a much more robust delivery system for effective deployment in the industry. The COAA has about 20 Owners members, dozens of contractor members and hundreds of volunteers working on best practice committees, but the COAA itself is a very small organization with $1 \frac{1}{2}$ full-time people. So while these volunteers span a wide range of knowledge and experience, making them ideal for developing best practices, a formal organization as small as the COAA and a group of volunteers simply can’t support the longer-term, sustained effort required to support the implementation of dozens of best practices. As a result, some of the best practices that have become (or are becoming) boilerplate in the industry have been implemented in partnership with organizations that have aligned interests. A few examples will illustrate this: Construction Safety Training System (CSTS), Workface Planning, Re-work.

In the case of CSTS, the initial development work for this computer-based learning tool was completed by a software development firm, but the COAA didn’t have the infrastructure required to deploy the training. Fortunately the Alberta Construction Safety Association (ACSA), whose primary mandate is developing and delivering construction safety training, stepped to provide the infrastructure to manage the
deployment. The COAA is also active on the ACSA board, so when new best practices came along like Field-Level Risk Assessment, these could be incorporated into CSTS revisions.

The Workface Planning Committee realized early in the best practice development work that a training program would be required for the Workface Planner. So while deliverables like the job description, pre-requisites, implementation guide, assessment / scoring tool and Field Implementation Work Packages were developed primarily by committee members, a Request for Proposal was send out to a large number of interested parties for development and delivery of the required training. The work was eventually awarded to Southern Alberta Institute of Technology (SAIT) who developed a one-day overview course and a one week Workface Planner course. So while we are still in early stages of deployment, it is clear to see that there is an effective delivery system that has the potential of making Workface Planning as common in the industry as CSTS is.

On the other hand, while the Rework committee along with the University of Alberta developed excellent tools for measuring re-work along with identifying and preventing the causes of re-work, the deployment model used was workshops at the annual conference and making the tools available on the website. While there are certainly some owners and contractors who have made very effective use of these tools, it is fair to say that industry deployment has not met expectations. To date, the COAA has not developed an alternative deployment strategy, so it is unlikely that the use of these tools in industry will increase significantly in the near term.

5 Best Practices Under Construction

The COAA considers construction best practices a journey, not a destination. So not surprisingly, there are a number of best practices and initiatives at various stages of development in each of our four strategic areas. Some of these are revisions to existing best practices while others are new initiatives. It is also fair to say that given the importance of effective deployment of best practices, all of the COAA committees are looking at innovative strategies to improve implementation of existing and new best practices.

Safety: the most pressing initiative is in the area of Alcohol and Drug policy, where a joint effort is underway with the Government of Alberta to develop and implement a pilot project in the heavy industrial construction sector by June 2009. Other safety initiatives include updating the Cranes and Hoisting best practice, new best practices on Incident Investigations and Noise Management and a collaborative effort with the Health and Safety Network on training records.

Workforce Development: An absenteeism study is underway with the University of Alberta to look at the causes and impacts of absenteeism and eventually develop a best practice to minimize both absenteeism and its effects. Following up on the success of the Construction Trades Foreman Skills Development tools, an Industrial Construction Crew Supervisor website and tools is in progress with an expected
completion date this year. An area that the COAA has not enjoyed much success in
to date is likely to change for the better with a new joint initiative with Women
Building Futures to increase the number of women in the construction trades
through a combination of owner commitments for female apprentices and best
practices to better condition the workplace.

Productivity: with the completion of the Alberta (Productivity) report, a significant
number of improvements are planned to the benchmarking program with CII over
the next two years. The WorkFace Planning

Committee is working on a Path of Construction best practice to improve workface
planning implementation. There are also several innovative WorkFace Planning
initiatives to improve implementation including a WorkFace Planner network and
a WorkFace Planning workshop planned for the fall of 2009.

Contracts: the contracts committee is surveying owners to determine the extent of
implementation of the existing contracts best practices and to develop strategies to
increase their use.

