FRAMEWORK FOR MANAGING INTEGRATION CHALLENGES OF PRODUCTION PLANNING AND CONTROL IN INTERNATIONAL CONSTRUCTION MEGA-PROJECTS

by

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Abstract

The public often associates mega-projects with poor performance due to delays and budget overruns. International mega-projects (IMPs) comprise multiple subprojects across widely spread areas, often with independent resources and individual plans. Such decentralization into clusters increases the integration planning and execution challenges. Changes to the schedule, budget, and scope, as well as poor design, are critical integration challenges within and across subprojects of mega-projects. International characteristics of project delivery compound additional complexity on integration aspects. It is essential for the production planning system in IMPs to be robust in addressing integration challenges to achieve necessary interface and realistic reporting. This study aimed to reveal the significance of operational gaps and resolve the integration challenges in IMPs. To achieve its goal, the study was divided to three phases. They are: 1) synthesize literature and practice with respect to production planning and control systems; 2) evaluate the performance of the production planning and control system at a mega-scale in a case study; 3) develop a framework to provide workable solutions to address the unique and complex integration challenges of IMPs.

The Last Planner® System (LPS®) was found to be an emerging production planning and control system with a promising potential. Fostered to complement, not to replace, the existing LPS®
model, the proposed IMPact framework is a roadmap aiming to improve the operations of IMPs, keeping them on track, and potentially replacing the negative image of IMPs with positive impressions. The validated framework provided a conceptual practical solution, based in LPS®, to address the challenges that project teams on IMPs have within and across subprojects. It is intended to be an adaptive system in an effort to improve delivery and performance of IMPs.
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List of Acronyms

AHP - Analytical Hierarchy Process

AIA - American Institute of Architects

BIM - building Information Modeling

CC - Critical Chain

CCh - Controlled Challenge

CEO - Chief Executive Officer

CM - Construction Managers

COAA - Construction Owners Association of Alberta

CP5B - Construction Package 5B

CPM - Critical Path Method

CWA - Construction Work Area

CWP - Construction Work Package

E&O - Errors and Omissions

EOT - Extension of Time

EPCM - Engineering, Procurement, and Construction Management

FIDIC - International Federation of Consulting Engineers

FIWP - Field Installation Work Package

FPF - Frequency of Plan Failures

GC - General Contractor

GCC - Gulf Cooperation Council
GDP - Gross Domestic Product

GM – General Manager

IFC - Issued for Construction

IGLC - The International Group for Lean Construction

IMP - International Mega-Project

IMPact Framework - International Mega-Project Framework

IMPs - International Mega-Projects

IPDS - Integrated Project Delivery System

ITS - Intelligent Transportation System

KPI - Key Performance Indicator

LBMS - Location-Based Management System

LCJ - Lean Construction Journal

LOB - Line of Balance

LPS® - Last Planner® System

LRT - Light Rail Transit

MC - Moderately Challenging

MRP – Make-Ready Plan

NEC3 - New Engineering Contract

NGT - Nominal Group Technique

OCM - Organizational Change Management
Chapter 1 Overview

1.1 Introduction

The inspiration to start this research was based on and developed by the challenges the author faced in planning and controlling the execution of several international mega-projects (IMPs): as Head of Section while managing temporary and training venues of the Asian Games (DOHA 2006); and, as Senior Project Manager of a US$410 million mega-project related to the infrastructure development of Federation Internationale de Football Association (FIFA) World Cup - 2022. The US$410 million lump-sum contract was based on a traditional design-bid-build model involving a competitive hard-bid process and based on a two closed-envelope approach (technical and commercial) with no prequalification process. The contract was awarded to the lowest bidder.

Many owners and government agencies mandate the use of critical path method (CPM) as a contractual requirement (Senior 2009). Common practice in IMPs in Qatar and most Middle East countries is to submit the fully detailed baseline schedule, always in the CPM, within 14-28 days of the project start date. This schedule must be detailed to very short durations of execution activities. Detailing the schedule in the first few weeks of a three-year mega-project to the production level with no input from site and trades’ teams relies heavily on assumptions and forecasting all elements.

A review of 16 delay studies conducted in 12 developing countries found that ineffective planning and control were contributing factors in 87% of the cases where projects fell significantly behind schedule (AlSehaimi et al. 2013). Similarly, the percent plan complete (PPC) is typically below 50% in construction projects experiencing delays. The PPC metric measures accomplished work against the commitment or planned work (Ballard and Howell 1998a). PPC was the first metric to measure and show the disconnect between production control and project planning.

Traditional construction management is based on the transformation concept, converting inputs to outputs (Koskela 1999). The baseline schedule is typically created using the CPM and sequenced according to a lengthy list of unpredictable but forecasted construction processes, variable productivity, and unknown unknowns (Abdelhamid et al. 2008). Often mega-projects
are managed by planners and other professionals without deep domain experience (Flyvbjerg 2014). The resulting baseline schedule may not address how activities will be executed nor consider maximizing value or minimizing waste-principles inherent in Lean Construction (Koskela et al. 2002). With the commencement of construction activities in the traditional approach, management often transfers its focus to control efforts disconnecting project planning from execution (Ballard and Howell 1998b).

The traditional approach to planning assumes that the construction team is capable of handling production variations at the site, and that all the required resources are available. Site operations are driven by a top-down push system, where lookahead and weekly plans are filtered from the detailed baseline schedule (Tommelein 2015). This model ignores the actual status of the work on site. Previously developed, often outdated plans are forced on construction team for execution. This results in an imbalanced system leading to execution failures with unmet commitments and delays (Abdelhamid et al. 2010; Koskela 1999). If the prerequisite work is not ready, workers and/or equipment have to wait, resulting in unnecessary waste. Similarly, if an activity requires fewer resources than are assigned to the system, the result is also undesired waste due to surplus workers and/or equipment. Both negatively affect the overall project performance. The growing awareness of failures in achieving time and cost targets motivated the development of alternative solutions (Ballard and Tommelein 2016).

One of these alternatives is the Last Planner® System (LPS®), which was touted as a new production planning and control method that complements CPM by addressing some of its shortcomings at the production level (Ballard and Howell 1994). The LPS® is structured in four phases (Ballard 2000):

- **Master Schedule (Needs to be done):** Major milestones are defined (using CPM)
- **Phase Schedule (Should be done):** Detailed plan of one phase of master schedule showing dependencies between activities (using CPM)
- **Make-Ready Plan, MRP (Can be done):** Rolling plan from 3-6 weeks (using new processes)
Weekly Work Plan, WWP (Will be done): Commitments are made and measured (using new processes)

Throughout these systematic phases, the LPS® creates an environment that facilitates cooperative discussion, debate, and rapid learning (Howell et al. 2011). The aim of production planning and control is to embrace a new philosophy rather than direct the project team on what to do. The team cooperatively decides how members will coordinate and improve workflow to reduce the gap between DID and WILL. The result of this process is higher productivity, more predictable workflows, a greater degree of team-building, respect, and reliable delivery of tasks (Ballard and Tommelein 2016).

LPS® provided the author with hope that mega-projects can be better managed. A mega-project typically comprises multiple subprojects located throughout a large area, with each subproject responsible for its own reporting. LPS® can be applied to each subproject using best practices already common in the industry. However, the challenge exists in the gaps between these subprojects so that aggregated production control and integration can be achieved at the mega-project level. The larger the project, the greater the number of subprojects and gaps between them, and the greater the potential for gaps to result in significant problems for the overall project.

1.2 Research Goal, Questions, and Objectives

The goal of this research is to reveal the significance of operational gaps and resolve the integration challenges in IMPs.

The objectives of this research are to:

- Identify the challenges that impede the site integration of subprojects in mega-projects.
- Evaluate the adaptability of the production planning and control system in addressing production integration challenges in the environment of IMPs.
- Develop a framework to address the challenges in an effort to improve the performance and delivery of mega-projects.
The research questions are:

- In practice, what are the challenges faced by stakeholders when integrating subprojects in an international mega-project (IMP)?
- How can production progress and alignment between subprojects be managed given the size complexity and the interface needs required for an IMP?

The research to investigate the integration challenges of production planning and control in IMPs was structured in three phases. They are: 1) synthesize the literature and experiential knowledge, 2) evaluate production planning and control system in addressing the integration challenges of IMPs, and 3) develop a framework to deal with these challenges.

The following section of this chapter introduces Lusail City project (the project that triggered this study), followed with context on mega-projects, IMPs, coordination vs. integration, and the Lean production philosophy in manufacturing. The compatibility of Lean principles with the construction industry is discussed and confirmed. Finally, the research methods, process, structure, and validation are presented.

1.3 The project that started it all - Lusail City (Qatar)

The discovery of oil in 1940 in the Dukhan field transformed Qatar’s economy overnight. This discovery propelled Qatar, an unknown country, to a world record holder of the highest Gross Domestic Product (GDP) of US$179,000 per capita in the world (Rizzo 2014). Despite its small area, Qatar has overcome many global challenges. From hosting the second-largest sport event in the world (the Asian Games) in 2006 to winning the bid in 2010 for the 2022 FIFA World Cup, deadlines on the country’s construction projects have to be met. To prepare for these events, a large number of building and infrastructure IMPs were generated to construct stadia, hotels, roads, mass transit systems, an airport, a seaport, hospitals, etc. Qatar embarked on a transformational undertaking of multiple IMPs with a combined budget of US$95 billion to be completed by 2018 (Scharfenort 2012). This study documents some of Qatar’s unprecedented development of IMPs, which are being executed in a relatively short time frame.

Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates-UAE) rely fully on external workforces to develop their cities, including white-collar expatriates and blue-collar workers. The fast evolution of Qatar’s economy has led
to a huge influx of international executives, managers, technicians and workers from all around the world, attracted by the challenge of participating in signature IMPs, the quality of life, and the hospitality inherent in Qatari culture. Based on 2010 Census results, Qatar’s population of approximately 1.7 million is diverse, with over 100 nationalities represented, of which Qatari citizens only number 300,000 (Scharfenort, 2012). A monumental and ambitious development in infrastructure to cater to this huge growth has been undertaken.

One of the most ambitious projects in the world was the vision of the Father Emir, His Highness Sheikh Hamad Bin Khalifa Al Thani. A brand new, ultra-modern development, Lusail City, is located on the Gulf coast 23 kilometers north of Doha, Qatar. It is an immense new urban center entirely planned, designed, and constructed in just 13 years. It will cover an area of partially reclaimed land of some 38 km². The development includes residential areas, medical centers, education city, shopping centers, commercial districts, a golf course, resorts, man-made islands, marinas, and leisure, entertainment, and sports facilities, in addition to the 80,000-seat stadium being built to host the opening ceremony of the 2022 FIFA World Cup. The portfolio of Lusail was divided into 105 contracts, of which 8 are IMPs. The case study examined in Chapter 3, CP5B, is one of them. More details about Lusail City can be found at: www.lusail.com.

By applying the most stringent international standards, contractors from across the globe were carefully selected to provide the infrastructure necessary to fulfill the vision that is Lusail City. Lusail City is the embodiment of Qatar’s national vision, which embraces: human, social, economic and environmental development. Lusail City will eventually have a population of 260,000 residents, with the most modern industrial, commercial, educational, luxury shopping and recreational facilities to provide an unmatched quality of life for its residents, businesses and visitors.

### 1.4 Mega-Projects

Mega construction projects can be defined as “large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people” (Flyvbjerg 2014). Canadian oil and gas construction projects are considered mega when they exceed CAD300 million (Rankin et al. 2008). From a contractual context, mega-projects are associated with endemic disputes and a large number of claims of significant magnitude (Dettman et al. 2010).
Mega-projects have powerful economic, social, and symbolic roles in societies. The astronomical construction cost is not the only identification factor. As well, the level of complexity in design and construction is a critical qualifying determinant. These are complicated endeavours involving construction coordination, methodology, technology, schedule, finance, governance, resources, organizational behaviour, environment, and workflow challenges (Brockmann and Girmscheid 2007).

Based on the standard project management constraints, cost overruns, time delays, and benefit shortfalls have dogged many mega-projects (Jergeas 2008). Other researchers, like OMEGA group might judge the success and performance of mega-projects with different, softer evaluation criteria (OMEGA Centre 2012). However, for the purpose of this study, the standard project management perspective was embraced which resembles the worst case settings. Despite their negative image, mega-projects are essential for the development of public infrastructure. These negative perceptions change after delivery, resulting in signature projects whose legacies are remembered far longer than those of typical projects.

Even before starting the conceptual design of an IMP, project teams are soon challenged by integration issues. Due to the magnitude of a mega-project, the scope of work has to be split into smaller, more manageable subprojects, where subproject managers have a better opportunity to plan, monitor, and control scheduled activities. The contribution of all stakeholders is important for production planning and control. Moreover, many problems can be avoided or resolved if the stakeholders are actively engaged in front-end planning and fully integrated into the project team (Jergeas et al. 2000).

While some issues arise because of poor policy making and/or inaccurate forecasting, integration challenges are attributed to fragmentation between the subprojects. Among these subprojects, resource misallocations, inaccurate execution plans, scope gaps, and poor interface management can lead to confusion and frustration. These problems, combined with organizational behaviour issues of stakeholders, such as lack of transparency, absence of a clear strategic organizational governance policy, and unfamiliarity with local regulations, challenge the project team to avoid the execution failures that are ubiquitous in mega-projects (Lu et al. 2015).

It is common for oil-and-gas-related mega-projects in Canada to experience major cost overruns (McTague and Jergeas 2002). After many years of observing mega-projects experience cost and
time overruns of 50-100%, these were declared “disasters waiting to happen” (Flyvbjerg 2014; Jergeas and Lynch 2014).

Even taking size and scope into account, mega-projects face disproportionally large schedule and budget challenges compared to other project categories. Reasons include (Flyvbjerg 2007):

- Increased risks due to complex interfaces and long planning horizons.
- Planning processes that involve many participants with conflicting interests.
- Project scope that can change significantly over time.

Time, cost, resources, planning, integration, and coordination are all naturally large factors in mega-projects. Ensuring execution with sufficient integration among the fragmented subprojects creates a huge challenge due to the large scale of operations. Coordination within each subproject is not an easy task either. Crews in different segments of mega-projects may often execute out-of-sequence activities with little to no integration between them. Consequently, no significant gains to the project schedule can be realized and the outcome is likely to be delays, cost overruns, and waste at one end, with discontented owners at the other.

Mega-projects consume enormous resources that can be afforded only by giant international general contractors with very strong financial capabilities. A mega-project takes years to complete, and involves a huge complicated network of stakeholders with conflicting interests. The instability of the team in the long time-horizon of a mega-project’s life cycle weakens the leadership’s ability to maintain constant rates of progress (Flyvbjerg 2014). Poor design, inefficient procurement, human resource issues, information that was incomplete or late for project execution, and labour-related issues are confirmed challenges in mega-projects (McTague and Jergeas 2002). Mega-projects often suffer from organizational challenges, such as communication gaps, power struggles, conflicts, policy ambiguities, lack of transparency, frequent scope changes, uncertainty, politics, and public influence. These challenges, coupled with fast-tracked delivery pressure often demanded by owners, lead to the complex nature of the management and integration processes of mega-projects. Therefore, they are known for their unpredictability, struggling between the dynamic nature of progress, and organizational behaviour challenges.
Our ability to increase the success rate of mega-projects has not improved. The failure rate has remained constant at 90% over the past 70 years (Flyvbjerg 2007). For example, Boston’s Central Artery/Tunnel Project, known as the “Big Dig,” is one of the most remarkable mega-projects in USA history. Unfortunately, it is renowned for its major cost and time overruns. The estimated cost of US$2.56 billion in 1992 was dwarfed by the final cost of US$14.8 billion in 2007 (Greiman 2013). The Big Dig involved many complex processes and workflow variations. Integrated Project Management methods, where all participants share the same interests and are involved in the decision-making process, were only fully implemented six years into the project. This project also employed Partnering, a non-contractual agreement aimed at improving integration and project performance. However, it did not adopt continual improvement initiatives learned from previous breakdowns, leading to an accumulation of errors that ultimately affected project delivery (Greiman 2013).

Another important mega-project was Europe’s “The Chunnel,” a 51.5 km double-rail tunnel crossing the English Channel to connect England and France. Unfortunately, it also suffered schedule and cost overruns. The estimated duration and cost were 5 years and US$5.5 billion, which increased to 6 years and US$14.9 billion (Anbari et al. 2005). Forty-six contractors were selected through competitive bids, and participated in the construction. Because the objective was to link two countries, the project faced many coordination challenges due to differences in culture, specifications, and language. In addition, there were major scope changes that significantly affected the cost during execution. For example, to maintain a reasonable temperature in the tunnel, the design team was required to add a water-cooled air-conditioning system while construction proceeded (Kirkland 1995). Another major design change was widening passenger doors from 600 mm to 700 mm, which caused a nine-month delay (Anbari et al. 2005). These scope changes caused a massive cost surge, escalated the number of project participants, and consequently, the integration challenges among them.

Denver International Airport is another well-documented case; the original budget of US$1.8 billion almost tripled, reaching US$4.8 billion at completion. The cost of maintenance of the constructed part of the airport was US$1.1 million per day throughout the delay (Szyliowicz and Goetz 1995). Changes in design during construction led to major delays. Furthermore, many other factors contributed to increased integration challenges, such as poor planning, underestimation of project complexity, failure to understand the impact of change requests,
committing under uncertain circumstances, poor communication, incomplete designs, and a general lack of management (Szyliowicz and Goetz 1995).

RandstadRail railway in the Netherlands that was designed to connect the city of Rotterdam and the region of Hague. The project took 20 years to complete. Delays were due to major design changes in the rail route, disruptions, and long work suspensions because of differences in government regulations, policies, and public requirements between Rotterdam and The Hague (Giezen et al. 2015).

These four examples emphasize our general lack of ability to complete mega-projects according to plan. This failure is primarily due to unsatisfied prerequisites, poor integration, and insufficient planning. All are common delay factors in mega-projects. In other words, traditional construction management methods do not seem to meet the needs of the people responsible for implementing the plan.

1.5 International Mega-Projects (IMPs)

Projects with a lower monetary value can be classified as mega-projects depending on complexity of scope, time, logistics, risks, ambient sensitivity, stakeholder management, governance, and interface constraints. Conversely, repetitive giant projects free of these complexities and challenges are not mega-projects.

IMPs include a huge network of engaged stakeholders with conflicting interests, resulting in many participants concentrating on their own benefits. Moreover, stakeholders have different management systems, diverse organizational behaviour, different working cultures, varying documentation solutions, and complex workflows. Under the supervision of multiple project managers, each stakeholder strives to complete a complex schedule with unforgiving milestones, intense project control efforts, fragmented construction segments, and increasing integration challenges.

Mega-projects in an international context have additional levels of complexity. An international project can be defined as one undertaken in a region that lacks local engineering, construction, and management companies of the size, proficiency, and technical expertise to complete the project successfully. In the absence of local expertise, the owner draws from a pool of highly qualified resources around the world. However, this can result in a project comprising companies
from different countries with different working cultures, common practices, attitudes, and organizational cultures. The companies probably have not worked together before. In addition, the specifications, building codes, and standards in the host region are likely based on international standards, such as American and British standards. Forms of contracts are typically based on FIDIC (International Federation of Consulting Engineers) or AIA (The American Institute of Architects). Finally, local authorities are generally well-versed in issuing permits and approvals for standard local projects. Unfortunately, undertaking an IMP with its sheer size, complex scope, problematic technical innovations, and an international project team that lacks local experience, understanding of local regulations, culture, and permitting processes can lead to a breakdown of an otherwise well-performing approvals system.

1.6 Coordination vs. Integration

IMPs present major integration challenges for on-site production; a level of complexity that is different from that of a single project. With the large number of team members of an IMP, keeping weekly meetings productive is a challenge. Another is aligning the reporting schemes of multiple subprojects to produce a performance system that represents the overall performance of the IMP. This second challenge is a result of decentralizing the plans of multiple subprojects and teams, proximity issues, interface, and technical integrations. The inability of production planning and control systems to capture and manage integration challenges is one of the contributing factor for the failure of IMPS.

Coordination has many definitions in the literature. Often coordination is invisible, but its absence is clearly noticed when crises occur. Coordination is defined for unique situations as “managing dependencies between activities” (Malone and Crowston 1994). This definition helps to clarify the significance of dependencies between activities to the coordination functionality. If there are no dependencies, there is nothing to coordinate. Similarly, high dependencies as in IMPS need a much higher coordination. Priven and Sacks (2015) highlighted the importance of production planning beyond technical aspects to promote trust, communication, and social network among subcontractors to enhance coordination and improve production workflows. The social impacts and building relationships among construction teams can contribute to improved coordination. The contribution of all stakeholders is important for production planning and
control. Moreover, many problems can be avoided or resolved if the stakeholders are actively engaged in front-end planning and fully integrated into the project team (Jergeas et al. 2000).

A lack of coordination and a lack of information flow between stakeholders are critical factors that contribute a project’s failure to meet its desired objectives and benefits (Mahalingam et al. 2015). Coordination for production planning in this research refers to the interdependencies between tasks that comprise activities of a subproject or a sub subproject depending on the complexity of the mega-project. In the LPS®, coordination of tasks is greatly enhanced in the MRP and the WWP levels. The better the coordination at these levels, the more reliable the workflow will be and the more successful the subprojects will be. Unfortunately, LPS® does not serve the integration needs across subprojects, and this is one of the underlining factors limiting the use of LPS® in IMPs.

Execution problems also occur at the interfaces of subprojects, especially those with multiple connection points. In these tie-in situations, the impacts of poor interface planning can go beyond managerial and technical challenges and result in life-threatening hazards. More than 70% of accidents in construction are due to communication and interface failures between workers or the work team (Haslam et al.; Mitropoulos et al. 2005). For example, the author is aware of a tragic outcome between two adjacent IMPs. Valued around US$ 500 million, each project consisted of the construction of various infrastructure systems and roads. Both packages involved the installation of networks of wastewater pipes; the first package was completed and in service. When two workers in the adjacent package connected their downstream network to the existing 11 m deep manhole, they were unaware that an incoming 800 cm pipe was not only in service but had a high head-pressure. Their deaths could have been avoided with better planning and communication. The interface issues between subprojects are what this research refers to as the integration problem and requires a higher level view by the management team.

The majority of construction IMPs suffer from delays and budget overruns (Davies et al. 2014). The principles of Lean production developed in manufacturing industry were found to have great opportunities in resolving many of these problems when applied in construction. The following section explains and recognizes the differences between construction and manufacturing. This is followed by a convincing argument on the compatibility of Lean principles in construction.
1.7 Lean Construction

Construction projects are unique and have distinctive peculiarities i.e. on-site production, one-of-a-kind production, and a delivery date. Manufacturing can be categorized as extraction, fabrication, or assembly; i.e., collecting, shaping, or joining (Ballard and Howell 1998b). Construction is a combination of fabrication and assembly. However, customization in production is becoming a characteristic in manufacturing more than ever before (Ballard and Howell 1998b).

“Construction” in Lean Construction is viewed as the construction industry not only the construction phase. Lean Construction is defined as: “the impeccable alignment, and continuous and radical improvement of the entire supply chain, from programming to operations, in order to maximize value and minimize waste of a constructed facility” (Abdelhamid 2012).

Lean concepts are explored here to provide background on its development and potential for improving the performance of construction projects. Toyota Motor Company of Japan developed the principles of the Toyota Production System (TPS) in the late 1950s and early 1960s under the production engineering leadership of Taiichi Ohno (Ohno, 1988). The philosophy was established on the basis of eliminating all kinds of waste from production system using most efficient methods.

Established in 1993, International Group for Lean Construction (IGLC) coined the principles of Lean Construction (Howell 1999; Sarhan et al. 2017). IGLC finds construction fundamentally different from manufacturing. Therefore, reinterpreting the theory of TPS was necessary to develop a theory-based methodology for construction (Koskela et al. 2002). Koskela paved the way for implementing Lean production concepts in construction in 1992 (Abdelhamid et al. 2008). Motivated by Koskela, a new theory of production control in construction was introduced based on engineering and construction projects spanning five years (Ballard and Howell 1998a).

There are two alternatives to adapting the TPS to construction. First, peculiarities that do not fit can be eliminated by standardization, thereby allowing the direct application of TPS concepts. Second, where peculiarities cannot be eliminated, new methods must be developed to handle them (Koskela 2000). This principle was the foundation for establishing production planning and control methods in construction (namely, LPS®) which becomes the operating system of Lean
Construction. LPS® is situated in the core of many implementations of Lean Construction (Tommelein 2015).

Lean production concepts from manufacturing were introduced to construction. Lean production provides a very powerful management philosophy for organizations to become more efficient and effective, focusing on three key principles called the TFV theory, namely transformation (T), flow (F), and value (V) (Abdelhamid et al. 2008; Koskela 2000). Production is defined as the flow of material and/or information starting from raw materials to the delivery of the final product, transforming inputs to outputs, while value is the fulfillment of customer requirements (Koskela et al. 2006). In accordance with this new philosophy, any construction project consists of three major flows: design flow, material flow, and workflow, plus a number of supporting flows (Koskela 1992). All of these flows are critical components to the integration across subprojects and the coordination within subprojects of IMPs.

In the core of implementing Lean Construction, the Lean Project Delivery System provides the following linked opportunities to optimize the project rather than individual pieces (Mauck et al. 2009):

“Impeccable Coordination” entails predictable workflows among the trades. With traditional construction projects, on average only 55% of the work promised in a week is completed (Ballard 2000).

“Construction Projects as Production Systems” inspired by “Lean-Thinking” provides the flexibility of changing the work structure of design and construction to better allocate who does what, when, where and how to achieve Lean objectives and client requirements (values). In construction projects, production systems coupled with impeccable coordination allow for modularization, off-site fabrication, and multi-tasking to achieve the best performance.

“Construction Projects as Collective Enterprise” aligns financial incentives and creates the environment for an integrated team focusing on project performance rather than individual benefits.
1.7.1 Lean Production in Construction Industry

After observing Toyota’s production line, Ohno identified seven types of waste. As shown in Table 1-1, the 7 types of wastes are listed along with comparable examples in construction and design. Observation comments are made for more clarifications.

Table 1-1: Ohno's Seven Types of Waste with Examples from Construction

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overproduction</td>
<td>Excess materials of concrete or asphalt</td>
<td>Common occurrence in the construction industry</td>
</tr>
<tr>
<td></td>
<td>Over-excavation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design scope creep</td>
<td></td>
</tr>
<tr>
<td>Inventories</td>
<td>Storing raw materials at site</td>
<td>Causing storage cost, space limitation, security, safety, and environmental challenges</td>
</tr>
<tr>
<td></td>
<td>Holding work in progress</td>
<td></td>
</tr>
<tr>
<td>Over-processing</td>
<td>Painting internal walls of an underground utility tunnel</td>
<td>No value added</td>
</tr>
<tr>
<td></td>
<td>Design scope elegance</td>
<td></td>
</tr>
<tr>
<td>Defects</td>
<td>Non-conformance to quality in construction and design</td>
<td>Resulting in rework</td>
</tr>
<tr>
<td>Unnecessary motion</td>
<td>Movement at site</td>
<td>Lean logistics plan to minimize unnecessary movement and transportation</td>
</tr>
<tr>
<td>Unnecessary transport</td>
<td>Double handling of materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transportation of workers to/from labour camp to field and to/from break area</td>
<td></td>
</tr>
<tr>
<td>Waiting</td>
<td>Idle equipment</td>
<td>Typical type of waste in construction industry</td>
</tr>
<tr>
<td></td>
<td>Designer awaiting owner approval</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Workers waiting for work or work waiting for workers</td>
<td></td>
</tr>
</tbody>
</table>

The construction industry lags behind manufacturing with respect to efficient use of resources, productivity, and quality (Eastman and Sacks 2008). Client decision-making, design management, and construction management are considered endemic challenges in contemporary construction projects (Koskela 2000). The Lean approach focuses on improving the value stream and flow of processes by eliminating waste (Koskela 1992). Waste is any activity or condition that does not add value to internal or external customers.

Table 1-2 reviews two efforts to identify waste or unproductive time. Despite the different observation methods, they are surprisingly similar (Ohno 1988; McTague and Jergeas 2002).
Construction Package 5B (CP5B), the selected project for the case study presented in Chapter 3 to evaluate the LPS®, applied many initiatives of Lean construction to eliminate waste and generate value. For example, the rebar installation of the underpass wall structure (1,018 m long). Forty segments of the underpass wall, out of 108 segments have an average height of 14 m, which is 6 m higher than maximum height ever constructed in Qatar. The GC applied rebar prefabrication methodology by using a huge rebar cage on the ground and lifting it up to its final position on completion of the assembly process. This Lean Construction initiative reduced the cycle time of rebar installation from 30 to 19 days for each segment. Productivity was greatly increased, and operations were much safer than under the conventional rebar assembly method. Quality achieved the highest standards, construction cost was optimized, and the delivery of this part of the work was ahead of schedule.

The Lean production philosophy in manufacturing has been used to plan and execute many construction projects. However, applying such a paradigm to the construction of IMPs would be very challenging due to the difficulty of ensuring a high level of integration in these complex operations. For example, in the mega-project referenced earlier that inspired this research (CP5B), it was found that the available Lean production planning and control solutions cannot be applied directly to address integration challenges of IMPs.
Lean Construction was followed closely by the introduction of the Last Planner® System (LPS®) (Ballard and Howell 1994). LPS® is Lean Construction’s production planning and control system. The underlying reasons behind developing LPS® include:

1. produce practical plans that can be utilized at the production level.
2. address the shortcomings in traditional common approach and its inability to build consensus amongst project stakeholders and support the site’s day to day project execution efforts.
3. realize the inherent principles of Lean Construction to minimize waste and maximize value.

The Lean production planning and control system are claimed to have been used successfully in several mega-projects. However, no literature was found outlining the degree to which the method was used, neither confirming the success and the limitations of the implementation. LPS® has not been widely accepted in large-scale construction projects due to the fragmented and complex nature of construction industry coupled with lack of Lean education (Fernandez-Solis et al. 2013). Therefore, it is reasonable to conclude that the suitability of available Lean production planning and control methods in IMPs has yet to be sufficiently explored.

1.7.2 “Planning” vs. “Production Planning and Control”

It is very important to clarify a few terms.

**Pull systems** receive a lot of attention as they exploit the immense knowledge and cooperation of the field trades to achieve the project goals. Pull systems are driven by field-level managers including trades and subcontractors. In a pull system, these field managers provide input to the production plan and make the plan.

**Push systems** are developed and driven by the upper levels of project management. They develop the production plan based on the baseline plan, and then coordinate the trades and subcontractors to achieve that plan.

**Project Planning** is a process whereby experts decide in advance the needed activities and their sequence to achieve the project (Kelley and Walker 1959). Planning focuses on long-term goals, and should result in a comprehensive strategy of what should be done, when, and by whom.
**Project Control** is “putting plans into action to cause objectives to be achieved. The job of project controls is to set cost and schedule targets in alignment with project scope, and to monitor progress toward those targets” (Ballard and Tommelein 2016).

**Production planning** is the detailed process required to operate day to day with maximum reliability, efficiency, and value. Production planning focuses on the flow and how works will be done (Abdelhamid 2004). The production plan must remain nimble to adjust the workforce for changes, delays, bottlenecks, and other minor hiccups with minimal downtime or waste.

**Production Control** functions as a steering mechanism to keep operations on track by continually aligning progress with its targets. Control is achieved when promised assignments are met (Abdelhamid 2012). When targets are not materialized, it is detected quickly using a customized problem solving technique. Then, alternative ways to achieve the targets are developed in a rapid learning and reliable promising fashion (Ballard and Tommelein 2016).

**Construction Scheduling** is the process of determining the work breakdown structure of the project, estimating resources, estimating the activity durations, determining the start and finish dates of each activity, and sequencing the project activities based on independencies, constraints, and logic.

Production planning is not limited to construction scheduling because one of the primary objectives of production planning is to improve the plan for the coming week by better predicting construction workflows, maximizing value, and eliminating waste (Koskela et al. 2014). In traditional practice, there is a gap between planning (developing methods to achieve objectives) and construction scheduling (putting plans into action to achieve objectives). Production planning and control is thought to be the missing piece in the project management toolbox (Ballard and Tommelein 2016).

### 1.8 Research Scope and Methods

#### 1.8.1 Phase 1: Synthesize Literature and Practice

The purpose of phase 1 is to synthesize the state-of-the-art knowledge, empirical data, and expert knowledge about the integration challenges of production planning and control in IMPs. The research questions of Phase 1 are:
What characteristics of IMPs impact the integration of production planning and control of site operations?

Can production management integration issues be addressed using traditional project management tools and techniques?

What solutions are available (in literature and in practice) for production planning and control of IMPs?

Which production planning and control solutions provide a sufficient level of integration to overcome the complex and uncertain challenges of IMPs?

The research methodology used in Phase 1 adapted the following approaches:

- Critical literature review with gap analysis. Eight production planning and control methods selected from literature were presented and summarized to illustrate the evolution of construction planning and production planning methods as well as to highlight their similarities, differences, strengths, and limitations in a mega-project context.

- Structured interviews with experts: interview questions were designed to identify gaps in current practice in terms of the effectiveness of planning methods and tools used at the production level to run construction operations. Planning methods were investigated and evaluated according to user satisfaction and achievement of project objectives and benefits. Thirty-two experts with a minimum of 15 years of experience each from 10 IMPs were interviewed in a structured interview process to augment the literature review. It was concluded that available production planning and control systems require special treatment to address the integration challenges of IMPs. The interviewed experts reported changes to the schedule, budget, and scope as well as poor design as critical factors affecting the delivery of IMPs.

1.8.2 Phase 2: Evaluate in a Case Study

As inspired by Phase 1, evaluate the adaptability of the production planning system to address integration challenges in the environment of IMPs. LPS® was found to be an emerging production planning and control system in construction. Therefore, it was selected for evaluation in a case study in Phase 2. The research questions of Phase 2 are:
How does the production planning system perform at the scale of IMPs?

How do integration challenges of IMPs impact production planning features?

The purpose of this phase is to evaluate the adaptability of the LPS® in addressing production integration challenges in the environment of IMPs. An exploratory approach case study was used. Construction Package 5B (CP5B) in Lusail City, Qatar, was selected for the case study. The CP5B project team was trained by a professional LPS® expert to develop make-ready plans and measure PPC. They were coached on running weekly work-plan meetings. The interactions and records of implementation events were documented for two major milestones (8 weeks for milestone I and 15 weeks for milestone II). Details of the milestones are outlined in Chapter 3.

Implementing the LPS® helped to pull CP5B project from failure and put it on-track towards successful delivery of milestones. The LPS® raised the organizational behaviour of the mega-project to a higher tier of excellence. The commitment-driven aspect of the LPS® proved invaluable as it clearly defined the responsibilities of each team member, created accountability, ownership, and built a sense of pride when targets were achieved. Validating committed dates are required to prevent setting unrealistic dates or under-committing.

Structuring work for subprojects that form a mega-project can be done as if it were a separate project. However, ensuring sufficient level of integration among subprojects is challenging. The production control aspect of the LPS® between subprojects is where integration requires different treatment. The complexity associated with the fragmented subprojects of IMPs appears to increase in a non-linear fashion, and it is not scalable. Upon evaluating the performance of LPS® in an IMP, 13 integration challenges were identified that relate to IMPs generally and to the LPS® specifically. This phase of the study triggers the need for a new framework for LPS® to deal with the integration challenges of IMPs.

1.8.3 Phase 3: Develop a Framework

IMPs have a poor record of budget and time overruns (Davies et al. 2014; Jergeas 2008). Traditional construction planning methods have failed to improve the industry’s performance on IMPs. Lean Construction methods and the associated LPS® have been implemented successfully in many projects, but the application of the LPS® in IMPs is limited due to integration challenges and organizational behaviour issues inherent in IMPs.
Following the outputs of phase 2, the purpose of phase 3 is to develop a framework to address the integration challenges of the LPS® in IMPs. Three knowledge elicitation techniques were used at different stages of this part of the research. The description and a brief literature review of these methods are presented in Chapter 4. They are:

1) A modified two-round Delphi method was used to identify, verify, and rate integration challenges in IMPs. Thirty-one integration challenges were identified.

2) After the development of the framework, a Nominal Group Technique confirmed its internal validity.

3) Finally, external validation was achieved in a Focus Group study.

The measurement system of the framework was tested on a real IMP. The validated framework provided a conceptual practical solution to implement LPS® in IMPs. It is intended to be an adaptive roadmap to address the integration challenges and to potentially improve the performance of IMPs. Developing a framework to address integration challenges of LPS® in IMPs helps to take a holistic view of the problem, identify key issues, and draw relationships into a broad coherent framework that proposes practical solutions. The IMPact framework provides a systematic, consistent approach to support the project team and ensure that synchronization is accomplished within and across subprojects. The IMPact framework adapts and complements the standard practice of LPS®, but customizes its implementation to address the integration challenges of IMPs. “IMP” correspond to International Mega-Project while “act” resembles the effectiveness of the framework to potentially transform the performance of IMPs.

Forty-seven experts in construction industry representing 15 nations participated in this research. They are from Canada, Egypt, Greece, India, Iraq, Jordan, Lebanon, Palestine, Philippines, Qatar, Romania, South Korea, Turkey, United Kingdom, and USA. Each expert has at least 15 years of experience in mega-projects. Some have experience in LPS® from 2-16 years. The characteristics of the participating experts and their level of participation at each phase of the study are outlined in Table 1-3.
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<thead>
<tr>
<th>Title</th>
<th>Background and Experience</th>
<th>Phase 1</th>
<th>Phase 3</th>
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<td>Overall (years)</td>
<td>LPS° (years)</td>
<td>Project Type</td>
</tr>
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<td>Owner</td>
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<td></td>
</tr>
<tr>
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<td>30 0</td>
<td></td>
</tr>
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<td>25 0</td>
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<td>28 3</td>
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<tr>
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<td>36 1</td>
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1.9 Research Structure

The study followed a three-paper based approach. Each paper was developed in an independent phase of the research. The three papers were submitted for publication consideration in reputable journals. When the three papers were consolidated into a single document to form this thesis, they were called Chapters 2, 3, 4, respectively. An overview (Chapter 1) and a conclusion (Chapter 6) were included to introduce the study and present the findings collectively. Chapter 5 reflects on the theoretical implications of the proposed framework. Paragraphs from the background section of each paper were incorporated into the literature review in Chapter 1 to avoid duplication. Minor modifications and clarifications were made to improve the flow, but for the most part, these sections are identical to those found in the published papers.

As represented in Figure 1-1, the phases (papers) were designed to interconnect in a sequential order to address the three main objectives of this study, as explained in more detail herein.
A summary of the research approach is presented in Table 1-4. For details about the journal publications, please refer to Appendix A. While pursuing the first objective of this research, eight production planning methods were found in literature, of which the LPS® was observed to be emerging in practice. This finding initiated a case study to evaluate the performance of the LPS® in IMPs in phase 2. Based on the results, it was concluded that the LPS® needs a framework to be adapted in the challenging atmosphere of IMPs. That was the motivating factor of the third phase.

Table 1-4: Overview of Research Approach

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
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<tbody>
<tr>
<td>Objective 1</td>
<td>“Synthesis”</td>
<td>Objective 2 “Evaluation”</td>
<td>Objective 3 “Solution”</td>
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<tr>
<td>Output</td>
<td>LPS® is emerging</td>
<td>Due to decentralization of subprojects, LPS® requires different treatment in IMPs</td>
<td>IMPact Framework</td>
</tr>
<tr>
<td>Corresponding</td>
<td>Chapter 2</td>
<td>Chapter 3</td>
<td>Chapter 4</td>
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<td></td>
<td></td>
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<tr>
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<td>Under Review</td>
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<tr>
<td>Reference</td>
<td>El-Sabek and McCabe 2017a</td>
<td>El-Sabek and McCabe 2017b</td>
<td>---</td>
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<tr>
<td>Research Method</td>
<td>Structured Interviews with 32 experts</td>
<td>Case Study</td>
<td>Delphi (20 experts) NGT (6 experts) Focus Group (11 experts)</td>
</tr>
</tbody>
</table>

Because the research involved interviewing and surveying human subjects, an application for a research ethics review of the processes, interactions, and analysis was submitted to and approved by the University of Toronto Research Ethics Board. Participants were informed of their right to refuse to answer any of the questions or to withdraw from the research entirely; that their opinions would be anonymized, and the results published in aggregate form only.
Validation ensures that a method, process, model, or analysis was planned and conducted correctly, used rigorous and ethical techniques to achieve its goals, and resulted in a high-quality product (Lucko and Rojas 2010). Verification, on the other hand, is a measure of whether actions were performed according to predetermined parameters. Validation of a research outcome depends upon the purpose of the study (Law 2007; Lucko and Rojas 2010). Validity is generally classified into two main areas: internal and external. Internal validity relates to how rigorously the study was done with respect to meeting its objectives. External validity refers to how rigorously the generalized inferences from the study perform for prediction purposes across different settings and times (El-Diraby and O’Connor 2004; Liu et al. 2014). Other types of validity found in the literature e.g.: face, content, criterion, statistical, and construct validity (El-
Diraby and O’Connor 2004; Lucko and Rojas 2010) do not apply here. For the purposes of this research, internal and external validations with groups of experts were deemed most appropriate, and were implemented.

Researchers in construction management are encouraged to take ontological and epistemological perspectives to address the challenges of the construction industry (Edwards and Holt 2010; Love et al. 2002). This approach offers a robust understanding of the influence of organizational behaviour and performance issues that are attributed to many problems faced in construction projects. With mixed methods, researchers attempt to validate research findings by investigating and generating data from diverse perspectives (Torrance 2012). To achieve valid results, triangulation employs multiple research methodologies from several sources to study the same phenomena (Jonsen and Jehn 2009). The triangulation concept of social science research was interpreted in construction in a broader methodological context for validation purposes and as a means to solve the subjectivity concerns of qualitative research (Love et al. 2002; Jonsen and Jehn 2009).

This study is based on collaborative problem-solving relationships between researchers and practitioners aiming to manage a change and to create a new knowledge in the presented IMPact framework. Very little literature is available on integration challenges of IMPs, which makes a quantitative analysis difficult. Therefore, the qualitative approach has been used. Validity “is the accuracy of scientific findings which fits well with quantitative research” (Khan and Tzortzopoulos 2016). Due to the subjectivity of interpreting qualitative data, the validity concept is unsuitable for qualitative research (Dick 2014; Khan and Tzortzopoulos 2016). Therefore, the practical relevance model was developed by Khan and Tzortzopoulos (2016) to replace it. Hence, this model was used to examine the external validity of the IMPact framework based on prescribed criteria and attributes with respect to correctness, usefulness, and effectiveness.

Furthermore, since the construction phase of IMPs typically lasts 3-5 years, it was not feasible to validate the IMPact framework through direct application on new mega-project(s) during the span of this research. Alternatively, the feedback and evaluation of experienced construction professionals were sought using methodological triangulation of the following rigorous, well-recognized and commonly-used methods. Additionally, data triangulation was collected from different perspectives of construction project participants, namely, owners, consultants, and
general contractors. Therefore, following this justified approach, which is less formal compared to traditional practice, it is practically concluded that a reasonable form of validity is achievable (Dick 2014).

1) Delphi Technique: The invitation, questionnaire, and template of the consent form of the Delphi are provided in Appendix E for round 1 and Appendix F for round 2. Comments received from Delphi participants are provided in Appendix G.

2) Nominal Group Technique (NGT): The invitation, voting questions, and template of the consent form of the NGT are provided in Appendix H.

3) Focus Group: The invitation, voting questions, and template of the consent form of the focus group are provided in Appendix I.

1.11 Conclusion

Mega-projects attract international designers, consultants, and GCs from all corners of the world. Standards, specifications, and building codes are based on international standards. Therefore, the findings of this study are transferable to any mega-project worldwide with similar settings where integration challenges matter, taking into account the variability provided by local culture and associated challenges.

This chapter provided an overview of the research and an introduction to the following chapters. Due to the difficulty of consolidating three independent research phases into a single thesis, presenting a lot of details in this chapter was unavoidable. It outlined the research significance, objectives, scope, methodology, and process. Characteristics of mega-projects and the definitions of integration and coordination were presented and discussed. By understanding the nuances of IMPs, a new definition was introduced.

It was the vision of the Father Emir, His Highness Sheikh Hamad Bin Khalifa Al Thani and continued by the Emir, His Highness Sheikh Tamim Bin Hamad Al Thani to construct a city of the future. Throughout the development of this research, the author had the privilege to participate in the meticulous planning effort in Lusail City, turning that vision into reality to provide a quality of life, and community for thousands of families from all over the world.
Chapter 2  Synthesis Approach

2.1 Introduction

Little is published about how production planning and control of the challenging construction sites of mega-projects are handled. Compounding the complexity with an international context can substantially lower the risk of successful delivery. In the first part of this chapter, characteristics of mega-projects found in the literature are reviewed. Some advocates consider certain production planning and control systems state-of-the-art, while others argue the opposite. In the second part of this chapter, the literature review is augmented with the experience of practitioners through interviews with a selected number of experts involved in mega projects. Thirty-two experts with a minimum of 15 years of experience from 10 mega projects were interviewed using a structured interview process. Ten multiple-choice questions and one open-ended question were used to collect data and generate discussions. Various types of mega projects were selected representing construction fields like high-rises, museums, hospitals, stadia, residential buildings, infrastructure, bridges, and roads in Arabian Gulf countries (i.e. Qatar and United Arab Emirates). The interview process was designed to elicit experiential knowledge on the topic. Each interview took about two hours. Discussion was recorded in handwritten notes.

A mandatory contractual requirement in Middle East is the use of specific software based on the critical path method (CPM) to develop the project execution plan during the bidding process, and eventually the post-award master baseline schedule. For example, the following Article - Contract Administrative Procedures reads:

“Within Twenty Eight (28) days from the EFFECTIVE DATE, CONTRACTOR shall prepare and submit for review by the owner or its REPRESENTATIVE a planning package which shall include the following: a) Work Breakdown Structure. b) Detailed EXECUTION PROGRAMME of work using the Software Primavera P6\(^6\). The EXECUTION PROGRAMME shall be based on the Scope of Work and consistent with the CONTRACT EXECUTION PLAN (including the SCHEDULED COMPLETION DATE and any intermediate Milestones).”
The purpose of this chapter is to investigate how common production planning and control systems address the integration challenges of international mega-projects (IMPs) to identify state-of-the-art knowledge available in the literature and in practice (Objective 1 of the study).

The first part of this chapter presents a brief review of eight planning and production planning systems selected from the literature. Next, data from interviews with 32 experts from IMPs are presented. Finally, the insights and opinions of the experts related to the planning and control of IMPs are discussed.

2.2 Research Objectives and Methods

The objectives of this part of the research are: 1) to better understand how the integration challenges of IMPs are addressed by common planning and production planning and control systems, and 2) to identify gaps in current practice by synthesizing the knowledge found in the literature with practical experience derived from interviews with 32 experts.

To achieve these objectives, this study employs a structured interview process in which a set of questions are developed in advance and asked to each interviewee with a consistently administered process (Campion et al. 1988). The purpose of the questions was to uncover the challenges on mega-projects and how well the planning/scheduling methods used were contributing to the control of the project. The interview questions and a list of multiple choice answers were developed based on the literature and the experience of the author in IMPs. The multiple choice format provided a standard terminology that assisted with the analysis and helped to focus the interviewees. Ten multiple-choice questions and one open-ended question led the discussion through the discovery of what challenges the project experienced, how the execution plan was developed and by whom, and the degree to which the plan supported the efforts of the project managers to stay on target. Each interview took about two hours. Detailed interview questions are provided in Appendix C. In brief, the questions were:

4. To what degree are these factors a challenge on your project?
5. To what level of detail is the execution plan developed at the bidding stage?
6. To what degree is the bidding plan depended upon for the actual project plan, assuming you are awarded the project?
7. Who participates in the development of your project plans?
8. How many times has your baseline schedule been revised or expected to be revised?
9. What are the causes of baseline schedule revisions?
10. What planning methods or tools do you use?
11. Why do you use these methods or tools?
12. Rate your methods/tools.
13. Are you satisfied with your planning methods and tools?

The 10 IMPs selected for examination represented a variety of construction fields, including high rises, civil infrastructure, and transportation systems in Qatar and UAE, one of the busiest construction regions in the world. Thirty-two experts (16 general contractors (GCs), eight Consultants, and eight Owners) in managerial positions in the 10 mega projects with a minimum of 15 years of experience each were invited to participate. They were mostly engaged in project management, construction management, or project planning. More information about the participants can be found after the literature review. Participants were informed of the purpose of the interviews and assured that their responses would be reported in aggregated form only. They were invited to withdraw or not respond to any question they wanted. The resulting data were compiled according to the number of responses each answer received. Responses were also categorized according to the role the participant had in the project. Verbal consents were obtained before each interview. However, in compliance with the requirements of the Research Ethics Board at the University of Toronto, written reconsent forms were secured for this part of the study from all interviewed participants. The template of the Reconsent forms is in Appendix D.

2.3 Production Planning and Control Systems

Many approaches to project planning have been developed in the past 80 years. Eight planning and production planning methods are selected from the literature and briefly described in chronological order of their development.

**Line of Balance (LOB)** was developed by Goodyear Company as a method of location-based planning in the 1940s (Frandson et al. 2015) and expanded by the US Navy in the 1950s (Kenley and Seppänen 2010). LOB is a graphical method of planning, controlling, and communicating the construction progress (Halpin and Riggs 1992). It is a velocity diagram, with time along the x-axis and location or work area along the y-axis. It is very effective when applied to linear or
repetitive construction projects, such as roads, pipelines, transmission systems, and high rises (Seppänen and Aalto 2005). It facilitates optimization of the overall schedule by balancing the slope of all of the activities, such that they are as parallel as possible. Standardized algorithms have been developed, allowing the method to be computerized (Al Sarraj 1990). However, LOB has not achieved broad global acceptance in the industry (Seppänen and Aalto 2005).

In the past 25 years, many modifications have been proposed to make CPM and LOB more effective, in particular for complex and mega-projects. These modifications typically focus on workflow or process rather than the mechanical formation of the schedule itself. Clearly, LOB and CPM are just tools, and it is up to the user to decide who is involved and at what stage during the development and implementation of the plan.

Military planning and World War II led to a major effort to create a new scheduling technique (Howell et al. 2011). **Critical Path Method (CPM)** was developed in early 1957 by Remington Rand and DuPont, and matured by the US Navy in early 1958 (Kelley and Walker 1959). Construction of a new chemical plant was the first live project for Kelley and Walker (1959) to test CPM. The application was limited to construction, without considering engineering and procurement phases.

CPM is a project management technique with the intrinsic objective to identify and calculate the critical path of the project in order to optimize it. After establishing the work breakdown structure, the development of a valid CPM schedule depends on identifying accurate and comprehensive dependencies (relationships) and estimating reasonable durations. Moreover, scheduling depends on predecessor and successor activities’ durations, and works can logically be executed simultaneously.