6 Summary

The COAA has and continues to develop construction best practices that help
ensure the COAA achieves it mission of providing leadership to enable our owner
members to be successful in their drive for safe, effective and productive project
execution. To date, 23 Best Practices have been developed in four strategic areas:
Safety, Workforce Development, Productivity and Contracts. Several more are in
development. Key factors that impact the success or failure of best practices
development and deployment are owner leadership and collaboration and an
effective means of best practice deployment.
CHAPTER SEVEN

OPTIMIZING WINTER CONSTRUCTION

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Abstract

Large-scale construction projects usually span the winter months, with accompanying cold temperatures. Cold weather substantially lowers the efficiency of construction. Mitigation actions could lower the cost and schedule impact of cold weather. This paper discusses the effect of winter on construction personnel and operations. This research indicates a way of planning not only construction operations but also the overall project timeline to account for winter weather. The method offers ways of using cold weather to the project’s advantage by fully utilizing the heavy haul transportation window. A construction dome is introduced that offers substantial access flexibility while maintaining a shop-like environment on a construction site.

1 Introduction

Adverse weather can have a detrimental effect on construction costs and on the overall duration of a construction project. Planning does not always consider the full implications of adverse weather. There are several measures that can be taken to mitigate and to minimize the effects of adverse weather.

In general, construction contractors seem ill-prepared for timely response to adverse weather. The literature covers the effects of low and high temperatures to some extent but offers little guidance on mitigation actions and steps that can be
taken to avoid negative impacts on cost and schedule. Labour productivity deterioration as it relates to changes in temperature has also been studied to some extent.

This paper focuses substantially on the effects of adverse weather on construction in northern Alberta, Canada and specifically on projects related to the Canadian oil sands. All of the proposed expansion of fundamental principles may not be applicable to other areas where cold weather construction takes place.

2 Objectives

The first objective of this paper is to add to published fundamental principles for mitigating the negative effects of adverse weather as well as for planning work around winter to minimize the effects of winter while using winter for the benefit of project execution.

The second objective is to introduce the concept of a construction dome that offers flexibility in location and access while maintaining a shop-like environment on a construction site.

3 Effects of Cold Weather on Construction Productivity

Construction efficiency and productivity decreases during the colder months. The specific impact of cold temperatures was researched by Thomas et al. (2009), who concluded that “an average loss of labour efficiency from cold temperatures is around 50%”. They used temperatures below 20°F (-7°C) as the basis for a “cold temperature”. Some of the causal factors that may cause drops in productivity include the layers of clothing needed for warmth, the time duration that labourers can endure exposed to cold temperatures and wind chill, safety concerns with respect to slippery conditions, and visibility.

A normal set of clothing required for moderate cold weather construction work is shown in Figure 1. The effect of cold weather on the human body was addressed by Koehn et al. (1985). “At 10°F [-12°C] unscheduled warm-up and urination breaks were taken, and at 0°F [-18°C] workmanship deteriorated”. The time taken to undress and dress up again to address these bodily needs has a direct impact on cold weather construction productivity. The effect of wind chill was calculated by Gunars (1986). A wind speed of 20 mph [32 km/h] drops the air temperature from 0°F (-18°C) to a wind-chill equivalent temperature of around -30°F (-34°C). Heavier winter clothing will thus be necessary as the temperature gets colder or as the wind speed increases. The literature does not offer any guidance on the effect of wind chill; no conclusion can be made that both wind-chill and cold temperatures have the same effect, or reduce construction productivity to the same degree.
4 Effects of Cold Weather on Safety

McFadden et al. (1991) describe the effects of working in the cold as “inherently more dangerous than similar work in a warm climate”. They suggest that “the reaction times of the individuals are slower when they are cold, and heavy clothing interferes with movement, vision and hearing”. Short days (fewer daylight hours), slippery footing, and objects, ditches and inclines hidden by snow create unsafe conditions typical to cold weather construction. Visibility through windows that are frosted over is poor to nonexistent, and it can cause delays due to the time taken to defrost windows before mobile equipment can be used.

5 Principles of Weather Mitigation

Thomas et al. (2009) published a table detailing their suggestions for the fundamental principles of weather mitigation. They claim that “if these principles are followed, contractors can avoid losing large sums of money”. They intentionally left the principles general for greater applicability to a wide range of projects and conditions.

The principles cover specific sections, including: general management, excavation and site work, labour, and materials. The general section covers works schedules, annual cycles, schedule acceleration, reservation of work that can be done on inclement workdays and enclosing of buildings for weather protection. Excavation and site work addresses daily sealing of exposed areas, effective site drainage, the
possibility of early installation of permanent draining facilities, providing adequate working surface, ploughing wet ground to accelerate drying, all-weather roads and using the snow as insulation until the work area is needed. The principles suggested for labour include shifting work-hours and considering break trailers. The materials section covers protection and using pallets for material storage.