During the planning process, the activities required to complete a task are outlined in a flowchart with estimated durations. The flowchart is arranged with logical relationships between predecessor and successor activities. The critical and non-critical activities are determined by performing forward and backward calculations. The float for each activity is calculated to advise the project execution team of the effects of slippage on successor activities and thus completion. The longest path, or critical path by definition, is the path with zero float, establishing the overall duration and forecast completion of the project. Any delay to any activity in the critical path will delay completion of the project.
While CPM-based software was the driving force behind CPM strength in the market, successive iterations of the software have exponentially increased their complexity. Moreover, from one revision to another and from the first developer to a new owner, the CPM-based solution is becoming more difficult to use as well as unsuitable to run production operations on site. As the industry dominant method, CPM is perceived to be a solution for projects with numerous activities with complex interfaces, and is commonly used for all types and scales of projects in many fields. However, CPM is a task-based system that does not consider maximizing value and minimizing waste (Birrell 1987; Huber and Reiser 2003; Koskela et al. 2002; Mossman 2013).

Although CPM is undoubtedly the most commonly used planning method in the construction industry, it has shortcomings, namely: 1) a CPM diagram is a poor communication tool, and typically needs to be translated into another form, such as a GANTT (bar) chart or pictorial representations; and 2) for large projects, the dependency diagramming can become extremely complex and unwieldy with the level of detail needed. The role of planning is often seen as prioritizing scheduling rather than studying the method of work (Koskela et al. 2014). It was observed that CPM was developed as a management tool at the planning levels (strategic, master, milestone, etc…) but has morphed and extended to the production planning level (Senior 2009; Peer, 1974). As a result, the developed plan has very limited functionality to run site operations, and becomes obsolete before work is underway. Afterwards, updating the plan becomes a tedious method to report history, demonstrating the limitations of CPM as a site-level tool due to its lack of standard algorithms to deal with production problems or workflow variations (Senior 2009; Peer 1974).

**Takt Planning** was developed in late 1950s, and is widely used in manufacturing by Toyota Production System. Takt in German means rhythm. In Takt, time is “the unit of time within which a product must be produced (supply rate) to match the rate at which a product is needed (demand rate)” (Frandson et al. 2013). In manufacturing assembly lines, the Takt is the time the product spends at any workstation before it moves to the next one. Hence, Takt time is a design parameter for manufacturing lines with production cycle times (supply rate) as short as the Takt time so that production can meet the demand rate (Frandson et al. 2013). Six steps outline the planning process. The steps are listed in sequential order, however, implementation is iterative (Frandson et al. 2013): (1) Gather information, (2) Define areas of work (zones), (3) Understand
the trade sequence, (4) Understand the individual trade durations, (5) Balance the workflow, and (6) Establish the production plan.

Variation in production rates is inevitable due to unknown unknowns, and hence, presents an ongoing challenge to match and synchronize the timing of different tasks. Misalignment between Takt time and workstation capacity results in products accumulating between workstations or workstations left idle. This occurs when the performed production rate is faster than or slower than Takt (Frandson et al. 2013). In either case, the result is unwanted waste due to work waiting for workers or workers waiting for work. Balancing requires early detection and immediate response by mobilizing workers from activities not meeting Takt or keeping idle workstations busy with backlog.

Building such flexibility in a construction production system is very risky and costly given the complex, uncertain, and dynamic nature of construction, especially mega-projects. Hence, it is very difficult to apply in construction of IMPs in general, given the challenging and fundamentally different characteristics of the construction industry, as described earlier. Nevertheless, Frandson et al. (2013) posit that Takt time in construction is a design parameter for the flow of work. They presented a case study for the production of an exterior cladding system where Takt time was developed in the planning stage. Limiting Takt time to a single trade with a repetitive nature demonstrates the restrictions of applying this method in a more complex construction environment. Takt time in manufacturing helps to create a built-in demand-rate in a production system called a pull system with a steady flow, as opposed to a push system, which is forecast driven and does not ensure stable flow (Frandson et al. 2013).

**Task Planning (TP)** method was developed in the 1990s (Junnonen and Spanned 2004). TP is a production planning and control system. The method is goal-oriented, and combines the LOB approach and make-ready (lookahead) planning. Its objective is to identify prerequisites for each task. Just before the start of a particular task, management performs a detailed lookahead plan of how it will achieve time, cost, and quality requirements of the task (Junnonen and Seppanen 2004). TP ensures that the entire execution team including supervisors, subcontractors, and workers, know the scope and requirement of each task and the methodology to complete each task (Junnonen and Spanned 2004). Furthermore, TP is a production management method to plan
and control the task delivery as per the master schedule, maintaining project objectives for quality, safety, and budget.

In TP, the execution of a task is processed in the following sequence: 1) analyzing potential problems, 2) scheduling, 3) assessing costs, 4) identifying quality requirements and implementing quality assurance, 5) identifying prerequisites for the task, and 6) securing the progress of the task. Supervisors are responsible for planning the task. They should have clear knowledge of the scope and ensure that all the prerequisites of each task are available as required by the master schedule to execute the task with planned production rates. TP helps to identify the potential risks and problems in the early stages of the project to propose mitigation measures and overcome the consequences.

**Last Planner® System (LPS®)** was introduced as a practical method for production planning and control inspired by Lean production concepts of construction (Ballard and Howell 1994). The LPS® uses CPM for upper-level planning during the master planning phase to identify key milestones. However, LPS® focus is on short-term make-ready (lookahead) planning. Here, field teams commit to achieve the work in an environment that facilitates communication and collaboration. Commitments are measured and reviewed frequently. This system also aims to ensure that all prerequisites, directives, and necessary resources are met before any activity starts to reduce variations by better predicting production workflows. The LPS® developed as a new and radically-different planning method promoting production thinking in terms of flow rather than optimizing discrete activities. The LPS® is replacing the optimistic planning inherent in CPM with realistic planning by allowing trade supervisors, the “last planners,” to commit to work assignments they can complete safely and efficiently, while meeting all quality standards.

**Critical Chain (CC)** was developed in 1997 as a scheduling methodology that takes into account dependencies, resources, and safety margins (buffers) to define the critical path as the longest chain of dependent steps. The objective behind the development of CC was to address some of the shortcomings of CPM with respect to dealing with uncertain durations (Goldratt 1997). When developing a CPM schedule, the time required to cover uncertainties during execution is usually added to the task duration as a buffer. Such buffers result in an inflated project duration. Unlike CPM, the buffers in CC are removed from the activity level, to be strategically utilized in a centralized and effective approach by only one activity at any given
time (Goldratt 1997). This shortens the overall duration of the project. Buffers are removed from each activity and are shown explicitly at the end of the path.

When a delay occurs while performing an activity, a portion of the buffer is allocated to that activity and thus the particular activity will get special attention. This increases the visibility of the bottleneck, which presents an opportunity to sufficiently support the resource to overcome it. This system requires two durations for each task: the most probable and the most stringent (optimistic) durations. The resources are encouraged to complete each task within the stringent duration (Goldratt 1997). Active management of buffers and rigorous reporting of projected tasks to identify bottlenecks and resolve them are the cornerstones of the CC method.

The Location-Based Management System (LBMS) is an interactive method for project planning and control, which places importance on the relationship between the location of the work and the unit of work to be completed (Kenley and Seppänen 2010). Several initiatives emerged, modeling location based planning using LOB lines and CPM networks. The term location-based scheduling was first presented in 2004 (Kenley and Seppänen 2010).

The purpose of LBMS is to generate a plan where only one activity at a time is performed in each zone, with resources free to move from one location to another without waiting. LBMS depends on the location breakdown structure, tasks, quantities, resources, production rate, workdays, calendar, resources, and logical relationships between activities. Assessing the location breakdown structure is a critical part, which affects the quantity breakdown and the logical relationships. To finalize the logic, LBMS uses CPM external logic; however, unlike it, LBMS considers the internal logic as well (Kenley and Seppänen 2010).

LBMS follows the LOB method as a simple two-dimensional graph of locations and time on its axis where the lines representing each trade are continuous and not crossing. Only one trade at a time is allowed in each zone. The distance between sloping trade lines indicates the time buffer. LBMS is suitable for large projects with high complexity (Kenley and Seppänen 2010). It is further suggested that large projects can be scheduled more quickly, providing advantages to work crews and protecting them from poor planning. The result will be a full picture of the work, improved project performance, and increased reliability.
LBMS helps to compare actual progress and production rates so the execution team can foresee the slippages. Then mitigation measures; like revising the production rate and further location breakdown structure (areas/zones) are implemented for the delayed activities/tasks to recover the delays and bring the schedule on track.

**Workface Planning (WFP):** Consisting of engineering, construction, and labour provider companies in the oil and gas industry, Construction Owners Association of Alberta (COAA) developed WFP as a solution to address productivity concerns during the execution of mega construction projects in the industry (COAA 2007). The tool was presented by COAA in May 2006. Furthermore, in an effort to verify the WFP model, COAA conducted a survey to determine face validity and examine industry response. Of 716 surveys sent out, 212 responses were received. Using the Kruskal Wallis Test resulted in only two questions with statistically significant differences. Answers to the first question, should the owner be involved in all planning stages to align plans with the established objectives? revealed Procurement and Construction Management Contract (EPCM) disagreement on the statement compared to concurrency among participating owners and contractors. For the second question, should the foreman be familiar with the site prior to work execution? EPCM and owners were in agreement with the statement, unlike contractors.

Developed by experienced planners on a ratio of 1 planner per 50 craft, the scope is divided into:

- **Construction Work Area (CWA):** represents level 2 schedule for geographic area of all disciplines less than 100,000 hours.
- **Construction Work Package (CWP):** constitutes level 3 schedule for 40,000 hours of single discipline package within CWA.
- **Field Installation Work Package (FIWP):** FIWP is formalized as a level 5 schedule based on a single trade plan for 500 to 1,000 person-hours or 1-2 weeks respectively. Furthermore, FIWP includes detailed information about constraints, scope of work, safety, quality, trade coordination, timesheets and cost codes, material, scaffold, and equipment. Prior to issuance, Quality Control, Safety, and the Superintendent must sign off on the FIWP.

WFP provides experienced planners with guidelines as to the level of detail required by a plan depending on the scope of work. Levels include CWA for geographic area of all disciplines less
than 100,000 hours, CWP for 40,000 hours for a single-discipline package within the CWA, and FIWP as a level 5 schedule based on a single trade plan for 500 to 1,000 person/hours or 1-2 weeks. Furthermore, FIWP includes detailed information about constraints, scope of work, safety, quality, trade coordination, timesheets and cost codes, material, scaffold, and equipment. Prior to issuance, Quality Control, Safety, and the Superintendent must sign off on the FIWP. WFP has a production component derived from the fact that the plan is treated as “a product” prepared by the supplier (WFP planner) to the customer (site crew).

WFP is defined as a best practice process that improves productivity and quality, minimizing construction costs and schedules by improving information and the availability of materials and tools on site (Ryan 2009). Although proposed as the industry’s parallel to the LPS® with respect to the foreperson’s role and engagement in the planning process, industry practitioners appeared reluctant to redefine the roles and responsibilities of forepersons and planners. In a survey, 66% of interviewees agreed that planning responsibilities ought to remain with dedicated planners, not field personnel whose primary job is to be on site supervising workers and site operations (Rankin et al. 2008). A fundamental restriction imposed by WFP is that at least 80% of materials must be delivered and 100% of the engineering documents with the corresponding “issued for construction” drawings must be available before the start of any individual CWP. Industry experts estimated that a construction cost saving of 4-10% was achieved when WFP was used (Ryan 2009). Driven by owners, WFP has become a common contractual requirement on local projects in Alberta (Rankin et al. 2008).

2.4 Summary

The highlighted “planning” and “production planning and control” systems are summarized in Table 2-1. In the context of this chapter, their similarities, differences, strengths, and limitations in dealing with integration challenges of mega-projects are identified and analyzed based on the experience gained from this study because the literature is silent on the integration challenges of production planning and control in mega-projects.

CPM and CC are considered planning systems, whereas the others are production planning and control systems. The pull-system approach has been adopted in Takt, LPS®, and WFP, while the push system is applied in CPM and CC.
Someone might argue why not to modify CPM to short term lookahead planning to avoid the errors of forecasting thousands of mega construction project activities for the duration of the project. By doing that, the critical path cannot be determined and CPM is not applicable anymore.

Table 2-1: Overview of Production Planning and Control Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Year</th>
<th>Integration Challenges</th>
<th>Mega Compatibility</th>
<th>Relation to Other Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOB</td>
<td>1940s</td>
<td>Graphical, easy to read and follow</td>
<td>Not well accepted in the industry</td>
<td>Very difficult</td>
</tr>
<tr>
<td>CPM</td>
<td>1957</td>
<td>Detailed</td>
<td>Push system, does not support the production level at site</td>
<td>Predominantly used</td>
</tr>
<tr>
<td>Takt</td>
<td>Late 1950s</td>
<td>Pull system</td>
<td>Risk of misalignment between Takt time and workstation capacity</td>
<td>No</td>
</tr>
<tr>
<td>TP</td>
<td>1990</td>
<td>Goal oriented, task focused</td>
<td>Not detailed to weekly work plan</td>
<td>No</td>
</tr>
<tr>
<td>LPS®</td>
<td>1994</td>
<td>Pull system, collaborative, rapid learning</td>
<td>Difficult to ensure integration of stakeholders in IMPs</td>
<td>Potential</td>
</tr>
<tr>
<td>CC</td>
<td>1997</td>
<td>Attempt to address shortcomings of CPM for uncertain durations</td>
<td>Same as CPM</td>
<td>Difficult</td>
</tr>
<tr>
<td>LBMS</td>
<td>2004</td>
<td>Two-dimensional, simple</td>
<td>Limits one trade in each zone at a time</td>
<td>Difficult</td>
</tr>
<tr>
<td>WFP</td>
<td>2006</td>
<td>Collaborative, pull system</td>
<td>Requires many WF planners, prevents work from starting before design is complete</td>
<td>Yes, in open pit mining</td>
</tr>
</tbody>
</table>

2.5 Data from Construction Experts’ Interviews

Experts from 10 mega-projects were selected for interviews, as shown in Table 2-2. Some of these projects are complete, such as the Burj Khalifa Tower in UAE, while others are under development in Qatar. All the selected projects dictate the use of CPM as a contractual requirement. In two projects, the General Contractor (GC) used an in-house planning system. Implementing new systems demonstrates that several planning tools are emerging, and the industry has started to use them based on the scope, size, complexity, and duration of the project. Microsoft Excel (Excel) and the LPS® surfaced as preferred systems by the GCs. In a very few
projects, building information modeling (BIM) was used to support planning efforts. However, no literature was found documenting the use of BIM for production planning.

**Table 2-2: Selected International Mega-projects**

<table>
<thead>
<tr>
<th>Project</th>
<th>Planning System</th>
<th>Stage</th>
<th>Construction Value (US$ million)</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burj Khalifa Tower</td>
<td>CPM</td>
<td>C (2010)</td>
<td>1,500</td>
<td>3</td>
</tr>
<tr>
<td>Mesaieed Housing by AlAqaria Development</td>
<td>CPM, Excel, and In-house System</td>
<td>C (2015)</td>
<td>550</td>
<td>2</td>
</tr>
<tr>
<td>Extension of Hamad Medical City</td>
<td>CPM</td>
<td>C (2013)</td>
<td>350</td>
<td>1</td>
</tr>
<tr>
<td>Education City Stadium</td>
<td>CPM</td>
<td>I</td>
<td>Confidential</td>
<td>3</td>
</tr>
<tr>
<td>FIFA 2022</td>
<td>CPM</td>
<td>I</td>
<td>Confidential</td>
<td>1</td>
</tr>
<tr>
<td>Qatar National Museum</td>
<td>CPM</td>
<td>I</td>
<td>435</td>
<td>2</td>
</tr>
<tr>
<td>Lusail City - CP4B</td>
<td>CPM and Excel</td>
<td>I</td>
<td>439</td>
<td>1</td>
</tr>
<tr>
<td>Lusail City - CP5B</td>
<td>CPM, Excel, and LPS®</td>
<td>I</td>
<td>410</td>
<td>5</td>
</tr>
<tr>
<td>Lusail City - CP5A and 6A</td>
<td>CPM</td>
<td>I</td>
<td>330</td>
<td>2</td>
</tr>
<tr>
<td>Lusail City - CP7C</td>
<td>CPM, BIM, and In-house System</td>
<td>I</td>
<td>310</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

The following section provides responses to the 10 multiple-choice questions and any relevant comments provided by the participants.

1) **To what degree are these factors a challenge on your project?**

Respondents rated the factors as very challenging (VC:2), moderately challenging (MC:1), controlled challenge (CCh:0). Controlled challenges are factors that may have been evident on their project, but were controlled and therefore did not affect their project to a noticeable degree. The results are shown in Table 2-3 in order of decreasing score. The score was calculated as:
Score = (NVC*2+NMC*1+NCCh*0) / number of respondents at that level

Where,  
NVC is number of experts rating the factor as VC  
NMC is number of experts rating the factor as MC  
NCCh is number of experts rating the factor as CCh

Schedule, budget, and scope changes provided the greatest challenges on these projects, with scores over 1.50, but responses varied by type of respondent. Owners were most concerned about scope changes and schedule whereas GCs focused on budget and quality of design. Consultants felt their greatest challenges related to the schedule.

Table 2-3: Number of Responses on Challenges to Their Mega-Project

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>Schedule</td>
<td>1.71</td>
</tr>
<tr>
<td>Budget</td>
<td>1.61</td>
</tr>
<tr>
<td>Scope Changes</td>
<td>1.59</td>
</tr>
<tr>
<td>“Quality of Design” Caused Changes</td>
<td>1.35</td>
</tr>
<tr>
<td>Claims and Disputes</td>
<td>1.32</td>
</tr>
<tr>
<td>Authority Approval</td>
<td>1.25</td>
</tr>
<tr>
<td>Meeting Client Expectations</td>
<td>1.12</td>
</tr>
<tr>
<td>Procurement</td>
<td>0.89</td>
</tr>
<tr>
<td>Type of Contract</td>
<td>0.80</td>
</tr>
<tr>
<td>Site Logistics</td>
<td>0.71</td>
</tr>
<tr>
<td>Interface and Coordination</td>
<td>0.64</td>
</tr>
<tr>
<td>Communications</td>
<td>0.61</td>
</tr>
<tr>
<td>Labour Issues</td>
<td>0.60</td>
</tr>
<tr>
<td>Environmental Health and Safety</td>
<td>0.57</td>
</tr>
<tr>
<td>Staff Issues</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>Total Challenges Score</strong></td>
<td><strong>0.81</strong></td>
</tr>
</tbody>
</table>

Four factors scoring between 1.0 and 1.5 relate to interactions between the three stakeholders, and are of greater concern to consultants and GCs than to owners. For example, “Quality of Design” Caused Changes was much more challenging to consultants and GCs than to owners.

Furthermore, incomplete specifications or design drawings inevitably result in unnecessary delays and waste due to redesigns, work interruptions, claims, and disputes. Incomplete design drawings pose many challenges to GCs because the latter are often not given sufficient engineering details to develop shop drawings to execute project components. In these cases, the design team may assume that detailing is the responsibility of the GC, and the scope of details grow as they attempt to shed responsibility onto the GC. A challenge warranting greater concern
is the problems discovered after project completion where the designers did not consider operational requirements in their design. It is very important for the design team to be experienced in order to produce a quality design for mega-projects fit for the intended purpose. Owners had the most confidence that the design team would produce complete, high-quality documents in full compliance with codes, standards, and industry best practices. However, several experts reported in the interviews that even with highly-reputed global engineering firms, design drawings sometimes lack fundamental information, compliance with regulations, constructability, and operational requirements. There was a general sense that design documents are often issued prematurely, leaving the door open for more integration challenges, time and cost overruns, and contractual problems during construction.

Three-quarters of owners found Authority Approval moderately challenging. Local authorities in Qatar outsource some services to external consultants, who often lack the knowledge and experience of local regulations. Compounding this problem, government agencies have redundant responsibilities, creating an unnecessary bureaucracy that delays progress (Rizzo 2014). However, a few of the experts interviewed concluded that the impact of Authority Approval challenges can be minimized through very close and regular coordination with them in addition to understanding their requirements.

Material procurement and delivery must be managed and controlled to meet target completion dates. Problems of supply and procurement were the second-highest contributing factor (69%) in 16 delay studies conducted in 12 developing countries (AlSehaimi et al. 2013)

Often contractual terms in traditional construction management in developing countries are one-sided and do not facilitate a collaborative approach. As a result, communications and team meetings tend to be one directional, turning the project master baseline schedule into a contractual tool rather than a production planning and controlling tool. The owner’s comfort with this arrangement is indicated by 60% saying Type of Contract is a CCh.

2) To what level of detail is the execution plan developed at the bidding stage?

As shown in Table 2-4, the majority of the execution plans are developed to a high level only during bidding, and this is acknowledged by the majority of experts. A few reported that their programs are developed in detail to the activity level. Developing the program in detail during
the bidding stage will help the bidders understand the project’s scope of work, resulting in better competitive pricing. However, it was concluded that this approach would not add real value to site production after award.

Table 2-4: Overall vs. Stakeholders Feedback on Planning at the Bidding Stage

<table>
<thead>
<tr>
<th>Description</th>
<th>Owner (%)</th>
<th>Consultant (%)</th>
<th>GC (%)</th>
<th>Overall (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completely to the activity level</td>
<td>27</td>
<td>11</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Only detailed for critical activities</td>
<td>27</td>
<td>33</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>To a high level only</td>
<td>46</td>
<td>56</td>
<td>62</td>
<td>56</td>
</tr>
</tbody>
</table>

Common practice in IMPs in developing countries is to submit the detailed master baseline schedule, always in CPM, within 14-28 days from the project commencement date. This is quite a short period to understand the entire scope of work, develop, and analyze the detailed multi-year program. Such a contractual obligation leads to assumptions, predictions, and mistakes. This inevitably results in more integration challenges in production planning on the top of the challenges due to unpredictability and complexity of IMPs.

3) To what degree is the bidding plan dependent upon for the actual project plan, assuming you are awarded the project?

As reflected in Table 2-5, the majority of owners expected that the actual plan should depend on bid plans to a greater degree. As noted, GCs are required to submit the project plan within 14 to 28 days of contract award. This suggests an expectation by the owners that developing the full detailed plan requires less effort than the GC needs to achieve it, which is explained by the short allowable period. For a 3-5 year mega-project, this is a tremendous burden.

Table 2-5: Contribution of Bidding Plan to Actual Plan

<table>
<thead>
<tr>
<th>Description</th>
<th>Owner (%)</th>
<th>Consultant (%)</th>
<th>GC (%)</th>
<th>Overall (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not at all, we start over</td>
<td>12</td>
<td>0</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>To a minor degree (25%)</td>
<td>13</td>
<td>0</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td>To a moderate degree (50%)</td>
<td>25</td>
<td>71</td>
<td>50</td>
<td>48</td>
</tr>
<tr>
<td>To a great extent (75%)</td>
<td>50</td>
<td>29</td>
<td>0</td>
<td>21</td>
</tr>
</tbody>
</table>
4) Who participates in the development of your project plans?

The results in Figure 2-1 show that planning experts of the bid proposal team are heavily involved during the development of the bid plan only and not during the actual plan development or updates. Project managers (PM) and construction managers (CM) are involved only during development of the plan and updates. It can be asserted that PMs and CMs have better knowledge of site challenges than the planning experts. Therefore, their contribution to bid plan development should be encouraged to maximize the value attained by site experience and lessons learned.

![Who participates in the development of your project plans?](image)

**Figure 2-1: Participants in Plan Development**

Furthermore, the planning team’s involvement is evenly distributed on the bid and actual plans. Site engineers and supervisors are only involved on the actual plan and updates, while subcontractor and supplier involvement is primarily focused on the actual plan and updates. The
shallow involvement of field personnel decreases the integration level of the developed plan to
deal with integration challenges.

5) How many times has your baseline schedule been revised or expected to be revised?

Baseline programs are revised up to 5 times according to participating experts. Table 2-6 shows
that 67% of experts witnessed more than 2 revisions of the baseline schedule, which is typically
associated with extension of time, with or without prolongation costs. This shows a lack of
ability in predicting how long activities should take. This may be due to a lack of participation
from key personnel from the site team, subcontractors, and suppliers during the baseline
development.

<table>
<thead>
<tr>
<th>Description</th>
<th>Owner (%)</th>
<th>Consultant (%)</th>
<th>GC (%)</th>
<th>Overall (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once</td>
<td>12</td>
<td>0</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Twice</td>
<td>13</td>
<td>38</td>
<td>29</td>
<td>27</td>
</tr>
<tr>
<td>more than twice</td>
<td>75</td>
<td>62</td>
<td>64</td>
<td>67</td>
</tr>
</tbody>
</table>

With such a large number of revisions on the CPM baseline schedule, it is evident that plans are
not used at the production level. The CPM functions as a thermostat model (Kalsaa 2012;
Koskela et al. 2002; Abdelhamid 2004). Such a model triggers warning signs when a variance to
planned activities is detected. In other words, slippage is plotted on the planned against the actual
S-Curve after delays occur. At this stage, GCs must react and develop a recovery plan by adding
more resources to fast-track or crash critical activities, which results in unnecessary additional
cost (or waste in Lean language). Several experts declared that the CPM schedule is used mainly
for historical reporting and contract management rather than for planning activities. The
misapplication of CPM in the industry poses an alerting question to investigate the reasons
behind it.

6) What are the causes of baseline schedule revisions?

Respondents rated causes as fundamental (primary), major, or minor, with scores of 2, 1, and 0
respectively. Fifty percent or more of the participants said that revisions to baseline programs
have the upper six fundamental or major causes of revisions listed in Table 2-7. The remaining
causes were ranked as minor by 50% or more of the participants. The score was calculated as:
Score = (NFC*2+NJC*1+NIC*0) / number of respondents at that level

Where, 
NFC is number of experts rating the factor as a fundamental cause

NJC is number of experts rating the factor as a major cause

NIC is number of experts rating the factor as a minor cause

Table 2-7: Causes of Baseline Schedule Revisions noted as Fundamental or Major

<table>
<thead>
<tr>
<th>Cause of Revisions</th>
<th>Overall</th>
<th>Owner</th>
<th>Consultant</th>
<th>GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope change</td>
<td>1.47</td>
<td>1.3</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Delays in authority approval</td>
<td>1.00</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Unforeseen conditions</td>
<td>1.00</td>
<td>0.7</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Unforeseen milestones imposed</td>
<td>0.89</td>
<td>0.4</td>
<td>0.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Inaccurate forecast</td>
<td>0.71</td>
<td>0.8</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Underestimating duration of key activity</td>
<td>0.63</td>
<td>0.5</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>Unpredictability of site operation workflows</td>
<td>0.62</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Lack of understanding of prerequisites and constraints</td>
<td>0.57</td>
<td>0.6</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Inability of site team to fulfil commitment</td>
<td>0.52</td>
<td>0.9</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Lack of site team’s inputs to original plan</td>
<td>0.50</td>
<td>0.7</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Force majeure</td>
<td>0.36</td>
<td>0.1</td>
<td>0.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Not using the right planning tool</td>
<td>0.31</td>
<td>0.6</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Six out of eight consultants reported that a lack of site input is a major issue and leads to baseline revisions, whereas owners and GCs reported this as a minor issue. The inability of the site execution team to achieve targets is a major reason for baseline revisions, according to owners and consultants, but GCs consider it a minor reason. In other words, GCs see that causes are external to their operations, whereas owners and consultants see them as internal to the GC. Half of the consultants believed that poor understanding of the prerequisites and constraints in the plan is a major cause for program revisions.

The GCs suggested that, in addition to the listed causes, design changes and new authority requirements were fundamental causes of delays in mega-projects. One of the owners suggested that the lack of familiarity by international GCs of local regulations and practices was a fundamental cause.
7) What planning methods or tools do you use?

Experts were encouraged to report all the planning tools and methods that they used to run site operations in an open-ended manner, as shown in Table 2-2.

CPM (P6©, 43% and MS Project, 15%) actual applications for planning and scheduling are the predominant tool, with 58% of users. All the projects in this study dictated the use of Oracle’s Primavera Professional Project Management© software (P6©), which is CPM-based, as a contractual requirement. However, a further breakdown indicates that it is relied upon less in practice. The results of the following question reveals that 100% of the reviewed projects dictate P6© as a contractual requirement. Thus, 51% of the interviewed experts declared that they do not use P6© for planning, as governed by the contract; they use other, more appropriate tools for the day-to-day planning and control at the production level. Therefore, P6© is used mainly to satisfy the owners and to provide them with monthly progress reports. Hence, its role is to report history rather than to plan activities.

8) Why do you use these methods or tools?

The key objective of this survey was to ascertain the main reason behind the use of these planning method or tools (P6©, MS Project, LPS, Excel and BIM) identified by the experts interviewed in the earlier answer (Question No. 7). When responding to this question, the experts were asked to choose from five reasons based on their own experience 1) contractual requirement, 2) company preference, 3) my preference, 4) industry standard, and 5) state-of-the-art. As per Figure 2-2, P6© is the dominant tool dictated by their contracts.
Despite the pressure from the owners, the industry, and even their own companies, only 35% of the experts preferred P6© personally. The LPS® and Excel bar charts scored almost as high, with 30% finding the LPS® to be state-of-the-art. GC experts advised that Excel and the LPS® techniques are user-friendly, and make communication and understanding easier by site production crews.

Interviewees identified P6© as used primarily due to (in declining percentages) contractual requirement, the tool being an industry standard, company preference, or that interviewees classified it as state-of-the-art. Nevertheless, P6© is less preferred at an individual level where 65% of interviewed experts did not select it as personal preference. The LPS® and BIM have started to become part of contractual requirements in some projects.

9) **Rate your methods/tools as: 1=Good 0=Acceptable -1=Poor**

This question is a continuation of the previous questions, which tackles in detail the planning methods or tools that are mainly used on various mega-projects. This question attempts to evaluate the main planning methods or tools used on the selected 10 mega-projects. The scores highlighted in Table 2-8 confirm that CPM, as a contractually-driven tool, is poorly recognized by GCs without regard to its software configuration, whereas collaborative systems like the
LPS® and Excel-driven bar charts are better perceived and appreciated, especially by GCs who are responsible for the day-to-day work. The score was calculated as:

-score = NG + NA*0 - NP

Where,
- NG is number of experts scored the tool “Good”
- NA is number of experts scored the tool “Acceptable”
- NP is number of experts scored the tool “Poor”

Table 2-8: Overall Evaluation of Planning Tools

<table>
<thead>
<tr>
<th>Scoring</th>
<th>P6©</th>
<th>MS Project</th>
<th>Excel</th>
<th>LPS®</th>
<th>BIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promoting Top-down Approach</td>
<td>7</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Promoting Bottom-up Approach</td>
<td>-6</td>
<td>-5</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Promoting Team Work</td>
<td>-4</td>
<td>-2</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Communication Tool</td>
<td>-2</td>
<td>-2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ease of Modification / Updating</td>
<td>-2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Accurate Reflection of Physical Progress</td>
<td>4</td>
<td>1</td>
<td>-1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Flexibility</td>
<td>-8</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Owner</strong></td>
<td>3</td>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Consultant</strong></td>
<td>6</td>
<td>-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GC</strong></td>
<td>-20</td>
<td>-3</td>
<td>9</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td><strong>Overall Total Score</strong></td>
<td>-11</td>
<td>-3</td>
<td>9</td>
<td>14</td>
<td>7</td>
</tr>
</tbody>
</table>

10) Are you satisfied with your planning methods and tools?

Experts representing GCs view CPM as heavy, inflexible, inundated with excessive detail at an early stage, and time-inefficient. In their view, it is a poor tool to communicate planned activities with construction site teams. Many of interviewed GCs use MS Excel instead. GC experts confirmed that baseline programs are generally developed by a specialist under intense time pressures, with a limited involvement of site teams.

This question tackles the satisfaction level with the planning method used by each expert. Of 32 experts, 6 (19%) were Extremely Satisfied with P6©, 13 (41%) were Satisfied, and 13 (41%) were Partially Satisfied. While among the 11 experts who used LPS® in addition to P6©, 5 (45%) were Extremely Satisfied, 4 (36%) were Satisfied, and 2 (18%) were Partially Satisfied.
2.6 Discussion and Findings

Completing an IMP on time, on budget, and according to specifications is a monumental task requiring expertise, teamwork, and the right tools to support the project team. Unfortunately, the ability of traditional tools to support a successful outcome is viewed to be poor. Nine out of ten transportation and infrastructure projects in 20 nations spanning five continents had cost overruns (Flyvbjerg 2007). The experts interviewed reported that fewer than 20% of mega-projects are delivered on time, and even fewer are delivered on budget. One of the key factors contributing to this failure rate is selecting the right production planning system that effectively deals with integration challenges.

All the experts worked on IMPs that had a contractual requirement to use P6© for reporting progress to the owner. Although one would expect that the GCs would therefore use P6© for all planning and control in the project, they often resorted to simpler methods and tools that facilitated collaborative planning. The GCs were required to develop and submit their master baseline schedule in P6©, which contained 5,000 to over 20,000 activities within 14-28 days of project start. While such a plan is resource-loaded, it rarely incorporates inputs from key stakeholders in the field, such as sub-contractors or suppliers—there just is not enough time. There is also a difference in perception between GCs and owners about the degree to which the GC can use the bidding plan for the master baseline schedule. Fifty percent of owners thought that the bidding execution plan is used to a great extent whereas the GCs said it was used to a moderate degree at most.

Once submitted, most experts noted that owners spent 90 days or more reviewing and approving the GC master baseline schedule. Understandably, owners are reluctant to approve the baseline schedule as they are concerned about potential claims by the GC. It was also suggested that these baseline plans are eventually used to analyze delays and ask for time extensions. The experts confirmed that the GCs do not use P6© to run projects at the production level, mirroring the same conclusion for site management in the United States (Howell et al. 2011).

Owners assume that CPM provides a sufficient shield against a GCs delay claims (Huber and Reiser 2003). However, what happens in practice is different. Medium-to-large construction projects last 2-5 years. This long duration is considered a major contributing factor to uncertainty in the plan, as many elements and events are difficult to predict (Applebaum 1982). One expert
highlighted that using CPM diminishes with forecasts over six months. Another expert said “CPM is too detailed too early.” It loses short-term effectiveness with long-term planning, relying on forecasts and assumptions. Another expert observed that the misapplication of CPM resulted in a failure to reflect the actual reporting of physical progress.

With the high risks and integration challenges of IMPs, GCs are typically concerned about liquidated damages. Owners require that the GCs submit their P6© schedules very early in the project to establish a baseline for assessing damages. The industry has been strongly criticized for using CPM as a contractual tool rather than as the production optimization method for which it was created (Koskela et al. 2014; Senior 2009; Peer 1974). Because the CPM schedule does not promote teamwork, lacks flexibility, and is used contractually, GCs use alternative programs, typically Excel, to create GANTT charts to plan and control day-to-day project production operations. Often, they are different from what is reported to consultants and owners. Therefore, CPM is not the most effective method to address integration challenges of IMPs.

The inputs of experts in this study show a huge gap between literature and practice. The level of cooperation among project participants decreases as conflicting interests among participants increase and the overlap of common objectives shrink (Malone and Crowston 1994). Current bidding procedures and contract conditions do not encourage project integration as suggested in an ideal Lean Construction model. In the absence of alternative tools, CPM continues to be the dominant tool demanded by owners in international projects compared to seven other methods identified above.

IMPs often suffer significant delays, and GCs usually find ways to be compensated at the owner’s expense for prolongations and extensions of time. This is why owner experts are frustrated with the traditional project management approach, associated cost overruns, and project delays. Due to varying factors including corporate inertia, owners are unable to explore a revolutionary shift in the industry by encouraging the use of more practical tools. For this reason, there have been calls for reform policy and planning for mega-projects (Flyvbjerg 2007).

New tools like Excel, BIM, and the LPS® are being used for a few projects. Some people have tried to develop in-house planning systems to meet the needs of production crews. Two of the projects included in this study partially used the LPS®. Relative to CPM, the experts reported that the LPS® facilitated team collaboration and coordination, which allowed for successful
delivery. However, implementing the LPS® in IMPs faced increased challenges to ensure field integration among subprojects, leading towards full interface of the clustered project segments. Furthermore, this finding is reinforced in CP5B project inspiring this study, where it was found that the LPS® requires different treatments to address integration challenges of IMPs. This calls for further research to evaluate the adaptability of the LPS® in addressing production integration challenges of IMP environments and developing appropriate solutions to address these challenges.

One expert, representing an international GC, stated that the most pressing and significant challenges his company encountered included becoming familiar with the project’s local market, understanding the full scope of mega-projects, allocating the proper resources (manpower, equipment, and materials), satisfying local authority requirements, and managing all project risks, escalation of prices, and shortages of resources. To address these challenges, the expert recommended having full control on the delivery of IMPs by deploying:

1. An experienced technical team that can coordinate production with all trades and integrate operations across subprojects.
2. A strong procurement team that is familiar with the local market.
3. An experienced construction team that understands the scope and executes the work in the allotted timeframe, without compromising on quality.
4. An experienced commercial team for timely invoicing, administering the contract scope changes, and managing subcontractors/suppliers.

As the above recommendations might seem to be common practice in normal circumstances, the risk, complexity, and characteristics of IMP combine to make an especially challenging working environment, even for experienced global organizations.

### 2.7 Conclusion

IMPs are unique for having mega relationship networks among project stakeholders, with significant impacts on communities and the environment. As confirmed by industry experts, delays and budget overruns are serious problems of IMPs; these delays could be compounded by the production planning and control tools used. Changes to schedule, budget, and scope, as well
as an inadequate quality of design are identified as the most challenging factors affecting the integration and delivery of IMPs.

Part of the study documents how IMPs are managed in practice through input by 32 experts who have built some of the world’s most recent signature IMPs. Experts’ feedback revealed that only a few methods are applied in practice. The leading system in construction, CPM is not the most effective method to address the pressing integration challenges of IMPs. The experts representing General Contractors (GCs) found CPM-based tools to be an excellent system for master planning yet ineffective for production-level planning and control. As such, many of the GCs interviewed use Excel instead. GC experts confirmed that baseline programs are generally developed by specialists under intense time-pressures, with a very limited involvement of site teams.

Despite its many shortcomings and waning applicability at the site production level, CPM remains the dominant planning tool driven by the owners’ demand in the construction industry. While it was intended as a planning tool, it is mainly used in practice to analyze delay and time-extension claims (Huber and Reiser 2003; Kenley 2004). New methods and tools are beginning to be deployed on IMPs. One of those methods is the LPS®, which has been successfully implemented in many projects, including those large in scale. However, confirming its wide-scale validity to deal with integration challenges of IMPs requires further research, as highlighted by interviewed experts.
Chapter 3  A Case-Study

3.1 Introduction

The inspiration for this case study came and was further motivated by the challenges faced in planning and controlling the execution of international mega construction projects.

The case study is based on a mega-project worth approximately US$410 million, for which the author was a Senior Project Manager. Serving about one third of Lusail City, the site of Construction Package 5B (CP5B) is spread over about 9 km$^2$. The project involves the construction of complex networks of roads, intelligent transportation systems (ITS), smart city solutions, telecommunications, power, potable water, irrigation, stormwater, sewerage, district cooling, pneumatic waste collection, and gas infrastructure systems. These networks then tie into and provide services to five neighbouring major district developers, 45 buildings, 10 construction packages, 8 light rail transit (LRT) stations, 17 km of light-rail track, 1 civil defense station, 7 health care centers, 15 mosques, 3 gas stations, 16 schools, 4 sports facilities, 2 electrical substations (66 kV), and 2 main 400 mega-Watt electrical grid stations.

Although the project was designed by a global consulting firm who previously developed tens of similar projects, the project suffered from many coordination challenges, causing major redesigns, aborted works, and disruptions. The general contractor (GC) raised over 850 Requests for Information (RFI), resulting in changes to 80% (or 1,200) of the Issued for Construction (IFC) drawings and thousands of shop drawings. As a result, the project master baseline schedule, which contained over 15,000 activities, was revised five times. Despite the project team’s collaborative efforts to keep the project on schedule, their efforts were quickly diminished. Program slippage was out of control, leading to decreased usability of the schedule for planning purposes. The project suffered major delays of 21 months from the original completion duration of 30 months, while the cost impact was in disagreement for a very long time. Sadly, this dramatic example falls within the typical ranges for time and cost overruns of mega-projects (Jergeas and Lynch 2014).
The project experienced significant changes due to design errors and omissions, clashes, and a lack of design integration at tie-in points. This left the construction team with unnecessary layers of complexity in managing integration challenges on-site and exponentially increased risks as the project progressed. The duration of the project was initially 912 days, but was extended by an additional 991 days, thereby doubling the completion time. Unfortunately, completions of mega-projects on time and budget are rare (Davies et al. 2014; Flyvbjerg 2007). This reinforces the need for reform in mega-project policy and planning to deal with their extraordinary challenges (Flyvbjerg 2007).

The purposes of this chapter are to examine some of the systemic and situational causes of schedule overruns on international mega-projects (IMPs), and to describe how the Last Planner® System (LPS®) was used on CP5B to put the project on track for achieving milestones as planned. During this effort, the LPS® was evaluated to identify its strengths and limitations as it applies to IMPs (Objective 2 of the study). As few publications address the use of LPS® in IMPs, the results and lessons learned from this study are shared to advance LPS® practice at such a complex scale.

The first part of this chapter covers the literature of the LPS® and case study methodologies. The second part presents the case study details, data, results, findings, analysis, and discussion to evaluate the compatibility of the LPS® to tackle integration challenges of IMPs. Finally, the conclusion and recommendations are presented.

3.2 Last Planner® System (LPS®)

Synchronized with the intimate need for a Lean production philosophy in construction industry (Koskela 1992), Lean production concepts from manufacturing were introduced to construction. Inspired by the Lean principles to improve the value stream and flow of processes by eliminating waste and generating value, the LPS® become the operating system of Lean Construction. The LPS® was developed as a new and radically-different planning method promoting production thinking in terms of flow rather than optimizing discrete activities. The LPS® is replacing the optimistic planning inherent in the critical path method (CPM) with realistic planning by giving the opportunity to the trade supervisors, the “last planners,” to commit to work assignments that can be completed safely and efficiently, while meeting all necessary quality standards. The LPS® facilitates the tracking of commitments made by the field team, and ensures that those
commitments are measured. This system also aims to ensure that all prerequisites, directives, and necessary resources are met before the start of any activity (Abdelhamid et al. 2010). This reduced variations by better predicting production workflows (Ballard 2000). Its decentralized grass-roots design makes the construction plan agile and flexible to function as a steering mechanism by continually aligning progress with its targets (Ballard and Tommelein 2016). The extensive early planning efforts of CPM does not help when works go out of sequence. In such a case, immediate feedback is essential to adjust the schedule (Tommelein 2015).

The LPS® promotes respect among site teams by engaging them weekly to commit to what they can achieve rather than imposing on them an unrealistic plan to which they had no input. The LPS® approach enables planning to be an ongoing conversation rather than a prescribed task, and enables site crews to align construction operations for higher productivity and efficiency.

Figure 3-1 provides the detailed framework behind the LPS® as a pull production planning and control system designed to assist site teams to run construction operations in a continual improvement cycle.

![Figure 3-1: Existing Framework of the Last Planner® System](image)

(Ballard and Howell 1994; Ballard and Tommelein 2016) “Reprinted/Adapted with permission from the Lean Construction Journal (LCJ), a publication of the LCJ.”
Unlike the traditional construction management, CPM-based approach described in Chapter 2, the LPS® is a philosophy that embraces pull planning to manage a project by incorporating flow and value generation theories (Abdelhamid et al. 2008; Koskela 1992). Resources are pulled into the system according to the status of work. The LPS® pulls works back from project milestones, and works are executed at the last responsible moments (Ballard 2000). In a bottom-up approach, the LPS® incorporates the inputs of the “last planners,” during the production planning process to ensure a better flow of works. Furthermore, a pull plan is established in a collaborative discussion with the team to develop a realistic plan that can be used at the production level.

Mega-projects encompass many complex processes. As discussed in Chapter 1, some of the major challenges at The Big Dig, the Chunnel, and Denver International Airport projects involved an underestimation of these complexities. Complexities could be related to the unpredictability of mega-projects due to their long time-frame, execution strategies, construction methods, constraints, schedule, management of stakeholders, organizational issues, communication, and risks. These complexities result in a greater challenge if encountered in operations without being part of the plan. Using the LPS®, constraints are analyzed, minimized, and processed to study the feasibility of proceeding further. “Should” and “can” assignments are processed by analyzing complexities, and “will” assignments are determined. Based on “will,” weekly work plans are created by documenting commitments. Every week, prerequisites in the next 3-6 weeks are analyzed so that the path is clear and can be executed without unnecessary hurdles (Ballard 2000).

AlSehaimi et al. (2009) presented a research on the implementation of the LPS® in two projects in Saudi Arabia. They reported improvements in the PPC for the first project from 69-86% and 56-82% for the second project. The PPC graph of both projects showed sustainable, steady improvement of the PPC around 80%. For the first project, incomplete assignments were primarily caused by prerequisites that were not satisfied, whereas labour issues were the main factor causing delays in the second project. Both projects shared other delays, such as securing approvals and changes in priorities. AlSehaimi et al. (2009) reported that implementing the LPS® succeeded in improving the planning system of the projects and was a powerful overall project management practice. Therefore, they recommended extending similar implementations in developing countries.
The percent plan complete (PPC) is based on the actual activities completed for that week over the total activities planned. Coined as a core principle of the LPS®, this new metric measures the reliability of planning (Howell and Ballard 1994). The PPC is calculated using the following equation:

\[
\text{PPC} \% = \frac{\text{Completed Weekly Assignments}}{\text{Total Weekly Promised Assignments}} \times 100
\]

A repeated PPC score of 100% sometimes indicates that the team is either under-committing or being very conservative. It is the responsibility of the LPS® facilitator to detect such behaviour and work with the team to prevent it. The construction crew should be motivated to “push the envelope” by increasing productivity. Observing the best performing junctions in this study, a typical PPC score in the complexity of IMPs is between 85-95%. If the PPC falls below 80%, an investigation must be conducted to identify the root causes of the problem and eliminate them from the production system to avoid reoccurrence. While the project team should always strive to achieve 100% PPC, additional key metrics of the LPS® can be used, as detailed below (Ballard and Tommelein 2016):

Tasks Anticipated (TA): The objective of this important indicator is to measure the planning capability of a project team to predict actual activities executed in the make-ready time-horizon window. TA is calculated using the following equation:

\[
\text{TA} \% = \frac{\text{Number of Tasks Anticipated in MRP br a week and confirmed in WWP}}{\text{Total Number of Tasks in WWP for the same week}} \times 100
\]

Tasks Made Ready (TMR): TMR is the percentage of assignments planned for a particular week of the make-ready plan that are included in the latest rolling make-ready plan for the same week before execution. TMR measures the planning capability of a project team to identify and remove constraints in advance to allow scheduled tasks to start as planned. TMR is calculated using the following equation:

\[
\text{TMR} \% = \frac{\text{Number of Tasks Anticipated in MRP for a week and confirmed in WWP}}{\text{Total Number of Anticipated Tasks in Make-Ready Plan for the same week}} \times 100
\]
**Frequency of Plan Failures:** Uncompleted assignments of the WWP are generally assigned to a category describing the cause of the “plan failure.” As plan failures occur throughout a project lifecycle, their frequency is captured and tabulated in a Pareto chart to reveal the root-causes of unmet commitments and identify appropriate solutions to prevent reoccurrence.

### 3.3 LPS® Implementation in Mega-projects

Implementing LPS® can be a painful change from traditional management with respect to organizational behaviour and culture (Kalsaas 2012). It requires understanding of Lean Production concepts, intensive training, and continual development which can hardly be attained from reading only (Mossman 2013). The LPS® has been successfully implemented in many projects. However, publications documenting its application in IMPs are very limited. Although commonly used for large domestic projects, the LPS® has not been tested rigorously on IMPs.

Three case studies were found in the literature: 1) the US$151 million Temecula Valley Hospital in California, USA (Do et al. 2015), 2) US$5.5 billion Sutter Health Program in California, USA (Lichtig 2005), and 3) the US$8.5 billion Terminal 5 of Heathrow Airport in United Kingdom (Davies et al. 2009). From these very few examples, no information was found explicitly detailing or confirming the success and the limitations of implementing LPS® as a Lean production planning and control system in mega-projects. Therefore, in the absence of documented applications, the adaptability of the LPS® to be fully incorporated in IMPs is an important area to explore.

For example, Terminal 5 at Heathrow Airport was a massive undertaking with 147 sub projects, consisting of tens of thousands of activities coordinated between 60 contractors with a workforce of approximately 8,000. Construction started in September 2002, and completed as scheduled on March 27, 2008. The Lean production technique was adopted to help deliver the project on time and budget (Davies et al. 2009). Only materials expected to be used in the next 24 hours were delivered to the site to minimize storage challenges and double-handling. Quality planning, assurance, control, and improvement techniques were adopted with quality auditing performed at several levels. Queues were very well managed by supply chain management techniques, and 5 key performance indicators were adopted: 1) Verifications planned and work supervised, 2) Benchmarks agreed, 3) Work inspected and protected, 4) Compliance assured, and 5) Handover agreed and work completed. Ten key measures and 37 performance data were defined to
measure the performance. To carry out self-assessments and knowledge management, each team recorded progress data and measured the performance every month (Basu 2012). While Lean Construction techniques were used to manage the overall project, no literature was found documenting the details of the LPS® implementation journey at the site production level, including itemizing which part(s) of the project it was applied on, whether it was partial or full implementation, the methodologies used, benefits, limitations, or lessons learned.

3.4 Case Study Methodologies

The case study approach has many definitions. One such definition states: “in case study, researchers explore in depth a program, an event, an activity, a process or one or more individuals.” In this method, data are collected or observed over a certain period of time (Creswell 2003). In conducting case study research, researchers tend to include too many objectives or attempt to answer questions that are too broad. To avoid this, Baxter and Jack (2008) presented the following recommended guidelines to conduct case study research: 1) determine when to use a case study approach; 2) decide what is to be analyzed; 3) circumscribe the case study, i.e. draw boundaries; and, finally 4) determine the type of case study to be used.

In case studies, there are two participants: the researcher and the case object (Baxter and Jack 2008). The relationship between the two affects the outcome. There are three main approaches in case studies to deal with that relationship, namely: 1) exploratory, 2) descriptive, and 3) explanatory (Baxter and Jack 2008; Yin 1993). Four approaches used less often are: 1) multiple case studies, 2) intrinsic, 3) instrumental, and 4) collective (Baxter and Jack 2008; Stake 1995). Only the main approaches are reviewed here.

The **exploratory approach** is used when the problem is not clearly defined. This approach helps us understand the problem rather than provide conclusive evidence. It tackles problems for which little or no research has been carried out to open up possible insights like familiarity, feasibility, direction for future research, techniques, and formulation of new research questions. Exploratory research typically helps to diagnose a situation, screen alternatives, discover new ideas, and clarify existing concepts by answering the “how” question (Lim and Mohamed 2000). In this type of study, the researcher does not have a clear idea about the problem. Hence, the situation is diagnosed for problems, and further investigations on those issues are suggested. The format is flexible.
The **descriptive approach** describes people, products, and situations. It describes the phenomenon exemplified by the case object with respect to variables or conditions. Data from the descriptive approach may be qualitative or quantitative, or both (Baxter and Jack 2008; Yin 1993). It answers the “what” question (Tellis 1997). Descriptive research involves data-gathering, organizing, tabulating, depicting, and describing the data collected. Visual aids such as graphs and charts are used to help the reader to understand the data distribution. Descriptive statistics are very important in reducing data to a manageable form (Baxter and Jack 2008).