These principles can be used by owners as well as contractors for alternative planning of construction around the adverse winter effects, as well as planning differently for all the activities leading up to construction.

6 Effective Winter Construction

The annual cycle principle is defined by Thomas et al. as follows: “Use annual cycles to schedule around trades most affected by weather”. The erection of all equipment can be done cost effectively in cold weather. Road preparation from the lay down yard and for tailing cranes can be easier in winter frost conditions than in muddy soft soil conditions. Fewer crane mats are usually required, and the lifts are generally as safe as in warm weather. Module erection is also an activity that can be done cost effectively in cold weather conditions. Large and heavy modules can be transported effectively on site on frosted roads and can be lifted into place. This activity can open up substantial work fronts for cost effective construction when better weather conditions arrive. Piling work can also be undertaken sometimes more cost effectively in winter frost conditions than in hot weather conditions as less surface preparation is needed when the ground is frozen. The frost in the ground does not affect the cost of drilling piles substantially.

Ideally, winter and cold weather conditions can be used to the benefit of the project and for construction despite their negative effects. Winter temperatures can be used to maximize the weight of heavy load transportation, and they improve the effectiveness of the erection of heavy equipment as well as large heavy modules.

The Government of Alberta maintains a program controlling heavy hauls on the road system based on seasonal changes. They publicize a “spring season” on their website (http://www.infratrans.gov.ab.ca) when road bans are in place. During winter, it is permissible to transport heavier loads than in summer, allowing for the transportation of larger and heavier equipment. Better economy of scale on the size of facilities can be achieved by utilizing frosty winter road conditions. Vessels can be dressed completely in a shop fabrication environment, which normally has better productivity than a field erection. Modules can also be larger and heavier when they are transported in winter than what would be allowable in summer conditions. This again utilizes the more efficient method of module yard construction. Overall costs can thus be reduced by optimizing the transportation advantages that winter provides. However, this can only be realized by carefully planning the work around the heavy haul transportation window.
7 Execution Planning Around Winter

The general principles above address planning on a general basis, but do not address the effect that timely engineering and procurement can have on construction in adverse site conditions, including low temperatures.

Firstly the fundamental principles of winter mitigation could be expanded to include the effect of detailed engineering and procurement planning on winter construction. An optimal relationship between detailed engineering and construction was described by Bent et al. (1996), who claim that engineering should be 80% complete when piping fabrication and full mechanical construction work starts. This means that engineering should be around 80% at the starting point of pipe fabrication for module construction if the project is utilizing an off-site module fabrication strategy, as is the case in most of the recent Alberta mega projects. The modules should be fabricated in time so that they can be delivered to the site during the heavy haul transportation window. Procurement of long lead heavy weight equipment and packages should be done in time to ensure that the delivery will also match the heavy haul transportation window. Erection of the major equipment, packages and modules can then be done during the cold period. The above will set the date for the start of detailed engineering. A thorough basic
engineering package and a detailed execution plan is a prerequisite for effective
detailed engineering and procurement. The setting of the start of the detailed
engineering sets the date for the start of the basic engineering package
development, which subsequently sets the start date for design basis memorandum.

Secondly, the list of fundamental principles of winter mitigation could be further
expanded to include construction execution planning around the heavy haul
transportation window. A sensible plan for mega projects (larger than $1 billion)
can be as follows. Piling can be completed in the first winter. Site preparation, deep
undergrounds, shallow undergrounds and foundations could be installed in
summer and fall. When the cold temperatures set in during the second winter, the
heavy hauling and heavy lifts can be done, modules can be set and limited
structural steel can be erected. When spring and higher temperatures arrive, the
work fronts will be available for piping and electrical construction. The loss of
efficiency of construction during winter can be up to 50%. Progress planning
should take this into account. Six percent progress per month can be achieved in the
warmer months in Northern Alberta on mega projects; the planned progress in the
colder months should be less per month because it should only include work that
can be done cost effectively in winter conditions.