The **explanatory approach** is conducted for a problem that has not been clearly defined. While the explanatory case study research focuses on “why” questions (Tellis 1997), this method explains a phenomenon or situation. Often, explanatory and descriptive case study research are confused. The descriptive approach addresses the behaviour itself while the explanatory method addresses why a particular behaviour is the way it is (Yin 1993).

### 3.5 Case Study: CP5B at Lusail

Increased integration challenges of IMPs coupled with the super-sized project scope, risk, cost, and schedule provide many, compounding factors to delay or halt the construction progress. However, mega-projects have the opportunity to reap the greatest benefit from implementing novel practices, like the LPS®, that ensure delivery along with project objectives and benefits. However, little is published about the LPS®’s adaptability on an IMP scale. For this reason, CP5B as a mega international project was selected as a test to apply the LPS®. This case study is based on the exploratory approach, and follows the recommended guidelines of Baxter and Jack (2008), as described earlier. All data were collected at the project site. Participants were asked to identify the challenges of applying the LPS® in two evaluation sessions.

### 3.6 Project Brief

At the Lusail City program, the primary infrastructure of roads, utilities, plants, and landscaping to serve the entire development area is being constructed under a number of construction packages. The project selected for this case study is Infrastructure CP5B (shown in Figure 3-2). Valued at US$410 million, CP5B focuses on the major roads that will serve as a centerpiece of the Lusail City transportation system, mainly:

5. Roads: 11,400 m and 15 junctions (J)
6. Structural Works: 2 Major underpasses (UP): 1,018 m and 440 m in length
7. Utility tunnel (cut and cover): 3,200 m
8. Utilities: Potable water pipes: 16,583 m
9. Foul sewer pipes: 5,090 m
10. Stormwater pipes: 34,761 m
11. Irrigation pipes: 17,085 m

The construction to achieve this important package involves over 1,800,000 m$^3$ of excavation, 1,000,000 m$^2$ of asphalt pavement, 380,000 m$^3$ of concrete, and 113,000 m of various cables for communication, transmission, distribution and low voltage power supply.

Figure 3-2: Layout of CP5B Project

On the award of the construction contract on January 15, 2012, the winning bidder, an international general contractor (GC), started mobilizing resources and manpower over six months. The owner allocated six professionals to oversee project progress and monitor the performance of the CP5B consultants and the GC. Project management, site supervision, and cost consultants allocated another 91 professionals of various disciplines to support the
engineering and construction operations. The GC had 4,000 staff and workers. Participation in this IMP was very diverse, with personnel from 36 countries.

As a standard contractual requirement in Qatar, a comprehensive project master baseline schedule must be developed using CPM-based scheduling software. An S-Curve of the overall physical progress is drawn regularly on a time-percentage chart to provide an immediate overview of the project’s actual progress and its variance against the planned baseline schedule. Figure 3-3 is the S-Curve of CP5B. The master baseline schedule is also intended to serve as an overall roadmap where short-term schedules are extracted and used for execution, monitoring, and reporting.

Figure 3-3: S-Curve of CP5B

As a fundamental mandatory contractual requirement, the GC used CPM-based scheduling software to develop the project detailed master baseline schedule. In parallel to the contract-specified scheduling software, the owner initiated an unbinding strategy with the GC to monitor progress commitments by measuring the PPC of enabling works. Only two major construction activities were in progress on-site at that time, namely: 1) the excavation of 1.8 million m³ of
earth and rock to depths reaching 18 m and 2) drilling 121 deep wells for a dewatering system with an average depth of 21 m. This was the first time the GC was required to measure the PPC. Over three months, PPC results were extremely poor, falling in the range of 20-40%, revealing that the GC was achieving only 30% of its promised rate of progress, on average. Due to complex challenges in site coordination as well as other considerations, the GC was unable to identify and resolve the root cause of the failure to meet its commitments. Therefore, the GC unilaterally decided to suspend reporting PPC measurements, and relied on the contract-specified software using CPM.

During the next 18 months, the project suffered major delays. The GC realized that the specified software failed to produce a usable plan to support construction operations at the production level. Hence, the GC started using Microsoft Excel® to develop simpler and more practical plans for use by the site team.

While the project utilized a full CPM master schedule with over 20,000 activities, the GC could not determine the real physical progress most of the time. This is due to the magnitude of the project and the complexity of the software. Projects of this size and such challenging horizon windows will always have a high degree of unpredictability that add more barriers on the project team to properly and sufficiently consider during the planning stage. The baseline schedule failed to consider such unpredictability, resulting in complications to the anticipated progress. The situation became increasingly complex due to integration challenges driven by delays, cost overruns, and scope changes. The schedule suffered and setbacks compounded upon each other, rendering the baseline schedule obsolete for production planning and control purposes. Hence, the owner demanded a recovery and mitigation program to generate an effective plan for the project. The master baseline schedule was revised accordingly. Despite efforts to mitigate and recover, slippage reoccurred and the revised schedule again faced a revision.

Critical sections of the project loomed, which were to serve 900 VIP residential buildings in two key affluent districts of the new development. Under tremendous pressure from the owner, the GC was challenged to deliver these sections on time. The damages, consequences, and financial impacts of any delay in delivery were unaffordable for the owner, as a master developer, and the GC. Under these stressful mandates, demanding conditions, stringent evaluations, and careful consideration, the GC decided to institute the LPS® to help track the key contractual milestones
and practically plan site operations. The owner supported this idea. The situation provided an excellent opportunity to evaluate the adaptability of the LPS® in addressing production integration challenges in the complex atmosphere of an IMP, such as CP5B.

The master baseline schedule was revised five times during the contract period. Table 3-1 shows the chronology of revisions to the baseline program and how it became outdated. With the start of this case study, three revisions of the master baseline schedule had been issued. Subsequent revisions were due to excusable delay events beyond the control of the GC. The project is ongoing. The project team is striving to close punch-list items, non-conformance reports, minor remaining works, and the overall testing and commissioning to hand over the project. The project was substantially completed and became operational on March 31, 2017.

Table 3-1: Revisions of Master Baseline Schedule

<table>
<thead>
<tr>
<th>Revision #</th>
<th>Date of Submission</th>
<th>Date of Approval</th>
<th>Completion Date</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rev. 0</td>
<td>22-Mar-2012</td>
<td>16-Apr-2012</td>
<td>14-Jul-2014</td>
<td>First baseline submission incorporating original contract parameters.</td>
</tr>
<tr>
<td>Rev. 1</td>
<td>11-Jul-2012</td>
<td>4-Sep-2012</td>
<td>14-Jul-2014</td>
<td>Approved with comments. 1st revision of the schedule submitted 3 months after Rev. 0 approval due to major delays in mobilization</td>
</tr>
<tr>
<td>Rev. 2</td>
<td>28-Feb-2013</td>
<td>21-Mar-2013</td>
<td>14-Jul-2014</td>
<td>In 2nd revision, GC trying to recover in response to schedule slippage</td>
</tr>
<tr>
<td>Rev. 3 (EOT 1)</td>
<td>10-Jul-2014</td>
<td>5-Aug-2014</td>
<td>31-Dec-2014</td>
<td>Approved with comments. 3rd revision incorporated excusable delay events that resulted in 170 days extension of time (EOT 1)</td>
</tr>
<tr>
<td>Rev. 4 (EOT 2)</td>
<td>15-Jul-2015</td>
<td>15-Dec-2015</td>
<td>25-Mar-2016</td>
<td>Due to lengthy disagreement, completion date of Rev. 3 elapsed by 285 days before Rev. 4 was granted EOT 2 with additional 450 days</td>
</tr>
<tr>
<td>Rev. 5 (EOT 3)</td>
<td>7-Aug-2016</td>
<td>17-Jan-2017</td>
<td>31-Mar-2017</td>
<td>5th revision incorporated excusable delay events with an additional 371 days to the completion date.</td>
</tr>
</tbody>
</table>
3.7 LPS® Case Study: Milestone I and II

On October 4, 2014, the owner’s senior management and the GC agreed on the importance of solving the ongoing project delays and completing contractual milestones I and II on December 31, 2014 and June 30, 2015, respectively. The scope of these milestones is detailed in Table 3-2. The timeframe to procure remaining materials, develop engineering submittals, obtain authority approvals, and execute construction works was very limited. All under-road utilities had to be installed, inspected, tested, and backfilled before the subgrade surface was released to the roadwork subcontractor.

Table 3-2: Scope of Work

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road length</td>
<td>M</td>
<td>6,300</td>
<td>5,100</td>
</tr>
<tr>
<td>Number of Lanes</td>
<td>No.</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Number of Junctions</td>
<td>No.</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Highway traffic signal and road lighting duct</td>
<td>m</td>
<td>5,648</td>
<td>4,918</td>
</tr>
<tr>
<td>Utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storm water pipelines</td>
<td>m</td>
<td>11,102</td>
<td>3,869</td>
</tr>
<tr>
<td>Foul sewer pipelines</td>
<td>m</td>
<td>4,445</td>
<td>645</td>
</tr>
<tr>
<td>Potable water pipelines</td>
<td>m</td>
<td>11,562</td>
<td>2,011</td>
</tr>
<tr>
<td>Irrigation pipelines</td>
<td>m</td>
<td>13,174</td>
<td>2,179</td>
</tr>
<tr>
<td>Gas network</td>
<td>m</td>
<td>8,363</td>
<td>2,782</td>
</tr>
<tr>
<td>District cooling pipes</td>
<td>m</td>
<td>1,831</td>
<td>907</td>
</tr>
<tr>
<td>Pneumatic waste collection</td>
<td>m</td>
<td>204</td>
<td>378</td>
</tr>
<tr>
<td>Telecommunication ducts</td>
<td>m</td>
<td>27,664</td>
<td>5,433</td>
</tr>
<tr>
<td>11 and 66 kv cabling</td>
<td>m</td>
<td>4,296</td>
<td>9,479</td>
</tr>
<tr>
<td>Security system ducts</td>
<td>m</td>
<td>7,238</td>
<td>2,785</td>
</tr>
</tbody>
</table>

Given the previous challenging complications witnessed in CP5B, the task seemed impossible as there were approximately 3 months remaining to complete milestone I, and 9 months to complete milestone II, with a significant amount of remaining works still to be carried out. All project participants, including the senior management of all involved organizations, had no choice but to deliver the project within the required timeframe. Failure to achieve these milestones would result in unaffordable damages to all organizations, along with public inconvenience.

The project team participated in a planning workshop to define the best strategy to deliver these milestones. All stakeholders participated including the owner, PM/CM consultant, site supervision consultant, GC, and specialty trades’ subcontractors (wet utilities, asphalt, electrical,
and gas). The team looked for a different, more tangible approach that would afford better control of the physical work on a weekly basis. Despite the fact that they were becoming entrenched in conflict due to project pressures, on October 15, 2014, the majority of team members selected the LPS® as the tool with the greatest potential to get the project on track. As such, it was to be tested on the 1st milestone. The team quickly realized that the poor PPC results in 2012 were due to the “impossible” original plan forced on the production system. From October 26-29, 2014, an intensive professional training program was organized towards officially implementing the LPS® on October 30, 2014 for Milestone I, covering a period of eight weeks. Milestone II continued on the traditional approach, awaiting the evaluation outcomes of milestone I.

Because of the magnitude and scale of this IMP, the work was divided into smaller, more manageable subprojects, whose activities could be more easily monitored and controlled. Individually, each subproject had its own resources and ran independent LPS® sessions to report the PPC. For example, milestone I was divided into 5 major subprojects, namely: 1) J2, 2) from J2 to J3 (including J3), 3) from J1 to GD1 (including J1 and Junction GD1), 4) from JP1 to JP2 (including Junctions JP1 and JP2), and 5) from JP5 to underpass 1 (including Junction JP5). Each subproject was treated as an independent "work package," and delegated to a section manager responsible for completing the works in accordance with the agreed make-ready plan.

The site team faced many coordination and integration issues. As reflected in Figure 3-4, road junctions have a significant number of utility lines under the pavement. Junctions in the project were just as complicated. The challenge was to sequence the works to optimize the clash resolution, ensure high coordination among project segments, keep production in full operation, and getting the work done right the first time. Another major factor that made integration more challenging was the need to accommodate new requirements from the utility operators. For example, the operator of the potable water network initiated a late request to increase the chamber dimensions and reroute all pipelines under the roads to outside the paved areas.
The results of LPS® workshops were transferred into make-ready plans. Senior management of all parties, including the trades subcontractors, endorsed their approval by signing the make-ready plans to demonstrate their firm commitment, cooperation, and full collaboration. The trades’ subcontractors are the most vulnerable of the team; while they do not have contracts with the owner, they are responsible for achieving the work. That they joined with all the other project stakeholders to commit to an unconventional collaboration agreement outside their original contractual obligations was indeed an unconventional practice.

The team agreed to meet weekly to monitor progress, calculate the PPC, and document events that may have caused interruptions and delays. During weekly LPS® work-plan meetings, potential delays and significant setbacks were detected. Progress was measured at the selected activity level every week. Factors considered in choosing an activity were the weight of a work item, typical duration of activities for a work item, and the degree of ease in determining an accurate progress rate for each activity. During the LPS® workshops, key stakeholders defined the characteristics of PPC activities:
- Limited in number, to save time recording data on a weekly basis.
- Measurable, that identifies delivery as a “yes” or “no” with no uncertainty.
- Tangible, representative, informative, with significant weight or relevance to the overall physical progress.

With the stakeholders’ extensive knowledge of the site and the experience gained from the LPS® exercise, activities to monitor the physical progress in each subproject were optimized and agreed upon. Examples of selected roadwork activities are listed in Figure 3-5 in the template of a weekly work-plan summary, which is variable based on time and location.

![Figure 3-5: Weekly Work-Plan Summary Template](image)

The team opted to use Microsoft Excel® for the weekly work plan because of its accessibility and ease of use. The worksheet makes it easy to develop, maintain, and update progress of the weekly work plans. Unlike sophisticated software using the CPM platform, Excel® does not require professional planners and a lot of training to generate PPC calculation charts and reports. Site crews found that using Excel® worksheets was an effective facilitation and communication tool to implement the LPS® in multiple locations with massive construction/production operations.

Gradually, the LPS® workshops facilitated the overall goal of delivering the milestones into a real production plan for site crews to perform well-coordinated tasks within each segment of the project. However, the design interface and tie-in points remained a big challenge for integration. Unlike the practice and project culture prior to initiating the LPS® workshops, it was now realized that subcontractors represented a significant share of the planning effort. To resolve...
integration challenges, they had to participate in this exercise to promote improved understanding of the production planning, enhance communications, build trust, align expectations of stakeholders, and confirm commitments. In the past, subcontractors were given filtered plans extracted from the master baseline schedule without any participation in the planning stage. Such plans often failed.

Although the team had informally used the PPC to track progress at the beginning of CP5B, this was the first time they had implemented the LPS®. Hence, most of them were very conservative about giving commitments, like J2, J2-J3, and JP1-JP2, as shown in Figure 3-6. Others like J1-GD1 and JP5-UP1 over-committed on assignments they could not accomplish. However, over 3-4 weeks, all crews began to be more familiar with the LPS® with more training and explanations during weekly work-plan meetings. With increased familiarity, crews were more transparent in providing practical timeframes to complete tasks and report actual progress. J2-J3 chart shows a typical graph for PPC measurements.

By the second week, progress was severely declining in all sections. More problems and coordination challenges began to surface, resulting in a very poor PPC of 25% in JP1-JP2 and 21% in JP5-UP1, as more trenches were open, and the site more congested with limited access for equipment, materials, and workers. PPC in J1-GD1 was 0% in the fifth week due to a delay in authority inspection approval, which was outside the project team’s sphere of control. Nonetheless, the delay paralyzed production. The team identified many other contributing factors to the delay and adjusted the plan.
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<tbody>
<tr>
<td>Start week</td>
<td>01-Nov-14</td>
<td>W1</td>
<td>W2</td>
<td>W3</td>
<td>W4</td>
<td>W5</td>
<td>W6</td>
<td>W7</td>
<td>W8</td>
<td></td>
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<tr>
<td>Week</td>
<td>J2</td>
<td>95%</td>
<td>73%</td>
<td>51%</td>
<td>62%</td>
<td>75%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td></td>
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</tr>
<tr>
<td>J2-J3</td>
<td>100%</td>
<td>75%</td>
<td>67%</td>
<td>64%</td>
<td>67%</td>
<td>83%</td>
<td>100%</td>
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Figure 3-6: Percent Plan Complete Charts for Milestone I
Figure 3-6: Percent Plan Complete Charts for Milestone I (con’t)
With the success of milestone I using the LPS®, the owner hosted a big event to celebrate the first achievement of CP5B and to recognize the outstanding team effort.

The project team completed the rest of CP5B road network by milestone II of June 30, 2015 with a second LPS® exercise of 15 weeks. Although they continued to produce a weekly work plan for the activities of milestone II, the subprojects in milestone II were categorized differently. Learning from milestone I that the critical control points consuming the biggest efforts were the road junctions where all utilities are congested in confined areas, the team focused the full attention of LPS® workshops on the junctions. The team, including all subcontractors, focused on a typical junction, identified each utility, numbered them, discussed the work sequence among the trades, and developed a make-ready-plan by identifying pre-requisites, securing directives, and ensuring the availability of resources. The weekly work plan aided the team to identify make-ready needs for the broader picture and provided a standard communication tool to ensure goals were met. Daily huddles were maintained onsite between the GC, the supervision consultant, and the project management consultant to check progress and identify obstacles. Despite integration challenges, the improvement trend continued, raising the PPC every week until the successful delivery of the second milestone, as reflected in Figure 3-7.
Figure 3-7: Percent Plan Complete Charts for Milestone II
Figure 3-7: Percent Plan Complete Charts for Milestone II (con’t)
Of the 7 plans developed for each segment of milestone II, Junctions JP6 and J5 had the most amount of work to be completed by June 30, 2015, including deep irrigation pipes, gas pipes, electrical ducts, services to LRT track, and many other utility lines crossing the full junction east/west and south/north. Such complex design requires very careful construction phasing to prevent access problems to other works. The challenging nature of the sequence of works required close daily integration between all subcontractors to adjust the activities as necessary to prevent delays releasing work to the next trade. This proved to be difficult during the sixth week of the schedule for JP6 and the third week for J5, where the PPC dropped to 40% and 20%, respectively. This was due to a breakdown of equipment and lengthy backfilling of deep excavations with massive internal coordination and external integration issues. Resources were deployed to recover the backlog during the following weeks. As illustrated in Figure 3-7, the plan recovered successfully, allowing the curb installation and asphalt pavement works to begin on time to coincide with paving operations in the adjacent segments.

The project team invested a great deal of time tracking and measuring weekly progress, identifying root causes of problems, and finding appropriate solutions. In the absence of a single metric in the LPS® to measure mega-project status like overall progress percentage, the LPS® team communicated the PPC status to the entire team at regular meetings to better understand the current progress of CP5B. Conservative estimates of the team effort revealed that 1,100 person-hours were spent in LPS® sessions and workshops for milestone I and 1,570 person-hours were spent for milestone II.

3.8 Findings, Analysis, and Discussion

As specified in the contract, the detailed project master baseline schedule was developed in electronic CPM format; however, it was found that the execution of the work required a much more detailed task-driven system at the production level. It needed to be easily communicated and followed by the site team on a daily basis to detect and prevent delays early, to identify causes, and to find appropriate solutions. The introduction of LPS® tools resulted in a rapid learning process with enhanced productivity and efficiency. Even though implementing the LPS® in CP5B was limited to make-ready and weekly work-planning levels, and the project was about 70% complete, aggressive milestones were delivered on time without the frustrations witnessed in the past. A summary of evaluation findings from the LPS® exercise for CP5B are
listed below, as observed and discussed with the project team in two evaluation sessions at the end of each milestone. Each session was attended by 12 key participants in the LPS® implementation and took 3 hours of fruitful discussion to reach the following findings.

3.8.1 Things that performed well:

- Developing a detailed sequence of works for each task minimized waste in production rates by preparing make-ready plans and preventing work waiting for workers and workers waiting for work incidents.
- The LPS® promoted teamwork by developing specific targets and close interaction between the trades. Initially, the GC was reluctant to implement the LPS® because of concerns with management about their subcontractors and potential threats of penalties. This changed as progress improved, benefits realized, and successes were achieved.
- One of the challenges to completing the milestones was managing activities being carried out by three major subcontractors with conflicting interests in multiple sections. With unrestricted interactions between subcontractors, improved team cohesion during meetings, and returns of the daily huddles, the communication gap prior to implementing the LPS® was closed. The value of the trades’ contribution materialized, and unexpected events that could cause delays were minimized.
- With its great incremental and sustainable value, the LPS® allowed for a much more accurate way to monitor progress and develop practical plans to maintain the PPC above 80%.
- Surprisingly, the team stated that they had not participated in any planning effort in the project prior to LPS® workshops.
- With the successful delivery of milestones I and II, the GC and several other subcontractors stated that they will use the LPS® in their future projects.
3.8.2 2. Things that needed improvement

The following thirteen integration challenges C1 to C13 have been identified:

- **(C1) Interface and alignment of trades within and across subprojects:** The alignment of trades is challenging as the performance of subcontractors can vary to a great extent in different locations of an IMP.

- **(C2) Moving resources between independent subprojects of an IMP:** With highly independent delinked subprojects under dedicated site management teams, it is very challenging to share resources on a daily basis in the midst of fast-track operations in the subprojects.

- **(C3) Poor communication between independent subproject teams:** It is generally expected that the LPS® performs well in knowledge transfer and information-sharing within a subproject. However, communication between subprojects maybe challenging in the complex environment of IMPs.

- **(C4) Need for intensive training:** Imposing significant process changes on a complex organization requires a massive training program by a highly-qualified facilitator. The Lean Construction Institute holds the LPS® patent, and applies restrictions on consultancy services to ensure high standards and quality. However, finding the right consultant at a reasonable cost is a major obstacle.

- **(C5) Long weekly meetings and participation of busy site personnel:** Bringing site personnel (subcontractors and site engineers) to the weekly meetings consistently is difficult due to their busy schedules. Meetings tended to be long and exhausting.

- **(C6) Perception of micro-management:** Some advocates consider that LPS® may lead to intense micro-management, which is challenging in the environment of IMPs.

- **(C7) Massive efforts in developing MRP and WWP due to the mega-scope of the project:** The number of activities in an IMP is massive. Capturing them in the MRP and WWP is an immense undertaking.

- **(C8) No categorization of the degree of activity sensitivity of subprojects’ tasks:** Unlike the distinction of critical activities in the traditional approach,
all tasks in the LPS® are treated equally despite the variability in the complexity and sensitivity of site operations in IMPs.

- **(C9) Measurement of Percent Plan Complete (PPC) does not recognize the complexity of subprojects:** A cursory view results in all subprojects displaying the same level of complexity but, in reality, some subprojects may be more challenging than others.

- **(C10) Absence of a rigorous software to develop and update the detailed MRP of the subprojects:** Developing and updating the MRP without the support of sophisticated software is very difficult due to the massive number of activities in an IMP.

- **(C11) Binary nature of PPC calculations where no partial achievement is considered does not fit in IMPs:** The binary nature of PPC calculations is delivered or not delivered. No partial achievement is measured.

- **(C12) Absence of an overall PPC as a single performance indicator for all subprojects:** With multiple LPS® plans for each subproject of an IMP, there is no single indicator of project performance, such as the overall project completion percentage generated in traditional practice. Some subprojects may perform well with good PPC rates and manageable integration challenges while others may suffer unmet commitments, delays, and major integration issues. Because each subproject has different denominators of resources, scope, complexity, and challenges, it is not possible to average the PPCs of each subproject to generate an overall PPC. In the absence of a single indicator of project progress, it would be difficult to determine if the IMP is on track or not.

- **(C13) Fragmented multiple LPS® plans of subprojects:** At a mega scale, it is very challenging to integrate multiple LPS® plans of subprojects, especially when the plans reside on the walls of trailers scattered around the mega site. Providing the required level of interface among clustered subprojects is the biggest integration challenge of implementing the LPS® in IMPs.

Many of these challenges were similar in nature to the challenges identified by Lean Construction community (Fernandez-Solis et al. 2013; Neto and Alves 2007). As well as these
13 integration challenges, the absence of Organizational Change Management (OCM) imposes additional major obstacles. Organizational inertia or resistance of the team to change is one of the most common challenges found in LPS® implementation (Fernandez-Solis et al. 2013), especially if the team members come from different international backgrounds. OCM requires analysis to detect and manage resistance, organizational structural design, readiness assessment, marketing, expectations management, and stakeholders’ support. OCM of stakeholders’ resistance (particularly governmental authorities, operator, and contractors/subcontractors) can also be a major integration challenge to using the LPS®.

These findings collectively point to a need for the LPS® to expand its standard practices to fit in the context of IMPs. With the experience gained in this study, it is concluded that the LPS® cannot be applied directly on an IMP unless it is divided to multiple subprojects. Applying production planning and control systems on scattered sections belonging to the same mega-project increased the challenges in ensuring integration among subprojects, neighbouring developers, and adjacent construction packages. The author believes that these findings would have been much different had the LPS® been fully implemented from the beginning of CP5B, given that the need to split the mega-project into smaller manageable segments would be the same.

With the outcomes of milestone I and milestone II, the complexity associated with a mega-project appears to increase in a non-linear fashion and is not scalable. For example, even though milestone I had a bigger scope and had a shorter LPS® implementation then milestone II, it is not possible to simply say that milestone II was less complex than milestone I. Many factors contribute to the degree of complexity due to the nature of IMPs, as explained earlier.