Thirdly, the list of fundamental principles of winter mitigation could also be
expanded to include the effect of holidays on workforce planning around winter
construction. The holidays in December and early January will result in less
progress and progress during the two remaining weeks in December and one in
January can be close to zero. Late spring, summer and early fall months are the
seasons when maximum construction progress can be achieved in Northern
Alberta. The days are warm but not near the 110°F mark (43°C), where high
temperature progressive loss sets in. However, the brief summer season is also the
prime holiday season as it coincides with the summer school break. Construction
labour have usually worked a full year and want to claim their holiday breaks.
Construction planning should take high turnover into account and be ready for this
during the peak construction period. It is difficult if not impossible to keep the high
progress up during the summer break when there are labour shortages. One way to
overcome these labour constraints is to bring in temporary travelers and foreign
workers during the breaks to keep the overall bulk construction work and the work
on the critical path going. Construction work will be pushed into less productive
low temperature work season if the project planners do not plan to ensure that they
will have a full work force during the peak progress periods. However, these
activities will put constraints on the site indoctrination and safety training activities
and facilities.

Owners should take all these constraints into account when they do their overall
investment planning. Winter and cold weather occurrences do not change, and
holiday seasons occur every year during the same periods. Two principles can be
added to the table. The first one is to plan the complete project such a way that it
will minimize the effect that winter and cold temperatures may have on the project.
The second principle is to plan around known holiday periods.
8 Enclosures to increase winter productivity

The fundamental principle of enclosing of buildings for weather protection can be expanded to include the provision of site enclosures that can protect the work fronts from adverse conditions. This can be achieved by planning for and installing hoarding and construction domes on specific areas on a construction site.

One way of increasing construction productivity is to hoard in areas where construction can be executed with less exposure to the cold weather elements. The hoarded areas can be heated and construction can be executed with higher productivity than if it was executed open to the adverse conditions. Typical hoarding efforts are presented in Figures 3 and 4, which show winter construction at the Petro-Canada Edmonton refinery in Edmonton, Alberta, Canada. Hoarding can be done using a sprung structure and/or attaching the hoarding to erected structural steel to enclose large areas. Scaffolding can also be used to support localized hoarding and as additional support for the larger hoarding areas.

Hoarding provides maximum benefits when installed over the highest density work area. More labour hours worked inside the hoarded area will offset the cost of hoarding as well as heating.

Hoarding provides protection against snow and wind. Snow needs to be removed after a heavy snow fall if an area is not hoarded in. The interior also protects the workers from wind chill and blowing snows.

Figure 3. Typical hoarding in winter
Figure 4. Typical hoarding in winter

Figure 5. Inside a typical hoarding structure
It is clear from Figure 5 (winter construction at the Petro-Canada Edmonton refinery in Edmonton, Alberta, Canada) that work can be done effectively inside the hoarded areas. Pumps, small vessels, and heat exchangers can be set up, and piping can be installed around this equipment without being affected by cold temperatures, snow, and wind chill. The insulation properties of the sheet material utilized for the hoarding is not good, however, and it can be difficult to ensure the elimination of the wind chill effect when the tarpaulins used for hoarding are damaged or torn or when an area cannot be completely enclosed. The nature of the hoarding also requires substantial heating to ensure an acceptable working environment.

A further problem with hoarding is that it inhibits larger equipment installation and placement of larger spools. MegaWorks Structures Inc. developed a construction dome structure that overcomes most of the restrictions of fixed hoarding structures on a construction site. A number of construction dome sizes were completely designed and a smaller pilot dome was tested on the Petro-Canada site at MacKay River in northern Alberta, Canada. The results of the testing of the pilot dome confirmed all the design parameters.

The dome consists out of a series of cylindrical tubes that forms the sides and roof of the dome as can be seen in Figure 6. Each tube is inflated and self-sustainable. Separate tubes are also installed on the ends of the dome to provide a complete enclosure. Sheet material is installed on the outside as well as on the inside over the tubes for the side as well as for the end tubes to ensure that the dome is watertight. The larger entrances to the dome are at the sides and at both ends. The largest dome that was designed was 200 m long, 100 m wide and 45 m high. These dimensions allow the dome to cover a substantial part of a process plant under construction. A suspension structure is installed over the dome, and each one of the tubes is tied to the suspension structure. Each tube is also anchored to prevent shifting during high winds. A further way to mitigate high winds is to increase the pressure in the tubes during high wind conditions. Then pilot construction dome was exposed to cold temperatures and high winds, and it successfully passed all the tests. If one of the tubes is damaged, it can be repaired with a patch similar to fixing a leak on the inner tube of a car tire by deflating the tube, gluing an inside and outside patch over the damage area, waiting for the glue to dry, and re-inflating the tube. The process can be completed in a limited number of hours.
When it is necessary to install a major piece of equipment or a major module that is too large for the end doors, a number of tubes can be deflated (see Figure 7, showing the actual pilot construction dome on the Petro-Canada site). The inside and outside coversheets can be removed. Then, with the use of the suspension structure, the tubes can be moved aside. The major lift can then be done without any obstructions. When the lift is complete, the tubes can be inflated. They will
expand and fill up the empty space. The inside and outside sheets can then be installed and the dome is again water- and wind-tight.

A partial side opening can also be made for access for a smaller load (See Figure 8, showing the same pilot construction dome on the Petro-Canada site). This can easily be accomplished by deflating the required number of tubes and partially opening the inside and outside cover sheets. After the load is moved inside, the tubes can be re-inflated and the sheets re-installed to return the dome to a water- and wind-tight state.

Sufficient lighting to enable productive construction is installed inside the dome. Air is circulated inside the dome and monitored at a number of locations. If the air quality deteriorates at any spot, the air-conditioning unit replaces the air to maintain a healthy environment inside the dome.

The inside of the dome can be heated so that the temperatures will always be higher than 10°C. The dome will keep out both the snow and rain, and the wind chill factor is eliminated. It will also protect the work inside against winds that prevents crane lifts. A shop like site environment can thus be created with the installation of the dome.

Cost benefit analyses were done to determine the viability of construction domes. The viability is directly dependent on the number of construction labour hours spent under the dome. The dome protects the workers and the site against wind, rain, snow, and cold temperatures. Productivity improvement can thus be experienced throughout the year in northern Alberta. Winter has snow and cold temperatures. Fall and spring have snow, rain, wind, and some cold spells. It can
also be used for a super module yard on site and then moved to cover a construction area. Summer has rain and wind. The dome can be dismantled and re-erected in less than two weeks. Studies indicate that a dome can pay for itself on one construction project for dense construction areas, and if it does not pay for itself during the first project, it will do so during the second usage of the dome.

9 Conclusions

Weather plays a large role in construction execution. Cold weather conditions lower construction efficiency up to 50% and can have a severe impact on construction workers. Working in the cold is substantially more dangerous and extra precautions need to be taken to prevent incidents and to protect workers' health and safety. Previous publications identified a list of fundamental principles of weather mitigation. This paper suggests an expansion of the fundamental principles to offer further fundamentals for utilizing the winter conditions for overall project success by planning construction around winter, fully utilizing labour, preparing for availability, and installing enclosed structures on construction work sites.

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11 References


CHAPTER EIGHT

THE CANADA LINE RAPID TRANSIT PROJECT

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Abstract

The Canada Line Rapid Transit Project being a Public Private Partnership largely under the control of one company, SNC Lavalin Inc., has provided an ideal environment for fostering innovation. This paper describes the project, discusses the organization and presents many examples of innovation.

1 Introduction

Construction on Canada Line, a new 18.5 km rapid transit system that connects Downtown Vancouver with Vancouver International Airport (YVR) and Richmond City Centre, started in late 2005. Full transit service will commence on or before November 2009, in time for the 2010 Winter Olympics.

The $2 billion project is a public-private partnership between various levels of government and InTransitBC, the private sector concessionaire. SNC Lavalin Inc. (SLI) under an EPC Contract with the Concessionaire is responsible for all design, procurement and construction.

The alignment which is shown in Figure 1 travels from south to north from near Richmond Centre (Brighouse), along Number 3 Road to Bridgeport Station. From here the alignment splits in two. One segment travels westbound over the Middle Arm of the Fraser River and parallels Grant McConachie Way to a terminus at YVR
Airport Station. The second segment crosses over the North Arm of the Fraser River to the City of Vancouver. The alignment is elevated over Marine Drive and enters a tunnel portal at 63rd Avenue. The alignment then continues in a tunnel under the northbound lanes of Cambie Street until it reaches Olympic Village Station. The alignment downtown travels in twin tunnels under False Creek, Davie and Granville Streets to a terminus at Waterfront Station.

Figure 1. Canada Line alignment
There are four types of guideway structure:

- A 2.5 km long bored tunnel,
- A 6.5 km cut and cover tunnel,
- A 7.5 km elevated guideway which includes two bridges (over the North Arm and Middle Arm of the Fraser River), and
- A 2 km at-grade section near the airport.