3.9 Conclusion

The LPS® was introduced as a tool to help complete two critical milestones for the CP5B project. Before the original completion date of CP5B was reached, the GC had submitted its 3rd baseline schedule revision, and implementation of the LPS® was just a few months away. With a realistic view to satisfy site production requirements, the LPS® helped the CP5B team to bring the program to a substantial completion. The 1st milestone was set for completion by December 31, 2014 which consisted of finishing the construction of major roads serving VIP developers. The 2nd milestone required the completion of the remaining roads of CP5B by June 30, 2015. To
achieve these targets, massive efforts and commitments were necessary by the team members. Several participants were sceptical at the start of implementing the LPS®, but they agreed that the initial high commitment was required to adopt the new techniques and achieve reliability and delivery. With the commitment and dedication of all project team members in place, the GC successfully completed the two milestones.

Overall, the LPS® is a production planning and control philosophy that improves the predictability and reliability of construction workflows. A critical advantage is the collaboration of the “last planners” and decision makers at the execution level. LPS® is undergoing further enhancements and vetting on the mega-project scale as it has only been implemented on a limited number of IMPs. There is no doubt that implementation of LPS® in IMPs is a serious undertaking due to the difficulty in integrating challenges among scattered subprojects. To make it more adaptable on a mega-project scale, the CP5B team introduced some changes to LPS® by splitting the mega-project into subprojects and selecting a few critical activities in the weekly work planning to measure and monitor PPCs. However, it was concluded that the production control aspect of the LPS® is where integration requires different treatment. Therefore, a new framework for the LPS® is needed to deal with the integration challenges of IMPs. Finally, the impact of the LPS® on the construction cost of mega-projects, whether positive or negative, requires further investigation.
Chapter 4 A Framework

4.1 Introduction

In addition to their gigantic monetary value, mega-projects have extremely complex engineering and construction operations. From New York’s Chrysler Building, which opened in 1930 at 319 meters, to Dubai’s Burj Khalifa, which opened at 828 meters in 2010, mega-projects continue to push frontiers with no end in sight (Flyvbjerg 2014). Everything is supersized, including the challenges. Their legacy is remembered far longer than that of typical projects, as they attract the public and media attention. They have sophisticated scopes, long development durations, difficult logistics, many high-level risks, complicated networks of stakeholders, complex governance issues to navigate, convoluted organizational behaviour, and challenging interfaces.

Cases of cost and time overruns in mega-projects are well documented in the literature. Less than 10% are successful in delivering within budget and schedule, and meeting promised benefits (Flyvbjerg 2011). An international component adds another level of complexity to mega-projects. The definition of international mega-projects (IMPs) was introduced in Chapter 1.

As discussed in Chapter 2, the critical path method (CPM) has been the industry-dominant method of planning and scheduling for decades. For example, when schedule slippage occurs, a recovery plan is typically developed. When it becomes obvious that the recovery will not work (i.e. the project completion date is not possible), a revised baseline is issued, setting new targets with or without prolongation costs (El-Sabek and McCabe 2017a). Ignoring the root cause of failure of the original plan typically results in a recovery plan that is also doomed to fail (Ballard and Tommelen 2016; Senior 2009). While CPM is an excellent tool for developing complex high-level plans, it is less functional as a communication tool, as a day-to-day operational tool for production planning and control, and as a root cause tool at the task level (Birrell 1987). In general, with CPM being one example, the poor performance of traditional project management theories, tools, and methods often results in schedule delays, over-spending, and exposure to major risks (Li and Lu 2009). Therefore, to achieve better results, customized theories, tools, and methods for the management of mega-projects need to be explored.

To fill this functional gap in CPM, the Last Planner® System (LPS®) builds upon the high level CPM milestone plan and focuses on increasing the reliability of planning, maximizing value, and
eliminating the waste due to workflow variability (Abdelhamid 2004; Ballard and Howell 1994). At subproject the level, LPS® integrates the inputs of the field crews and trades during the production planning process in a collaborative discussion to ensure a better flow of works and develop a realistic plan that can be used at the production level (Ballard 2000). Then, it facilitates measuring and tracking the short-term production commitments made by the field team.

Since its inception, LPS® has been implemented successfully in many projects (Fernandez-Solis et al. 2013; Howell et al. 2011). Nevertheless, little is published about how LPS® can be implemented on the challenging operational sites of mega-projects. The application of LPS® in IMPs has been limited due to major integration challenges, organizational behaviour, scale, and complexity issues that characterize mega-projects, and restrict exploring revolutionary production planning and control methods. However, LPS® is a very promising method with a great potential to reduce schedule slippage relative to the traditional approach (Kalsaas 2012; Kim et al. 2015; Koskela et al. 2010; Priven and Sacks 2015).

Using the LPS® model in IMPs requires a different treatment to achieved similar success stories attained in smaller and local projects. Consequently, the problem statement of this study is to identify a systematic approach (framework) to extend the application of LPS® to IMPs by addressing the integration challenges in IMPs.

The objective of this Chapter is to develop a framework to address integration challenges of IMPs: hence, to solve the endemic failures of delivering IMPs. In the first sections, literature review on LPS® are presented. Next, research methods and the validation approach are outlined. Finally, the proposed IMPact framework is presented, explained, validated, and discussed.

4.2 Research Methodology

Twenty-one experts from industry participated in this research. Each expert has at least 15 years of experience in mega-projects, with 2-16 years’ experience using the LPS®. The characteristics of the experts and their level of participation are outlined in Table 1-1 in Chapter 1.

The major steps required to achieve the IMPact framework are outlined in Figure 4-1. Details related to the data collection, analysis, and discussions follow.
<table>
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<tr>
<th>Step</th>
<th>Task</th>
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<tr>
<td>1</td>
<td>Develop cause and effect diagram (fishbone diagram) using coordination challenges outlined in Chapter 3 (Figure 4-2)</td>
</tr>
<tr>
<td>2</td>
<td>Verify the correctness and completeness of coordination challenges in a Delphi study</td>
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<tr>
<td>3</td>
<td>Update the fishbone diagram to add the coordination challenges identified by Delphi participants (Figure 4-3)</td>
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<td>4</td>
<td>Propose solutions, develop processes to complement the LPS® application, and establish a framework</td>
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<tr>
<td>5</td>
<td>Complete the framework with bridging processes and best practices</td>
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<tr>
<td>6</td>
<td>Develop the details of the IMPact framework including supplementary processes</td>
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<tr>
<td>7</td>
<td>Perform an internal validation of the framework in NGT study</td>
</tr>
<tr>
<td>8</td>
<td>Based on the consensus of the NGT, modify the framework as appropriate</td>
</tr>
<tr>
<td>9</td>
<td>Develop a fishbone diagram using the processes of the IMPact framework (Figure 4-4)</td>
</tr>
<tr>
<td>10</td>
<td>Perform external validation of the IMPact framework using a focus group</td>
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<tr>
<td>11</td>
<td>Reflect and discuss the potential impacts of implementing the framework on a case study</td>
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**Figure 4-1: Roadmap of Research Process**

In step 1, a cause-and-effect diagram (Figure 4-2, also known as fishbone diagram) was developed to analyze and categorize the 13 integration challenges outlined in Chapter 3. To verify that the 13 challenges are representative and provide a comprehensive list of the LPS® in IMPs, a modified Delphi technique was developed in step 2.
Combining the additional integration challenges identified by Delphi participants, the fishbone diagram was updated in step 3 (Figure 4-3).
The Delphi survey resulted in producing the list of 31 integration challenges that impact the effective use of the LPS® in IMPs. Steps 4, 5, and 6 pertain to the design of a fully integrated framework that addresses the identified integration challenges. This involved proposing specific solutions and processes to integrate the LPS® application by addressing the challenges either by eliminating the challenges or by minimizing their impacts. The desired outcome is an overall increase in the effective use and application of the LPS®. This provided the major input to build the IMPact framework. Inspired by following the progression of the Plan-Do-Check-Act (PDCA) model developed by Deming as part of the Lean Manufacturing movement of the Toyota Production System, the IMPact framework was developed by defining the major steps necessary to correspond to the challenges in the fishbone diagram (Figure 4-3). For each major step comprising the framework, key activities are grouped and placed in their most logical and sequential flow, including those activities that solve integration challenges. Where process logic was interrupted or missing, the framework was complemented by bridging best practices in common use in the industry. The development process of the framework went through several iterations by the author (especially structure, color coding, naming convention, numbering system, shape and format … etc.). Once the structure of the IMPact framework was materialized, its details including supplementary processes were developed.

Nominal Group Technique (NGT) was chosen for internal validation of the framework in step 7 due to its structured application and use of discussion to reach consensus. Based on the consensus of the NGT experts, the IMPact framework was modified in step 8. The validation process generated further formulation of conceptual ideas that made the framework more robust in addressing all the integration challenges. The details and supplementary processes of the proposed framework were updated accordingly. In step 9, the fishbone diagram was modified (in Figure 4-4) using the processes of the proposed framework to reflect all the addressed integration challenges.
Figure 4.4: Fishbone for the Addressed Challenges by the IMPact Framework

Integrated Multiple LPS® Plans of Mega-Project Segments

LPS® Awareness

Measurement System Implementation

- LPS / Mega
- LPS / Best Practice
- Completing the framework based on program management best practices
- Pending Challenges

Effective Application of LPS® in International Mega-Projects
To ensure the external validity of the framework, a focus group study was conducted in step 10. This format allowed extensive discussion to take place, encouraging participants to exchange experiences and ideas, and delivering a more robust evaluation. Finally, in step 11, a reflection of the benefits and potential impacts of implementing the framework on a case study are presented in Chapter 5.

4.3 Framework development

Further to the research methodology described earlier, the details and data of major steps in the research process are presented in the following section.

4.4 Framework Foundation (Delphi Study)

Developed in the 1950s, the Delphi technique is a broadly-accepted method to obtain relevant intuitive insights from practitioners, and systematically use their judgments in combined or converged form (Hallowell and Gambatese 2010). It is a valuable tool when statistical methods are not possible or practical, or when qualitative input from people is required (Okoli and Pawlowski 2004). Over the decades, Delphi has been used in many domains and industries including framework development.

There are no set study guidelines for the Delphi technique. Final results are opinions, not facts (Cochrane et al. 2017). There are been many variations to the technique; however, they share a structure for effective group communication processes that allows a group of experts to deal with complex problems (Linstone and Turoff 1975). Participants go through an iterative multi-stage communication process designed to aggregate group opinion into consensus (McKenna 1994; Hasson et al. 2000). There is no specified rule for the number of participants. While some suggest minimum of 10 with no upper limit, others observe that the return is diminishing beyond 30 homogenous participants (Delbecq et al. 1975; Murry and Hammons 1995).

It provides the platform to check the validity of cross-disciplinary concepts, such as those found in the social, psychological, ethical, managerial, cultural, and anthropological fields (Linstone and Turoff 1975). The structured communication process includes (Linstone and Turoff 1975): 1) Feedback of individual contributions; 2) Assessment of the group view; 3) Opportunity for individuals to revise views; and, 4) A degree of anonymity for individual responses.
Advantages of Delphi technique are:

- Participants in a Delphi technique are domain experts; participants are more specialized compared to focus groups (Hallowell and Gambatese 2010).
- Delphi participants do not have to be in the same geographical location, making it more flexible than the NGT (Murry and Hammons 1995).
- The anonymous controlled-feedback feature of the Delphi generally produces better decision making than face-to-face discussions, and leads to a greater chance of a reasoned consensus (Murry and Hammons 1995).
- Best for reaching group consensus.

Disadvantages are:

- There are no set study guidelines and final results are opinions, not facts (Cochrane et al. 2017)
- Because experts never meet face-to-face, it is unknown if their full expertise has been utilized (Murry and Hammons 1995).
- The Delphi can be time-consuming to complete because it relies on experts’ timely responses (Murry and Hammons 1995).
- It cannot be determined if a participant fully understands the study (Murry and Hammons 1995).
- Requires participants to be self-motivated to provide quality data for the study (Murry and Hammons 1995).
- The minimization of discussion can inhibit the full development of ideas (Hasson et al. 2000).

The first-round questionnaire is usually open-ended, eliciting individual qualitative comments and judgments from the participants. Researchers compile the information collected to design a structured questionnaire for round 2. Here, participants are asked to evaluate, comment upon, and rank the compiled ideas or factors through the structured questionnaire. In a modified Delphi scenario, the first round begins with a structured questionnaire based on extensive literature or previously defined factors instead of eliciting those factors from the participants (Murry and Hammons 1995; Hsu and Sandford 2007).
Researchers take the responses from round 2 and calculate frequency distributions for categorical responses, or means and standard deviations for quantitative responses (Murry and Hammons 1995). Participants are given the comments from the second round along with the summary statistics, and asked to review their judgments, comment, and revise them as appropriate. The researcher can use the third round to present participants with outliers from the second round and their corresponding reasons, affording participants the full opportunity to consider all options. The iterative exercise ends once consensus is reached or it is determined that further rounds will not reduce the response variance. Because the responses in each stage are provided independently, the participants do not need to be in the same location.

The Delphi technique was initiated by inviting 23 experts with recent experience in the LPS® and IMPs, of whom 20 responded as detailed in Table 1-1 in Chapter 1. The questionnaire in the first round verified integration challenges C1-C13 and asked participants to evaluate, using a 5-point scale: 1) the degree to which they believe that C1-C13 restrict the use of the LPS® in IMPs; and, 2) the degree to which the use of the LPS® could be improved if these challenges were addressed. The causal scale was 0=none, 1=minor, 2=moderate, 3=good, and 4=great; the improvement scale was 0=none, 1=minor, 2=moderate, 3=good, and 4=great. Participants also had the opportunity to report challenges not captured in C1-C13 based on their opinions and experiences.

Participants were given a week to respond. Fifteen experts responded within four days. Two reminders were issued and the cutoff date was extended by three days. As round 1 closed, 20 out of 23 experts had responded. Six experts found the 13 integration challenges (C1-C13) exhaustive, while 14 reported 25 additional challenges, resulting in 18 unique additional integration challenges, which are coded as C14-C31.

- **(C14) Contractual terms:** Unless the general conditions of the contract are modified, it is very challenging to use the LPS® to revise the completion date, evaluate an extension of time, or conduct a time/impact analysis.

- **(C15) Commercial disputes:** The LPS® relies heavily on partnerships with the contractors. Any commercial disputes will affect the contractor’s and subcontractor’s cooperation. The results will be more challenges to the owner to enforce the weekly meetings.
• (C16) Integration challenges related to the owner’s procurement strategy: Projects are challenged to absorb changes throughout the long development period of IMPs where changes are introduced by internal factors (e.g.: change in priorities) and external factors (e.g.: financial crisis).

• (C17) Absence of commercial incentive to collaborate and make commitments.

• (C18) Fixing incomplete design during construction causes disruptive challenges to IMPs. Poor design lacks a high level of integration of subprojects or ignores the end user/operator’s operational requirements.

• (C19) Integration for testing and commissioning activities must be very well defined and integrated between subprojects to ensure proper tie-in interfaces and avoid any gaps or duplications.

• (C20) Despite finding them in all types of projects, unforeseen risks may cause serious delays in satisfying the pre-requisites of the WWP, which results in unmet commitments.

• (C21) Organizational Change Management (OCM): Many of the OCM components are already covered in different integration challenges identified earlier such as, communication, training, and key stakeholders’ involvement and engagement. Using the LPS® in IMPs requires additional OCM to facilitate change and reduce associated resistance.

• (C22) Developing a clear governance plan that is well understood by all stakeholders of the IMP is a key challenge.

• (C23) Sharing the priorities of each subproject, as each one runs independent weekly meetings.

• (C24) Commitment of design and construction teams to work together.

• (C25) Scope changes by the owner at different stages of the mega-project’s lifecycle may dictate the need for revising the Master and Phase Plans.

• (C26) Integration and implementation of design changes: Any design modification in one subproject may have a snowball effect on adjacent subprojects. This is more frequently seen in IMPs, resulting in additional challenges to the planning efforts.
• (C27) **Lack of competency in the LPS®**: The lack of process know-how requires extensive effort to learn, understand and building competency to correct. If misapplied, the LPS® is accused of under-delivering.

• (C28) **Absence of leaders (champions)**. These change agents must be convinced of the benefits of the LPS® and be willing to influence others. This is applicable at the subproject and IMP levels.

• (C29) **Sustaining the level of effort by all stakeholders**: There is a lack of key performance indicators (KPI) to monitor attendance at weekly meetings and suggest a reward scheme to sustain engagement. Often, there is a tendency to relax the integration process when things are working well; however, keeping a steady control of integration is important to avoid major problems down the road.

• (C30) Lack of daily monitoring on-site to track delayed activities and update the delays on the lookahead plans: It is challenging in the dynamic nature of IMPs to wait a week to obtain the PPC.

• (C31) **Incompatibility with existing schedule software program.** The LPS® requires a major paradigm shift from traditional approaches. OCM and technical compatibility challenges exist with CPM-based software.

The second round of Delphi required the 20 responding participants from round 1 to:

1) review their judgments in comparison with the group’s central tendency modes, comment, and revise them as appropriate; and

2) evaluate the newly-identified challenges. Responses were received within one week. Overall, the Delphi technique took about four weeks to complete; results are reflected in Table 4-1. To examine the degree of consensus from the experts, scores for Causal and Improvement were developed by calculating the percent of votes in scales 2, 3, and 4 using the equation below. A score of 70% or more represented consensus, and the Delphi rounds could end.

\[
Score \ (Causal \ or \ Improvement) = \sum_{i=2}^{4} \left( \frac{i \times \text{number of votes}}{\text{number of participants}} \right) \times 100
\]
Because results clustered around two or more points and to avoid any misleading interpretations from means or medians, the mode was used in round 2 instead for central tendency (Hsu and Sandford, 2007). In round 2, four participants were not motivated to change their rating to get closer to the mode of the group, while the remaining 16 modified 33% of their ratings to reach consensus. Challenges that scored 70% or more were incorporated in the framework development process.

Table 4-1: Delphi (Round II) – Evaluation of the Integration Challenges

<table>
<thead>
<tr>
<th>Challenge ID</th>
<th>Causal Scale* (Votes)</th>
<th>Causal Score (%)</th>
<th>Central Tendency (Mode)</th>
<th>Improvement Scale** (Votes)</th>
<th>Improvement Score (%)</th>
<th>Central Tendency (Mode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0 0 6 14 0</td>
<td>100</td>
<td>3</td>
<td>0 0 1 18 1</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>C2</td>
<td>0 0 14 5 1</td>
<td>100</td>
<td>2</td>
<td>0 0 1 4 15</td>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>C3</td>
<td>0 0 4 14 2</td>
<td>100</td>
<td>3</td>
<td>1 0 11 5 3</td>
<td>95</td>
<td>2</td>
</tr>
<tr>
<td>C4</td>
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<td>40</td>
<td>1</td>
<td>0 0 4 15 1</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>C5</td>
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<td>95</td>
<td>2</td>
<td>0 0 4 15 1</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>C6</td>
<td>0 3 14 1 2</td>
<td>85</td>
<td>2</td>
<td>0 1 2 7 10</td>
<td>95</td>
<td>4</td>
</tr>
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<td>3</td>
<td>0 0 14 2 4</td>
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<td>2</td>
</tr>
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<td>90</td>
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</tr>
<tr>
<td>C11</td>
<td>1 3 11 4 1</td>
<td>80</td>
<td>2</td>
<td>0 4 1 4 11</td>
<td>80</td>
<td>4</td>
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<tr>
<td>C12</td>
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<td>1 1 15 12 1</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>C13</td>
<td>0 0 3 16 1</td>
<td>100</td>
<td>3</td>
<td>1 1 13 13 2</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>C14</td>
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<td>95</td>
<td>2</td>
<td>0 0 1 13 6</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>C15</td>
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<td>95</td>
<td>3</td>
<td>0 1 15 11 3</td>
<td>95</td>
<td>3</td>
</tr>
<tr>
<td>C16</td>
<td>0 3 11 4 2</td>
<td>85</td>
<td>2</td>
<td>0 1 4 11 4</td>
<td>95</td>
<td>3</td>
</tr>
<tr>
<td>C17</td>
<td>1 1 9 7 2</td>
<td>90</td>
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<td>0 0 1 1 4 14 5</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>C18</td>
<td>0 0 9 8 3</td>
<td>100</td>
<td>2</td>
<td>0 1 4 13 2</td>
<td>95</td>
<td>3</td>
</tr>
<tr>
<td>C19</td>
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<td>95</td>
<td>2</td>
<td>0 1 9 8 2</td>
<td>95</td>
<td>2</td>
</tr>
<tr>
<td>C20</td>
<td>0 2 10 8 0</td>
<td>90</td>
<td>2</td>
<td>0 1 11 8 0</td>
<td>95</td>
<td>2</td>
</tr>
<tr>
<td>C21</td>
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<td>100</td>
<td>3</td>
<td>0 1 6 5 8</td>
<td>95</td>
<td>4</td>
</tr>
<tr>
<td>C22</td>
<td>0 1 5 10 4</td>
<td>95</td>
<td>3</td>
<td>0 1 5 9 5</td>
<td>95</td>
<td>3</td>
</tr>
<tr>
<td>C23</td>
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<td>95</td>
<td>2</td>
</tr>
<tr>
<td>C24</td>
<td>0 1 6 12 1</td>
<td>95</td>
<td>3</td>
<td>0 0 7 8 5</td>
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<td>3</td>
</tr>
<tr>
<td>C25</td>
<td>0 0 7 7 6</td>
<td>100</td>
<td>3</td>
<td>0 1 3 12 4</td>
<td>95</td>
<td>3</td>
</tr>
<tr>
<td>C26</td>
<td>0 1 5 9 5</td>
<td>95</td>
<td>3</td>
<td>0 0 4 10 6</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>C27</td>
<td>0 1 10 8 1</td>
<td>95</td>
<td>2</td>
<td>0 1 9 7 3</td>
<td>95</td>
<td>2</td>
</tr>
<tr>
<td>C28</td>
<td>0 0 3 13 4</td>
<td>100</td>
<td>3</td>
<td>0 0 7 7 6</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>C29</td>
<td>0 2 4 13 1</td>
<td>90</td>
<td>3</td>
<td>0 2 11 6 1</td>
<td>90</td>
<td>2</td>
</tr>
<tr>
<td>C30</td>
<td>1 4 3 10 2</td>
<td>75</td>
<td>3</td>
<td>0 5 2 7 6</td>
<td>75</td>
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<tr>
<td>C31</td>
<td>1 4 5 7 3</td>
<td>75</td>
<td>3</td>
<td>0 3 4 9 4</td>
<td>85</td>
<td>3</td>
</tr>
</tbody>
</table>
4.5 The Internal Validation (NGT)

NGT is a highly-structured process to solve a problem, an idea, or prioritize interests via consensus for the researcher (Delbecq et al. 1975). The number of participants in an NGT group ranges between 2-14, with a maximum of seven recommended to maximize the return of interactions between participants (McMillan et al. 2016). The participants are placed in one room but do not speak to each other in the first step. Questions are developed in advance. Participants are allotted a specified amount of time to record their answers. In step 2, the facilitator asks each participant to share one idea from their response list with the group; until all comments have been presented. During this step, there is no discussion between participants. The third step is a clarification phase in which the ideas are discussed one by one, and can be altered, excluded, supported, modified, or further clarified. In the final step, the facilitator asks the participants to rank the ideas independently and anonymously. The decision of the group is the calculated rank of the ideas from the individual votes.

NGT is applied in similar fields as the Delphi technique to reach consensus, with one major difference. Participants in an NGT are required to be in the same physical proximity while Delphi can be applied to a geographically-dispersed group. This is an important constraint that inevitably affects the choice of method (McMillan et al. 2016).

Advantages of NGT are:

- The controlled feedback feature encourages sharing of information and stimulates idea generation because all ideas are evaluated (Delbecq 1975).
- The NGT is more time-efficient than the Delphi (McMillan et al. 2016).
- The structured format facilitates equal participation (Delbecq 1975).
- Best for reaching consensus on a list of ideas (McMillan et al. 2016).
Disadvantages are:

- Because participants meet face-to-face, a power differential can occur that can hinder participant inputs (McMillan et al. 2016).
- NGT meetings require detailed preparation (Delbecq 1975).
- The structured format limits the meeting’s scope to a single purpose or topic (Delbecq 1975).
- Some participants may have difficulty conforming to the highly-structured format (Delbecq 1975).

Covering a diverse variety of construction fields from three ongoing IMPs, 6 out of 7 invited experts participated in the NGT study. Participants were briefed about the research and given a comprehensive overview of NGT. The NGT study took about three hours.

To verify its functionality, NGT participants examined all processes, components, and variables of the IMPact framework in a) addressing integration challenges and b) being an effective tool for production planning and control practice to improve the performance of IMPs. Where they detected gaps, the experts suggested modifications and rated the latter on a 5-point scale according to their impact.

In the end, 23 new ideas were filtered down to 14 after a thorough discussion. The six participants anonymously evaluated the degree to which the 14 ideas improved the proposed framework in addressing the challenges. The evaluation scale was 0=not at all, 1=minor, 2=moderate, 3=good, and 4=great. Scores for each idea were calculated based on the following equation:

\[
NGT \text{ score} = \sum_{i=0}^{4} i \times \text{number of votes}
\]

Based on their degree of consensus, the 14 suggestions for improvement were grouped into three categories (major, moderate, and minor), as outlined in Table 4-2.
### Table 4-2: Scores of Improvement Ideas

<table>
<thead>
<tr>
<th>Idea</th>
<th>Votes</th>
<th>NGT Score</th>
<th>Good and Great Scores (3+4)</th>
<th>Consensus Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0= Not at all</td>
<td>1= Minor</td>
<td>2= Moderate</td>
<td>3= Good</td>
</tr>
<tr>
<td>I10</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>I11</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>I13</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>I3</td>
<td>1</td>
<td>5</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>I1</td>
<td>2</td>
<td>4</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>I113</td>
<td>4</td>
<td></td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>I14</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>I2</td>
<td>1</td>
<td>2</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>I12</td>
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<td>14</td>
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<tr>
<td>I9</td>
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<tr>
<td>I7</td>
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<tr>
<td>I8</td>
<td>2</td>
<td>2</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>I6</td>
<td>2</td>
<td>2</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>I5</td>
<td>3</td>
<td>1</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

Considering major and moderate ideas, 11 enhancements were incorporated into the IMPact framework, making it more robust and confirming its internal validity. Table 4-3, presents the details of the corresponding solutions incorporated in the IMPact framework similar to the fishbone diagram, which was developed to reflect on the framework processes corresponding to the integration challenges (Figure 4-4).