There are 16 stations on the line, eight underground, six elevated and two at-grade.

The elevated guideway was constructed using the precast segmental methodology. The 3 m long precast segments were lifted into place using a special truss (Figure 2) and post tensioned together into a beam. The majority of the elevated alignment is dual guideway with track for both directions of travel. Single guideway sections are located near the termini and at the junction between the Airport and Richmond lines. The bridge over the North Arm of the Fraser River has a 180 m navigational span and is the first Extradosed Cable Stayed Bridge built in North America (Figure 3). Since it is located beneath the flight path to the Airport, the towers had to be shorter than normal which lead to a relatively flat cable angle. The structure was built using the balanced cantilever method as was the Middle Arm Bridge (Figure 4).

Between 63rd Avenue and 2nd Avenue in Vancouver the cut and cover technique was employed to build the tunnel. In this method, a trench was excavated from the surface using backhoes. The sides of the excavation were supported using soil anchors and shotcrete. The cast in place concrete tunnels were then constructed,
backfill was placed over the top and the road surface reinstated. The tunnels were of both side-by-side and stacked configurations (Figure 5) depending on the space available for construction.

![Figure 3. North Arm Bridge](image)

A Tunnel Boring Machine (TBM) was used to tunnel under False Creek in Vancouver. Twin bored tunnels were constructed between 2nd Avenue in the south

![Figure 4. Middle Arm Bridge](image)
and Granville/Pender in the north. The tunnels are lined with pre-cast concrete segments (Figure 6).

The Canada Line is a traditional metro transit system with a fully segregated alignment. The vehicles are powered via pick up shoes from a power rail alongside the running rails (Figure 7).

Figure 5. Stacked cut and cover tunnel
Figure 6. Bored tunnel

Figure 7. Canada Line vehicle
The system will operate with fully automated trains on 3 minute headways to provide frequent service and meet capacity requirements.

Construction started in late 2005, and revenue service will commence on or before November 30, 2009 in time for the 2010 Winter Olympics.

2 Project Organization

There are four public funding partners, the Federal Government, Provincial Government, Greater Vancouver Transportation Agency (GVTA) and the Vancouver Airport Authority (YVRAA). The public partner is Canada Line Rapid Transit Inc. (CLCO) a subsidiary of GVTA (Figure 8). The private partner called InTransitBC, LLP (ITBC) entered into a Concession Agreement with CLCO and GVTA in July 2005 after a competitive tendering process. ITBC is comprised of SNC-Lavalin Inc. (SLI) and two pension funds. The Concession Agreement allows ITBC to design, build, operate and maintain the Canada Line over a 35 year period and requires the Canada Line to be open for public revenue service by November 30, 2009.

ITBC awarded the following two sub-contracts:

- Engineering / Procurement / Construction (EPC): SLI
- Operations and Maintenance: ProTransBC Operations Ltd. a subsidiary of SLI

![Figure 8. Project organization](image-url)
SLI is delivering the EPC Contract through a series of design/build joint ventures formed by its affiliate SNC-Lavalin Constructors (Pacific) Inc. (SLCP), certain design and supply subcontracts and conventional design-bid-build subcontracts as follows (Figure 8).

- A Joint Venture (RSL JV) was formed by SLCP and Rizzani de Eccher of Italy to design/build the elevated guideway and two bridges over the Fraser River (Buckland and Taylor designed the North Arm Bridge).
- The twin Bored Tunnels underneath downtown Vancouver were designed and built by a Joint Venture (SSJV) formed by SLCP and SELI, an Italian Contractor.
- SLCP acted as Construction Managers for the cut and cover section; Cambie Street Constructors were the contractor. SLI provided the design.
- Trackwork and some of the E&M systems were installed by the RSL JV. SLI provided the design.
- E&M systems, stations and other fixed support facilities such as the Operations and Maintenance Centre (OMC) were generally delivered using design-bid-build subcontracts.
- The vehicles, automatic train control system and communications system were delivered through three design/supply subcontracts awarded to specialist suppliers. SLI is the systems integrator.

In most construction projects many small contacting parties are engaged in a large number of independent subcontracts providing little incentive for innovation and effective integration. However, the Canada Line has provided an ideal environment to foster innovation because of the dominant role of SNC-Lavalin companies at all levels of the project, as can be seen in Figure 8. Some of these innovations will be discussed in the next section.

3 Examples of Innovation

As noted above SNC-Lavalin has been involved at most levels of the project; Concessionaire, EPC Contractor, subcontractor and operator. The following examples of innovation include some at the time of bidding, some in the management structure and some in the detailed construction methods.

- The RFP for the project called for the alignment to be underground for approximately 6 km in Vancouver. SLI proposed a bored tunnel in downtown Vancouver and under False Creek. They proposed the more efficient cut and cover method for the remainder and extended it so that the total tunnel length was 9 km. The cut and cover alignment allowed the stations to be closer to the surface making them more user friendly and thus encouraging higher ridership since the travel time from surface to the platform would be reduced. It also meant shallower and faster station excavations. Since the cut and cover tunnel could be constructed in several locations simultaneously there were additional schedule
advantages which were critical since the line had to open for the 2010 Winter Olympics.

- SLI worked with the local construction industry to develop an efficient cast in place concrete construction method using special tunnel forms (Figure 9). The ground support was the commonly used shotcrete and soil anchor system. This ensured that there was sufficient local capability to construct the tunnel in the time frame. In addition SLI hired a very experienced Construction Manager to help their subcontractor with project management and optimize their pour cycle and work methods.

- SLI elected to act as systems designer/integrator and not name a vehicle supplier in its proposal. It was therefore able to tender the vehicles to a broad range of suppliers and able to select the best value and ensure that the other systems were suitable for the selected vehicle.

- The size of the excavation pit required to launch and service the tunnel boring machine was modified so that one of the stations could be later constructed inside it. This led to a risk that if the tunnel was delayed, the station would also be delayed. In order to mitigate this risk the critical rooms required to install the systems equipment were relocated nearby between the cut and cover tunnels. This space would have to have been excavated in any case.

Richmond is located at the mouth of the Fraser River so is founded on inter-beded layers of silts and sands that are prone to liquefaction in an earthquake. SLI worked closely with a geotechnical consultant and a Professor from UBC to design an innovative piling system consisting of

![Figure 9. Tunnel forms](image-url)
expanded base (Franki) piles with a steel casing (Azizian and Robinson, 2007). The piles were founded in a layer of dense sand approximately 13 m below grade. The expanded base compacted the ground at the tip so it was not susceptible to liquefaction. In addition the steel casing made the piles more flexible so that any liquefied soil above the base would “flow” around them. In this way the normal method of improving the ground by jetting in gravel columns was avoided. This reduced the affected area and averted moving several utilities.

- Also in Richmond a detailed study was performed to optimize the alignment so the piles would mostly avoid a large concrete storm sewer which ran parallel to the alignment. SLI also worked with the City to produce an almost straight alignment that also satisfied their “urban design” needs.

- The stations were constructed towards the end of construction. This could have led to a significant conflict between the formwork and shoring for the upper floors of the stations and the installation of the trackwork on the lower level. SLI worked with the structural engineers for the stations, the shoring designer, the contractor and the trackwork installer to minimize the conflict. This was achieved with the use of heavy shoring posts and steel beams (Figure 10) and/or redesigning the roof so it could be poured in two pours with a horizontal pour joint (Figure 11).
Figure 10. Shoring above tracks

Figure 11. Horizontal joint pour in slab
The bored tunnel alignment had three low points each of which required a sump to collect water inflows. The sumps were to be built at the side of the tunnel which entailed removing part of the precast concrete tunnel lining, temporarily supporting the opening and then pouring the sump under and on the side of the tunnel. At one location the contractor drilled an exploratory hole in the liner that immediately flowed water and sand under artesian pressure which had not been foreseen from the geotechnical investigation. The hole was sealed without delay and it was quickly decided that it would be too dangerous to construct the sump. SLI immediately brought together their structural and mechanical designers and contractors to brainstorm alternate solutions. Without delay a decision was made to place a horizontal sump in the invert of the tunnel inside the lining (Figure 12). A pump was procured that was tubular in shape and could operate in a low head of water.

Figure 12. Sump invert
4 Conclusions

The above section has described a few of the examples of innovation that were employed on the Canada Line Project. Innovation was fostered throughout the project by SNC-Lavalin because of its dominant role in all aspects of the project.

The project is currently on budget and ahead of schedule largely because of the synergy within the project team and their innovative thinking.
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