### Table 4-3: IMPact Framework Improvement Suggestions

<table>
<thead>
<tr>
<th>Improvement Ideas of NGT</th>
<th>Applicable Improvement Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I1) Ensure that the measurement of PPC in WWP is sustainable</td>
<td>This idea is satisfied with the solution addressing idea No. I11 introducing KPI for teamwork and coaching.</td>
</tr>
<tr>
<td>(I2) Consider impacts due to Interface challenges of scope changes and design E and O which are critical to be addressed in LPS plans</td>
<td>This idea is satisfied with the solution addressing ideas No. I12 and I13 introducing Building Information Modeling (BIM) and interface matrix to deal with scope changes and design E and O. The new loops allow for updating the plans in this instance.</td>
</tr>
<tr>
<td>(I3) Processes 3.4 and 5.1, 5.2, 1.4, 2.3 require automation based on knowledge to avoid bogdowns. Artificial intelligence solution was suggested for consideration</td>
<td>With the control cards measurement system, these processes are semi-automated. Only data entry is required. Introducing BIM will help greatly. However, using artificial intelligence in this framework is a new concept outside the scope of this study and</td>
</tr>
<tr>
<td>Improvement Ideas of NGT</td>
<td>Applicable Improvement Solutions</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>(14) Software based on visual interface was recommended incorporating automatic tabulation of MRP boards and introducing a new measurement step for recovery if things are going wrong</td>
<td>requires further research.</td>
</tr>
<tr>
<td>(I4) Loop step 4 to step 3</td>
<td>Ideas No. 15 to 19 were suggested by one participant. They were ranked as minor in the NGT voting. Lack of consensus is mostly attributed to the fact that each participant supported only his idea and voted for it. However, the concept of introducing reverse loops was logical for steps 2, 3, 4 and 5. It was added accordingly.</td>
</tr>
<tr>
<td>(I5) Loop step 5 to step 3</td>
<td>Performance review meeting was changed in Process No. 6.1 from monthly to weekly.</td>
</tr>
<tr>
<td>(I6) Loop step 5 to step 4</td>
<td>Timed meetings were added to Process No. 6.1. KPI was added to Process No. 1.4. Continual coaching and mentoring were added to Process No. 1.3.</td>
</tr>
<tr>
<td>(I7) Loop step 5 to step 3</td>
<td>BIM was added to process No. 4.4 and process No. 3.2</td>
</tr>
<tr>
<td>(I8) Change the loop from &quot;step 7 to step 1&quot; to &quot;step 7 to step 3&quot;</td>
<td>Interface matrix was added to Process No.3.2. to align tie-ins within / across subprojects and adjacent projects with respect to time, T&amp;C, sequence etc.</td>
</tr>
<tr>
<td>(I9) Add Loops &quot;step 5 to step 4&quot;, &quot;step 4 to step 3&quot;, &quot;step 3 to step 2&quot;, and &quot;step 2 to step 1&quot;</td>
<td>Step 6 was changed to “Reflect, Record, and Communicate”</td>
</tr>
</tbody>
</table>

Furthermore, participants made the following comments and observations:

- Process No. 2.3: Communication across subprojects should allow for communications across boundaries.
- Process No. 3.2: Cross-check for integration should include a health check of the IMP based on a quantified calculative assessment to meet the objectives.
- Process No. 4.3: Sharing information, knowledge transfer, and language barriers: Develop a web-based lessons-learned center, and use social media as a communication vehicle for sharing knowledge.
• Process No. 5.1: Calculating achievement based on weight measurement system is a challenging effort.
• Process No. 5.2: Complex nature of IMPs makes it harder to calculate and consolidate PPC for the whole project.

4.6 The External Validation (Focus Group)

A focus group can be defined as: “a carefully planned discussion designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment” (Sink 1991). They are group interviews except that, unlike individual interviews, they rely on the interaction of the group to provide qualitative data. The discussion is guided by a skilled facilitator who provides the topics. Focus groups are conducted with 7-12 people. Participants should be relaxed, and the discussion should flow naturally to maximize the sharing of ideas.

Focus groups can be self-contained as a complete study, supplement other methods, or used with other qualitative methods. Self-contained focus groups should provide data sufficient to fulfill the purpose of the study. Focus groups are used in a variety of fields including social sciences, education, political science, public health, research, and marketing.

In a focus group, the researcher identifies the purpose, develops the plan, identifies the sampling frame, and recruits participants. Open-ended questions are prepared, and a proper location is selected to accommodate the participants and ensure their comfort. The participants are asked to discuss pre-defined questions. The data are analyzed and interpreted to produce the final report (Stewart and Shamdasani 1990).

Advantages of focus groups are (Morgan 1997; Morgan 1998):

• Focus groups provide an opportunity to observe participant interactions.
• Facilitation of the meeting keeps the discussion within the scope of study.
• Focus groups are relatively time- and cost-efficient to conduct.
• The open discussion format provides a large data set.
• Focus groups can be utilized to study a wide variety of subjects using diverse participants. They are best for assessing motivations and attitudes.

Disadvantages are:
Opinions can be skewed by a dominant participant in the group (Stewart and Shamdasani 1990).

The direction of the researcher can limit how and what participants share in a focus group (moderator bias) (Morgan 1997).

Focus groups require that all participants be in the same location.

Analyzing and interpreting open-ended responses is difficult (Stewart and Shamdasani 1990).

The results may not be easily generalized to a larger population (Stewart and Shamdasani 1990).

A focus group study was initiated to ensure the external validity of the IMPact framework. Eleven of the 15 invited experts participated, six of whom also engaged in the NGT. The focus group study took about 2.5 hours. The discussion and evaluation were designed to examine the practical relevance (Figure 4-5) of the proposed framework based on prescribed criteria and attributes with respect to correctness, usefulness, and effectiveness (Khan and Tzortzopoulos 2016). As detailed in Table 4-4. The evaluation attributes are:

- **Diagnosis**: Accuracy of identified processes and integration challenges,
- **Treatment**: Suitability of suggested components in the framework in practice,
- **Execution**: Conformity of proposed processes, tools, and techniques in addressing the challenges,
- **Applicability**: Appropriateness of the proposed framework in IMPs,
- **Practicality**: Usability of the framework in terms of simplicity and clarity,
- **Flexibility**: Adaptability of the IMPact framework for improvements and customization in practice,
- **Efficacy**: Ability of the proposed framework to achieve the intended results,
- **Measurability**: Ability of the action to be quantified, and
- **Acceptability**: Level of trust that practitioners place in the framework.
Using a 5-point scale (0=none, 1=minor, 2=moderate, 3=good, and 4=great) focus group participants were asked to evaluate the IMPact framework against each of the prescribed criteria/attributes. To detect any potential bias between the NGT (O1-O6) and new (N7-N11) focus group members, their evaluation scores were tested using analysis of variance (ANOVA). Statistically-significant differences were found in only two of the nine attributes (P<0.05). Because the NGT-based focus group was more familiar with the IMPact framework, the higher scores they attributed to Flexibility and Measurability are not surprising, as they may have begun to think about implementation in their own projects.
Table 4-4: Evaluation Scores of Focus Group

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Attributes</th>
<th>NGT Group</th>
<th>New Group</th>
<th>Mean (All)</th>
<th>Mean (NGT)</th>
<th>Mean (New)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctness</td>
<td>Diagnosis</td>
<td>4 4 4 3 3 3 4</td>
<td>4 3 3 3 3 3</td>
<td>3.5</td>
<td>3.7</td>
<td>3.2</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>2 3 4 3 3 4</td>
<td>3 3 2 4 4</td>
<td>3.2</td>
<td>3.2</td>
<td>3.2</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Execution</td>
<td>3 3 3 3 4 4</td>
<td>2 3 3 3 3</td>
<td>3.1</td>
<td>3.3</td>
<td>2.8</td>
<td>0.10</td>
</tr>
<tr>
<td>Usefulness</td>
<td>Applicability</td>
<td>3 3 3 4 3 4</td>
<td>2 3 4 3 3</td>
<td>3.2</td>
<td>3.3</td>
<td>3.0</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Practicality</td>
<td>3 2 4 3 4 4</td>
<td>1 2 3 4 3</td>
<td>3.0</td>
<td>3.3</td>
<td>2.6</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Flexibility</td>
<td>3 4 4 4 4 4</td>
<td>1 2 3 3 4</td>
<td>3.3</td>
<td>3.8</td>
<td>2.6</td>
<td>0.03*</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Efficacy</td>
<td>4 4 4 3 3 4</td>
<td>3 4 4 4 4</td>
<td>3.7</td>
<td>3.7</td>
<td>3.8</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Measurability</td>
<td>3 4 4 3 4 4</td>
<td>3 3 2 2 3</td>
<td>3.1</td>
<td>3.5</td>
<td>2.6</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>Acceptability</td>
<td>3 3 4 3 4 4</td>
<td>4 3 3 4 3</td>
<td>3.4</td>
<td>3.3</td>
<td>3.4</td>
<td>0.84</td>
</tr>
</tbody>
</table>

* Statistically significant (NGT and the new group)

4.7 The Proposed IMPact Framework and Discussion

The IMPact framework presented in Figure 4-6 was structured based on the applicable guidelines and recommendations of previous researches of Lean Construction community (Ballard and Kim 2007; Hamzeh 2011). The IMPact framework consists of seven transactional steps, two continual steps, and one supplementary step. To facilitate the execution of these steps, 25 processes were developed. The feedback loops allow new initiatives to be implemented to ensure continual improvement, generation of value, and elimination of waste. The framework is an adaptive system, subject to realignment based on project needs and continual improvement initiatives, as embodied in the guiding principles of Lean Construction.
Continual Step (A) Integrate and Control Changes: since every project has changes with different degrees and scales that may take place at any time during the project life cycle, it is important to continuously evaluate such changes, mitigate their impacts, and integrate executed changes in the current plans.

Continuous Step (B) Organizational Behaviour (Engage and Communicate): managing people is one of the most difficult challenges due to different interests, influences, and human nature. Consequently, employing OCM to manage human resistance is one of the most important roles for project manages/champions. Communicating constantly with stakeholders and engaging them frequently can increase their support, and minimize potential resistance, which will smooth the path to complete the project.

The processes of the IMPact framework belong to four groups:

1) Group I: original LPS® processes

Figure 4-6: Proposed IMPact Framework

A) Integrate and Control Changes

B) Organizational Behavior (Engage and Communicate)
2) Group II: processes pertaining to the LPS® and IMP directly

3) Group III: processes combining LPS® issues with best practices

4) Group IV: processes adapted from best practices of program management.

4.7.1 Detailed description of the major steps and “Group II” processes of the proposed framework.

(1) Prepare: the first step of the framework focuses on preparing and synchronizing the project team, organization, tools to use, and utilizing the LPS® as a production planning and control system. Hence, in this step, the project governance, roles and responsibilities, and the LPS® approach are defined and communicated to different stakeholders. It is critical to prepare the implementation plan, and to get the team prepared to use the LPS®. This means that they should be trained on LPS® concepts; and any early resistance is detected and dealt with through the appropriate communication of OCM and promotion of the LPS®.

(2) Strategize: in the second step of the framework, stakeholders determine the objectives, their common vision, and the strategic direction of the IMP. For example, they define and agree on the limits and number of subprojects. Strategizing produces the way forward and key milestones to be achieved in high-level plans (e.g.: Master Plan and Phase Plan). It also promotes accountability, transparency, and determines how the different trades or subprojects will communicate to integrate their activities to prevent potential interface challenges. It is crucial to do this prior to developing the detailed planning with all team members so that everybody understands their accountability and agrees on how to communicate.

(3) Plan Operations: Develop detailed plans for site operations, considering logistics constraints and construction methods.

(3.2) Cross-check for integration: Conduct workshops to align the individual MRP of subprojects and define interdependencies. This can be achieved using an interface solution (e.g.: Building Information Modeling (BIM) and developing an interface matrix to integrate all the tie-ins within / across subprojects and adjacent projects with respect to key variables, like time, testing and commissioning (T&C), sequence, logistics, procurement etc.)
(3.3) Identify the degree of activities sensitivity: identify sensitive activities which have high interdependencies with other trades within and across subprojects. Use the Phase Plan to monitor important actions and emphasize the delivery of sensitive activities during WWP meetings. The delivery of sensitive activities is very important to release works between trades. This will result in a better integration between trades to maximize utilization of resources and reduce workflow variations. The concept of “activity sensitivity” used here is a major departure from the common term “critical activities” used in the traditional approach to CPM.

(3.4) Assign weights to activities based on the level of effort: determine a weight for every activity within the function or trade based on the amount of effort (e.g.: number of person/days or person/hours for an activity out of the total number of person/days or person/hours for the respective function or trade).

(4) Execute: This step involves the actual operations of an IMP.

(4.2) Validate the undertaking of scheduled activities: validate the design with respect to constructability, errors and omissions (E&O), completeness etc. by conducting another layer of cross-checking for integration among trades.

(4.4) Align the operations of trades: Adjust plans according to inputs or obtain confirmation of validity using an interface solution (e.g. BIM) for a shared vision within and across subprojects.

(5) Measure: This step involves the monitoring and tracking of operational activities.

(5.1) Measure the performance of subprojects based on progress and the weights of activities, including partial achievements: Capture the progress of activities in subprojects according to the plan. This involves using control cards, which can be structured in various ways (e.g.: spreadsheet), to measure and track progress in each subproject with respect to trades or functions. Employing Analytical Hierarchy Process (AHP), use control cards to list all related activities with assigned weights (as per process 3.4) to a specific trade (e.g.: roadwork, excavation, electromechanical) or project function (e.g. engineering, construction, quality control, surveying). The performance measurement system also measures the partial completion of an activity, as illustrated in Figure 4-7.
(5.2) Integrate and consolidate the overall PPC to report the performance and progress of the mega-project. Produce the overall project performance progress after consolidating the PPC of each subproject. The compilation of the progress scores of each control card within a subproject will enable PPC to be generated for the subprojects. Each subproject will have a weight in the total project based on effort measured in person/days or person/hours. Consequently, the project-consolidated PPC is calculated by adding the subproject PPC multiplied by the respective weight factor (WFn) for each subproject, enabling the project team to produce an overall PPC for the mega-project, represented in the following equation:

\[ \text{overall PPC} = \sum_{i=1}^{n} \text{PPC}_n \times \text{WF}_n \]

(6) Reflect and Communicate: This step involves reviewing the effectiveness of the LPS® and capturing any improvement required.

(6.1) Conduct weekly project-performance review and lessons-learned meetings: Host a weekly workshop to review the overall health and performance of the IMP, including integration challenges, issues, risks, progress status, lessons learned, improvement ideas, acknowledge outstanding contributions by team members, and celebrate successes.

(7) Improve continually: This step involves the incorporation of continual improvement ideas for both the IMP performance and the framework itself.

(7.2) Review the practicality of the IMPact framework and adjust accordingly: review the applicability of the overall framework and implement enhancements where necessary to determine how to best incorporate agreed suggestions to continually improve planning,
execution, and monitoring activities, as well as ideas to further eliminate waste and maximize value.

The following step is a recommendation only. Because it might not apply to all IMPs, it was excluded from the body of the framework.

(8) Utilize an Integrated Project Delivery System (IPDS) with Relational Contracting to minimize contractual constraints.

Based on their nature, the 31 integration challenges were grouped in seven categories. Table 4-5 links the challenges with the corresponding processes in the framework and outlines the process groups from I to IV. For example, challenge (C1) was addressed in process (4.4) of the IMPact framework pertaining to Group II - LPS® and IMP aspects.

However, 6 challenges were not incorporated in the framework because they cannot be addressed directly, as discussed in more detail next.

- **(C20) Unforeseen risks that may delay the pre-requisites:** Many risks cannot be eliminated. However, it is essential to develop and maintain a comprehensive risk management plan to monitor all types of risks and determine an appropriate response strategy to manage them accordingly. Enhancing communications across different trades may reduce the risks of interface delays. Integrated Project Delivery System (IPDS) allows money to be transferred between contracts. The IPDS approach will reduce risks exposure to all project stakeholders.

- **(C25) Scope change by the owner:** Most owners of construction projects make changes during execution. However, better communications and planning can reduce adverse impacts. Scope changes cannot be eliminated, especially for new, necessary requirements.

- **(C7) Massive efforts in developing the MRP and WWP:** This is a challenge for new users of the LPS® in IMPs. Therefore, building in capacity and a learning curve for using the LPS® may reduce time and effort, especially after repetition.
- (C30) Lack of daily monitoring on-site to track the delayed activities:
  Daily monitoring and reporting to track delayed activities can only be
  achieved if a sophisticated software is deployed and used with an integrated
  web-based reporting scheme by the site team.
- (C10) Absence of a rigorous software to develop and update the detailed MRP
  and (C31). Incompatibility and connection with existing schedule software
  program: See Future Research below.

Table 4-5: Mapping Processes of IMPact Framework with Integration Challenges

<table>
<thead>
<tr>
<th>Challenge Category</th>
<th>ID of Integration Challenges of LPS® in IMP</th>
<th>Original LPS® Processes (Group I)</th>
<th>Processes of the IMPact Framework</th>
<th>Solutions</th>
<th>LPS®/ Mega (Group II)</th>
<th>LPS®/ Best Practice (Group III)</th>
<th>Program Management Best Practices (Group IV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragmentation (Main Challenge)</td>
<td>C13</td>
<td>2.2 3.1 4.1</td>
<td>3.2 6.3 7.1 and 7.2</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Contractual Constraints</td>
<td>C14</td>
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<td></td>
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<tr>
<td></td>
<td>C15</td>
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<tr>
<td>Interface Issues</td>
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<td></td>
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<tr>
<td></td>
<td>C2</td>
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<td></td>
<td>C18</td>
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<td>3.2</td>
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<tr>
<td></td>
<td>C20*</td>
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<tr>
<td>Organizational Behaviour Challenges</td>
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<td>2.3 and 6.2</td>
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<td></td>
<td></td>
<td></td>
<td>✓</td>
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<tr>
<td></td>
<td>C22</td>
<td>1.1 and 1.2</td>
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<td></td>
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<td></td>
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<tr>
<td></td>
<td>C23</td>
<td>4.3</td>
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<tr>
<td></td>
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<td>(B)</td>
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<td>Change Control Challenges</td>
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<tr>
<td></td>
<td>C26*</td>
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<td>C6</td>
<td>2.4 and 3.5</td>
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<tr>
<td></td>
<td>C7*</td>
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<tr>
<td>Challenge Category</td>
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<td>Original LPS® Processes (Group I)</td>
<td>Processes of the IMPact Framework</td>
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<td>Solutions</td>
<td>LPS®/ Mega (Group II)</td>
<td>LPS®/ Best Practice (Group III)</td>
<td>Program Management Best Practices (Group IV)</td>
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<tr>
<td>Fragmentation (Main Challenge)</td>
<td>C13</td>
<td>2.2 3.1 4.1</td>
<td>3.2 6.3 7.1 and 7.2</td>
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<tr>
<td></td>
<td>C27</td>
<td></td>
<td>1.3</td>
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<tr>
<td></td>
<td>C28</td>
<td></td>
<td>1.4</td>
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<td>C9</td>
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<tr>
<td></td>
<td>C11</td>
<td>5.1</td>
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<td>C29</td>
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<tr>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>C31*</td>
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</tbody>
</table>

* Integration challenges cannot be addressed directly

To reinforce its external validity, the measurement performance system of the IMPact framework was tested on an ongoing real project, utilizing the LPS® as the main production planning and control system. For this purpose, a spreadsheet was maintained to calculate the overall PPC of the project. The positive results obtained from the implementation of the measurement performance system confirmed the practical relevance of the IMPact framework in practice.

Because the IMPact framework is a major shift in the way IMPs are usually planned and executed, its successful implementation requires the support and encouragement of top management and enforcement of a persuasive OCM strategy until benefits are realized and a cultural shift has occurred. New teams struggle to accommodate the additional planning and integration efforts needed (e.g.: challenge C7) because they are not used to production planning in the first place. In traditional approaches, schedules are developed in detail by planners with little if any input from site teams and trades (Ballard and Tommelein 2016). These schedules are then forced on the execution teams; they all too often fail. The effort spent on weekly meetings is needed to avoid failures. Once milestones start being met, the massive effort is soon accepted as essential to good production planning and control.
The rich conversations between team members during the MRP and the WWP processes were also observed. Their focus aligned on how the work would be executed, uncovering integration issues that were resolved before they became execution failures. Addressing these problems and satisfying prerequisites resulted in higher productivity and efficiency during the construction operations—a result that was highly appreciated, and raised team morale. The IMPact framework presents a structured approach for addressing the integration challenges of the LPS® in IMPs, and for delivering IMPs successfully. It is a very powerful educational tool to assist new users to comprehend the implementation process of the LPS® visually. It is user friendly, and increases the level of confidence of the project team. Finally, the framework is flexible in allowing new users to integrate the best-performing tools into its processes.

Similar to the LPS®, Workface Planning (WFP) was developed because available planning methods did not support successful delivery of mega-projects in the oil and gas sector. Inspired by LPS®, WFP was the industry’s solution to address productivity concerns and provide opportunities for collaboration (COAA 2007). It is situated midway between the centralized planning philosophy of CPM and the decentralized production planning approach of the LPS®. WFP engages field supervisors in the planning process to provide inputs but the workface planner is responsible for developing and updating field installation work packages (FIWP).

4.8 Conclusion

From the early days of an IMP and as progress advances, integration challenges multiply causing progress disruptions and delays. A well-established planning system is expected to manage these challenges and steer the efforts of field crews towards project targets, engaging site teams with respect and open channels of communications. The proposed framework is an adaptable system and flexible for continual improvement initiatives, as embodied in the guiding principles of Lean Construction. It was fostered to complement, not to replace, the existing LPS® model. Therefore, it provides a roadmap with workable solutions to address the unique and complex integration challenges of IMPs. In developing this framework, it is hoped that future project teams start using the IMPact framework to better control and manage IMPs. This will potentially help to change the negative image of delivering IMPs and keeping them on track.

The design of the research method employed the use of conventional critical literature review, a modified 2-round Delphi, NGT, and focus group studies. The Delphi survey confirmed the
existence of integration issues in multiple LPS® plans of IMP segments. NGT confirmed the internal validity of the IMPact framework and the functionality of its foundations. Focus group outcomes produced informative results about the correctness, usefulness, and effectiveness of the proposed framework to ensure external validity.

The development of the IMPact framework was based on earlier experiences from applying the LPS® in IMP where evaluating the LPS® for delivery of two major milestones on a real IMP identified 13 significant obstacles (C1 to C13) that caused integration issues among IMP segments and limited the use of the LPS®. An additional 18 integration challenges (C14 to C31) were derived from Delphi study. As reflected in Figure 4-4, the framework has addressed directly 25 of the 31 integration challenges. The six outstanding challenges that could not be addressed directly were explained earlier.
Chapter 5  Discussion

On completing the focus group study, one of the participating experts, known to be a strong supporter of traditional practice, shared his feedback on the IMPact framework. He said: “After a careful review of the Research Validation Process, I find that each component of IMPact framework has a great relevance in addressing the integration challenges of international mega-projects. I wish that we had this framework available before we had implemented the Last Planner® System in the 5B mega construction package. It would have been used as a roadmap for the completion of our project.”

Inspired by this comment, the following discussions tries to shed light on how the IMPact framework could have been applied in Construction Package 5B (CP5B), following step 11 of Figure 4-1 (roadmap of the research process).

5.1 Reflection on the IMPact Framework

At this stage of the research, an in-depth hypothetical reconsideration of CP5B case study presented in Chapter 3 was conducted, assuming the IMPact framework was used. The observations supporting this argument are extended to reflect the perpetuated benefits of the IMPact framework. A reflection of the benefits and potential impacts of applying the proposed framework are presented herein for the major steps:

5.1.1 Prepare

Applying a new technique requires intensive training and close monitoring by the implementation champion. Introducing the IMPact framework at the beginning of the project is essential in order to engage all stakeholders in the training program. This will not only enhance the awareness of implementation plan, but it will also improve the understanding of the project goals and identify potential bottlenecks promptly.
Facilitating continual coaching would have been a great initiative in helping the team to prevent slippages in the schedule. Identifying problems early in the construction stage allows the GC to reorganize, realign, recover, and avoid waste of misallocated manpower and equipment.

Teamwork is essential for the success of the IMPact framework and the project. All parties involved have to work harmoniously throughout with close integration and participation. This is the shortest path towards eliminating resistance and developing team spirit. CP5B did face some resistance to the Last Planner® System (LPS®) because the GC hesitated to share problems with the management team. Transparency by all parties from the start of the project is essential to remedy any problem as a team.

Achieving project completion to the satisfaction of the owner starts with a well-defined responsibility matrix of stakeholders and a governance plan.

Early implementation of the IMPact framework would have been a great benefit in getting all parties involved throughout the exercise. CP5B had close coordination between the task leaders within subprojects. However, team integration across subprojects was missing. Due to everybody’s busy schedules, attendance at weekly meetings shrank gradually. Had the LPS® been a contractual requirement in CP5B, all team members would have been more comfortable and less resistant in participating in the process.

5.1.2 Strategize

The nerve center of any project is the site office. This is where the daily functions are concentrated on integrating the design specifications, scheduling material supplies, defining labour requirements, hosting daily progress meetings, and conducting production planning. Given the immense logistical demands inherent in a construction project of the size and complexity of an international mega-project (IMP), the site office has to respond quickly, efficiently, and precisely to daily demands. This is crucial to meet budget and schedule criteria. One of the early strategic decisions is determining the location and finalizing the design of the site office(s).
Applying a common strategy where everyone follows the same approach is critical in establishing an efficient project control system as well as in accustoming everyone to viewing the project from the same perspective.

Strategic development of the subproject structures is a key to the success of delivering an IMP on time. Keeping the completion of CP5B milestones in mind (major roads and overall project completion), the project sections (subprojects) are to be strategically designed to satisfy all constraints, maximize efficiency, and control integration challenges between subprojects.

Dividing the mega-project into subprojects strategically requires the involvement of all team members.

CP5B did not have an accountability system in place during the LPS® efforts. For example, a reward scheme for recognizing outstanding completion of percent plan complete (PPC) each week could have motivated the teams.

5.1.3 Plan Operations

By developing realistic execution plans (production schedules) in accordance with the IMPact framework, many of the unnecessary revisions of baseline schedule and recovery programs could have been avoided.

One of the keys to success is enhanced integration between subcontractors (trades) within and across subprojects (junctions in the referenced case study). Collaborating and sharing information between trades lead to a practical, smooth, and realistic planning of construction operations. On the other hand, breaking installed services, damaging the waterproofing system of underground structures, and safety hazards are just a few of many examples of improper integration between trades placing progress at high risk and sometimes halting it altogether.

An integration planning facilitated in the IMPact framework is extremely important to achieve project objectives (for example, ensuring proper tie-ins within and across subprojects). The greatest challenges were observed in integrating among six trades working on wet and dry utilities’ installations with the same corridor or junction with
hundreds of crossings and tie-in points. Had the IMPact framework been implemented at the beginning of the project with clear synchronization between the subprojects, an interface/integration plan would have been prepared and executed on site addressing many of the integration challenges.

The IMPact framework could have made a fundamental impact in better understanding the interface activities and prerequisites; in particular, the integration within and across subprojects for the sequence of utilities’ installations, clash analysis, and shop-drawing development as prerequisites to start construction activities. This could have been very beneficial for CP5B in resolving design issues (clashes) and authority approvals/requirements, which were major obstacles to achieving contractual milestones. In addition, the GC’s organization and its management of subcontractors could have been closely monitored to prevent miscommunications and align the efforts of all participants towards targets.

In an environment where multiple subprojects interface with conflicting interests, it is very challenging to manage logistical and interface problems without a system like the IMPact framework. The challenge is much worse with the external interface with neighbouring contractors and subcontractors. Poor interface management will inevitably lead to major waste due to potential delays, unnecessary costs, and accidents.

5.1.4 Execute

CP5B did have a cohesive team where communications between the GC and the management team were constant and effective. However, due to the late implementation of the LPS®, the GC had a difficult time in responding efficiently to resource allocations within and across subprojects which reduced production rates. Enabling sharing of resources and information supports the inspiring principles of Lean Construction to fight waste. Sharing resources between subprojects increases the efficiency of production if properly studied to integrate the overall effort in project delivery. This applies to the GC’s resources and to the supervision consultant and the management team in sharing personnel to inspect, test, and approve the works. If implemented, such an aspect could
have helped CP5B to complete the priority locations, prevent down-times, and increase productivity.

5.1.5 Measure

Assigning weights to activities’ sensitivity in CP5B could have improved overall performance in preventing slippages and producing accurate weekly reports. Studying the plan in this respect would have helped with accurately planning the required resources for sensitive tasks. For example, the installation of large stormwater pipes along the underpass (UP1) was a very lengthy and complicated work, which had the same assigned weight as minor pipe installation in the verge of Road A1. In the proposed performance measurement system of IMPact framework, activities are assigned weights based on the level of effort. Such assignments are carried over to calculate individual PPC of each subproject and consequently the overall PPC of the IMP.

Measuring the performance of subprojects based on progress and weights is important in identifying the tasks that require much closer attention; and is also essential in determining the weekly PPC, which in return measures the success rate in meeting commitments. Accurate PPC data would have helped plan future tasks better and develop strategies for improving resource allocation.
5.1.6 Reflect, Record, and Communicate

Weekly project performance meetings are essential in monitoring progress on site and in identifying potential delays in meeting deadlines. CP5B conducted weekly meetings to measure PPC, however due to busy schedules, attendance at the meeting dropped gradually. Documenting and sharing lessons learned are great addition that might have helped CP5B finish the project earlier by sharing knowledge and experience within CP5B and externally from other similar projects in the Lusail City program.

Updating changes on all communication channels and sharing with all participants is important in the dynamic nature of mega-projects where the number of team members is large and changes are common.
5.1.7 Improve Continually

Discussing improvements periodically in CP5B would have been very beneficial. Due to the aggressive schedule of the project, the team was overwhelmed in striving to achieve contractual milestones. Improving and adjusting the IMPact framework in the presence of experience champions would have helped customize the framework to project needs and potentially improve the performance. Improvement would also have extended to the productivity of people, machinery utilization, prompt responses to design changes, interface issues, and commissioning mandates with adjacent packages.

In light of the above discussions, it is believed that the performance of CP5B would have been improved if the IMPact framework was utilized.
Chapter 6 Conclusions

6.1 Contributions

This research contributes to a better understanding of production planning and control systems in dealing with site operation issues and integration challenges across subprojects. The insights obtained from evaluating production management system in an international mega-project (IMP) revealed the significant impacts of integration challenges on production planning. The outcomes of this study help practitioners to develop a deeper perspective of integration challenges influencing the delivery of international mega-projects (IMPs).

It contributes to the body of knowledge by providing details of how the Last Planner® System (LPS®) was implemented in an IMP. This study documents the inputs of professionals participating in some of the world’s most famous IMPs with respect to their observations, experiences, and lessons learned. From the lessons learned and findings documented in this study, readers will gain an appreciation of the challenges of IMPs and how the LPS® functions at a complex scale.

The IMPact framework was developed to systemically address integration challenges and provide guidance to potentially improve the performance of IMPs. Because there are no published guidelines or available framework combining managing the integration issues within and integrating interfaces across subprojects in IMPs, the outputs of this study presents critical findings. Such a record is aimed to add to the very scant literature in this regard.

The findings of this research have methodological and practical implications. The validated framework provides a conceptual practical solution to address integration challenges of LPS® within and across subprojects of IMPs. The methodology used in this study can be applied to other researches pertaining to the development and validation of frameworks or an approach for investigating production management issues in general.

6.2 Limitations

One of the limitations of this study is that the IMPs included are all in the Middle East. The advantage of restricting the study to one geographical region is that the projects are more easily compared because they have similar geographical, political, cultural, and organizational
challenges. It is hoped that this study has identified one of the major but avoidable challenges related to production planning and control, and that the findings can be used elsewhere, as appropriate.

Another limitation is related to the expert sample size of 32 in Chapter 2. A larger sample might provide greater insights to the responses.

The implementation case study of the LPS® presented in Chapter 3 was conducted after 70% of the project was completed. The project team did not have any LPS® experience before implementation. The case study involved two milestone stages of the infrastructure project, and the LPS® was applied to make-ready and week work planning. The percent plan complete (PPC) was limited to top critical activities defined by the project team.

Because it was not specified in the contract, LPS® implementation could not be enforced from the beginning. The impact of the LPS® on the construction cost of CP5B, whether positive or negative, was outside the scope of this study. Therefore, further investigation is required before concluding on the commercial impacts of implementing the LPS®.

Six out of 11 of the participating experts in focus group were previously engaged in the NGT. However, their data were isolated from 5 focus group experts and presented separately. Statistical analysis showed little difference between the previously engaged and newly engaged experts.

Finally, due to time restrictions, the proposed IMPact framework was tested and observed only on a single ongoing real project. IMPact framework was developed methodically and still needs a full implementation by an IMP team. Further implementations by industry practitioners are encouraged.

6.3 Conclusions

Construction is often a challenging industry as stakeholders have conflicting interests. The level of cooperation among project participants decreases as interests’ conflict and the overlap of common objectives shrink. Current bidding procedures and contract conditions do not encourage project integrated delivery, as recommended in an ideal Lean Construction model.
Thirty-two industry practitioners with experience working on IMPs provided feedback on production planning methods in a structured interview process in phase 1 of this study. The practitioners concluded that only a few of the methods were applied in IMPs. Production planning and control systems were examined for their ability to manage site operation issues and integration challenges. One of the emerging systems, the LPS®, was implemented on an IMP and its performance assessed.

As reported by the participating experts, due to the Owners’ support to critical path method (CPM), it was morphed from being a planning and control tool supposed to be used to coordinate resources, procurements, operations at construction site, and reporting progress into a contract control method. Owners continue to insist on using CPM based software considering its sophisticated capabilities in calculating impacts of extension of time claims and calculating interim progress payments (if resources were loaded in the software). However, general contractors managed to utilize CPM-based software for protection against liquidation damages. Between the conflicting interests of owners and general contractors (GCs), CPM-based software is often used for contractual claim rather than for planning to support the execution of construction activities. Moreover, CPM has been recognized as one of the most important innovations in construction management in the 20th century, yet with its push system, it follows transformational approach with no consideration on flow and value views (Tommelen 2015).

Practitioners are frustrated with the poor performance of the traditional project management approach in IMPs, which results in cost overruns and project delays. For example, from the perspective of the GCs interviewed, CPM-based software is ineffective for production-level planning and control and inefficient in communicating planning activities with construction site teams. However, for multiple reasons, including corporate inertia, they are resisting the exploration of a revolutionary shift in the industry that uses modern and more practical tools. Therefore, CPM-based software remains the dominant planning tool in the construction industry, with its main functions being delay analysis and claims for extension of time (Kenley 2004).

One of the methods used on the CP5B project, CPM, was deemed unsuccessful to address the integration challenges of IMPs. Hence, a new emerging method in production planning and control (namely, LPS®) was the alternative. The goal of the LPS® is to improve a project’s
workflow predictability and reliability. A defining characteristic of the LPS® is the collaboration of the “last planners” and decision makers at the execution level.

The LPS® was introduced as a tool to help complete two critical milestones in the CP5B project. The new method was initially challenged. To implement the LPS® effectively, stakeholders were asked to increase their levels of effort, communication, and commitment. As the efforts started to materialize in achieving project milestones, all stakeholders did eventually buy in to the method. The LPS® was implemented successfully on large-scale projects, but its adaptability for handling the integration challenges of IMPs required different treatment.

Successful implementation of the LPS® requires that all involved personnel attend and participate in the weekly meetings. Participants are expected to make commitments and be forthright if they are unable to fulfill a promise. The interactions between project teams help to unfold prerequisites and constraints allowing for better communications between trades, and to release works at the last responsible moment in a pull planning fashion (Abdelhamid et al. 2010). This communication drives the pull system to expose constraints and bottlenecks. LPS® implementation is a different mindset from traditional practice, facilitating early detection of program slippage and finding immediate mitigations through the accountability of all project team members.

The IMPact framework, inspired by the paradigm of LPS® and Lean Construction principles, provides a perfect opportunity for maximizing and generating value. The IMPact framework is expected to significantly improve project performance towards a better delivery of IMPs with difficult integration challenges, long timeframes, many stakeholders, and major risks. While this study was motivated by IMPs in particular, the results, findings, and recommendations are likely applicable to projects of varying sizes or locations where the integration of subprojects is critical to the success of the project.

With successful implementation of IMPact framework, integration challenges are expected to be managed without frustration to the client and other stakeholders. Exploiting such opportunities requires strong leadership, professional practice, and culture change at every level of the organization throughout project lifecycle. By developing the proposed framework as a vehicle to adapt the LPS® to IMPs, projects will have the opportunity to utilize it in an effort to achieve
better performance. Although the use of new systems will initially require an increased commitment, the return on investment is reliability and delivery.

6.4 Future Research

The author recommends repeating the investigations of applying LPS® to other IMPs with ideal situations (full implementation) to evaluate the performance LPS® at a mega-scale and to study the impact of the LPS® on the construction cost, whether positive or negative.

It is suggested to implement the IMPact framework for future researchers to investigate: 1) the efficiency of the performance measurement system of the IMPact framework to calculate the overall PPC based on level of effort weights, and, 2) the significance of improving delivery and performance of IMPs.

Additional future research may examine the potential integration of the IMPact framework with the Workface Planning (WFP). Furthermore, using artificial intelligence in this framework is a new concept, outside the scope of this study, but worth exploring. The integration between BIM 360, Touch Plan, V-Planner, and Villego® software needs to be tested and validated to develop and update the detailed make ready plans.
References


Chapter 2

Title: Coordination Challenges of Production Planning in the Construction of International Mega-Projects in The Middle East

Manuscript ID: 1276109 (UICE-2016-0966.R1)

Authors: Luai M. El-Sabek, and Brenda Y. McCabe,

Journal Title: International Journal of Construction Education and Research

http://dx.doi.org/10.1080/15578771.2016.1276109

Submitted on: August 29, 2016

Accepted with comments on: December 21, 2016

Revised on: December 2, 2016

Final Acceptance on: December 21, 2016

Status: Published (online on: February 13, 2017)

Publisher: Taylor and Francis Group, LLC
Chapter 3

Title: Coordination Challenges of Production Planning and Control in International Mega-projects: A Case Study

Manuscript ID: 16_010

Authors: Luai M. El-Sabek, and Brenda Y. McCabe,

Journal Title: Lean Construction Journal

https://www.leanconstruction.org/media/docs/lcj/2017/LCJ_16_010.pdf

Submitted on: September 18, 2016

Accepted with comments on: February 18, 2017

Revised on: February 28, 2017

Minor comments received on: April 1, 2017

Final revision was submitted on: April 1, 2017

Final acceptance on: April 2, 2017

Status: Published (online on: April 18, 2017)

Publisher: Lean Construction Institute
Chapter 4

Title: Framework for Managing Integration Challenges of Last Planner System in International Mega-Projects

Manuscript ID: COENG-6229

Authors: Luai M. El-Sabek, and Brenda Y. McCabe,

Journal Title: Journal of Construction Engineering and Management

Submitted on: April 29, 2017

First round of comments received on: June 14, 2017

Revised on (Rev. 1): July 20, 2017

Second round of comments received on: August 30, 2017

Revised on (Rev. 2): September 12, 2017

Status: Under Review

Publisher: American Society of Civil Engineers (ASCE)
Appendix B – Approval of Health Sciences Research Ethics Board (REB)

January 20, 2017

Dr. Brenda McCabe
DEPT OF CIVIL ENGINEERING
FAC OF APPLIED SCI & ENG

Mr. Luai El-Sabek
DEPT OF CIVIL ENGINEERING
FAC OF APPLIED SCI & ENG

Dear Dr. McCabe and Mr. Luai El-Sabek,

Re: Your research protocol entitled, "Coordination challenges of production planning & control in international megaprojects: An exploration"

<table>
<thead>
<tr>
<th>ETHICS APPROVAL</th>
<th>Original Approval Date: January 20, 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expired Date:</td>
<td>January 19, 2018</td>
</tr>
<tr>
<td>Continuing Review Level: 1</td>
<td></td>
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</tbody>
</table>

We are writing to advise you that the Health Sciences Research Ethics Board (REB) has granted approval to the above-named research protocol under the REB's delegated review process. Your protocol has been approved for a period of one year and ongoing research under this protocol must be renewed prior to the expiry date.

Any changes to the approved protocol or consent materials must be reviewed and approved through the amendment process prior to its implementation. Any adverse or unanticipated events in the research should be reported to the Research Oversight and Compliance Office - Human Research Ethics Program as soon as possible.

Please ensure that you submit an Ethics Renewal Form or a Study Completion/Closure Report 15 to 30 days prior to the expiry date of your current ethics approval. Note that ethics renewals for studies cannot be accepted more than 30 days prior to the date of expiry.

If your research is funded by a third party, please contact the assigned Research Funding Officer in Research Services to ensure that your funds are released.

Please note, all approved research studies are eligible for a routine Post-Approval Review (PAR) site visit. If chosen, you will receive a notification letter from our office. For information on PAR, please see http://www.research.utoronto.ca/wp-content/uploads/documents/2014/08/PAR-Program-Description-1.pdf.

Best wishes for the successful completion of your research.

Yours sincerely,

[Signature]

Elizabeth Peters, Ph.D.
REB Chair

Research Oversight and Compliance Office - Human Research Ethics Program
McMichael Building, 12 Queens Park Crescent West, 2nd Floor, Toronto, ON M5V 3H8 Canada
Tel: +1 416 946-2273 • Fax: +1 416 946-5703 • ethics.review@utoronto.ca • http://www.research.utoronto.ca/research-administration/ethics/
Appendix C – Interview Questions of Chapter 2

Name: ____________________________
Years of experience in construction projects: ______________________________

1) To what degree are these factors a challenge on your project?

<table>
<thead>
<tr>
<th>Factor</th>
<th>Very challenging</th>
<th>Moderately challenging</th>
<th>Controlled challenge</th>
<th>Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
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<tr>
<td>Schedule</td>
<td></td>
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<tr>
<td>Scope changes by client</td>
<td></td>
<td></td>
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<tr>
<td>Quality of design-caused changes</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Authority approvals</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Procurement</td>
<td></td>
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<tr>
<td>Labour issues</td>
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<tr>
<td>Staff issues</td>
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<td></td>
</tr>
<tr>
<td>Site logistics</td>
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</tr>
<tr>
<td>Communications</td>
<td></td>
<td></td>
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<tr>
<td>Meeting client expectations</td>
<td></td>
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<tr>
<td>Environmental health and safety</td>
<td></td>
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<tr>
<td>Interface and coordination</td>
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<tr>
<td>Claims and Disputes</td>
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<tr>
<td>Type of Contract</td>
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<tr>
<td>Other (specify)</td>
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</tbody>
</table>

2) To what level of detail is the implementation plan developed at the tendering stage?

<table>
<thead>
<tr>
<th>Level</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Completely to the activity level</td>
<td>Other (specify)</td>
</tr>
<tr>
<td>Only activities for critical components</td>
<td></td>
</tr>
<tr>
<td>To a high level only</td>
<td></td>
</tr>
</tbody>
</table>

3) To what degree is the tendering plan depended upon for the actual project plan, assuming you are awarded the project?

<table>
<thead>
<tr>
<th>Degree</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Not at all, we start over</td>
<td>To a great extent (75%)</td>
</tr>
<tr>
<td>To a minor degree (25%)</td>
<td>Completely (90%+)</td>
</tr>
<tr>
<td>To a moderate degree (50%)</td>
<td>Other (specify)</td>
</tr>
</tbody>
</table>
4) Who participates in the development of your project plans?

<table>
<thead>
<tr>
<th>Tender Plan</th>
<th>Actual Plan</th>
<th>Updates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Manager</td>
<td></td>
<td></td>
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<tr>
<td>Construction Manager</td>
<td></td>
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<tr>
<td>Design Manager</td>
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<tr>
<td>Planning Team</td>
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<tr>
<td>Site Engineer</td>
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<tr>
<td>Forman</td>
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<td></td>
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<tr>
<td>Subcontractor</td>
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<tr>
<td>Suppliers</td>
<td></td>
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<tr>
<td>Client</td>
<td></td>
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<tr>
<td>Site Supervision Consultant</td>
<td></td>
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<tr>
<td>Estimators</td>
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<tr>
<td>Senior Management</td>
<td></td>
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<tr>
<td>Project Control Manager</td>
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<tr>
<td>Others: specify</td>
<td></td>
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</tbody>
</table>

5) How many times has your baseline been revised or expected to be revised?

6) What are the causes of revisions?

<table>
<thead>
<tr>
<th></th>
<th>Fundamental Cause</th>
<th>Major Cause</th>
<th>Minor Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope Change</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Inaccurate Forecast</td>
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<tr>
<td>Authority Approval Delays</td>
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<tr>
<td>Unrealistic milestones Imposed</td>
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<tr>
<td>Lack of site team inputs to original plan</td>
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<tr>
<td>Inability of site team to fulfill commitment</td>
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<tr>
<td>Unpredictability site operation workflows</td>
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<tr>
<td>Lack of understanding of prerequisites and constraints</td>
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<tr>
<td>Not using the right planning tool</td>
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<tr>
<td>Underestimating key activity durations</td>
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<tr>
<td>Unforeseen Conditions</td>
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<tr>
<td>Force Majeure</td>
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<tr>
<td>Other: (Specify)</td>
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</table>

7) What planning methods or tools do you use?

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<tr>
<th></th>
<th>Fundamenta</th>
<th>Major</th>
<th>Minor</th>
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<td>3.</td>
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<tr>
<td>4.</td>
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</table>
8) Why do you use these methods or tools? (Choose as many as apply)

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<th>3.</th>
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<tr>
<td>Contractual require</td>
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<tr>
<td>Company preference</td>
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<td>My preference</td>
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</tbody>
</table>

9) Rate your methods/ tool as:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>0=Not Applicable</th>
<th>A=Good</th>
<th>B=Acceptable</th>
<th>C=Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication tool</td>
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<tr>
<td>Promoting Team Work</td>
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<tr>
<td>Promoting top-down approach</td>
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<tr>
<td>Promoting bottom up approach (grass roots)</td>
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<tr>
<td>Ease of Modification / Updating</td>
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<tr>
<td>Accurate reflection of physical progress</td>
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<tr>
<td>Flexibility</td>
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</table>

10) Are you satisfied with your planning methods and tools?

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<th>1.</th>
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<th>4.</th>
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<tbody>
<tr>
<td>Extremely Satisfied</td>
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<td>Satisfied</td>
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<tr>
<td>Partially Satisfied</td>
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<td>unsatisfied</td>
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</table>

11) Specify what could be improved with your current methods or tools?
Subject: Reconsent to Participate in a Research Survey (Phase I)

Dear Sir,

Thank you for participating in our research survey (Phase I), in April 2015, as a part of our ongoing research titled “Integration Challenges of Production Planning in the Construction of International Mega Projects in The Middle East.” The study is a part of thesis for Doctorate of Philosophy in Civil Engineering, at the University of Toronto.

The objectives of this phase were to: A) better understand how the integration challenges of international mega-projects are addressed by common planning and production planning and control systems and B) identify gaps in current practice by synthesizing the knowledge found in literature with practitioners’ experience derived from the interviews with 32 participants (experts) asking the following questions:

1) To what degree are these factors a challenge on your project?
2) To what level of detail is the execution plan developed at the bidding stage?
3) To what degree is the bidding plan depended upon for the actual project plan, assuming you are awarded the project?
4) Who participates in the development of your project plans?
5) How many times has your baseline schedule been revised or expected to be revised?
6) What are the causes of baseline schedule revisions?
7) What planning methods or tools do you use?
8) Why do you use these methods or tools?
9) Rate your methods/tools.
10) Are you satisfied with your planning methods and tools?

As a practitioner in mega-projects, you were an ideal candidate to participate in this interview to share with us your valuable opinions and suggestions. Your responses and the information have been and will continue to be treated confidentially. Aggregated data are reported in an article which is expected to be published in a reputable journal, and be part of the final thesis of this research. Please find attached a draft of that paper for your reference and reading pleasure. As it was explained, participation in this survey was completely voluntary. However, we hope that you found your engagement interesting enough to consider it time well spent. Your participation was a valuable addition to our research and findings which could lead to greater public benefits to improve the performance of international mega-projects.

To reinforce the verbal consent obtained at that time, we would highly appreciate your reconfirmation of the terms of participation by signing or responding to this email.
This research is being conducted by the undersigned researchers independently without any funding from any organization.

Regards,

Luai M. El-Sabek, PE, PEng, PMP
Ph.D. Candidate - Construction MGMT
University of Toronto
Department of Civil Engineering
35 St George Street; Room 134
Toronto, ON M5S 1A4
Phone : (647) 800-4664
E-mail : Luai.Sabek@mail.utoronto.ca

Brenda McCabe, PhD, PEng, FCSCE
Associate Professor
University of Toronto
Department of Civil Engineering
35 St George Street
Toronto, ON M5S 1A4
Phone : (416) 9463505
E-mail : brenda.mccabe@utoronto.ca

PARTICIPATION
Without any negative consequences or penalties whatsoever, you are totally free to decline to participate or not to answer any question that you do not feel comfortable answering. At this time, should you choose to withdraw, your data will be removed accordingly.

There were no foreseeable risks envisaged due to your participation in this study neither on you nor on your organization.

CONFIDENTIALITY
Final responses remain anonymous and not binding. No personal information or names have been or will be disclosed.

The information you provided was used only for academic purposes related to the study. The research study you are participating in may be reviewed for quality assurance to make sure that the required laws and guidelines are followed. If chosen, (a) representative(s) of the Human Research Ethics Program (HREP) may access study-related data and/or consent materials as part of the review. All information accessed by the HREP will be upheld to the same level of confidentiality that has been stated by the research team.

CONTACT INFORMATION
If you have any questions or you need additional information about the study or your level of involvement, please do not hesitate to contact us.

If you feel you have not been treated according to the descriptions in this form, or that your rights as a participant in research have not been honoured during the course of this study, or you have any questions about your rights as a research participant, concerns, or complaints that you wish to address to someone other than the researchers, you may contact a staff member at the Research Oversight and Compliance Office - Human Research Ethics Program, at the University of Toronto, at +1 (416) 946-3273 or ethics.review@utoronto.ca.
CONSENT
We respectfully appreciate your cooperation to sign and return this form as soon as possible by reconfirming your acceptance. You have the right without prejudice to withdraw your consent in which case your data will be removed immediately.

Checking the “Agree” box indicates that:

- You read and understand the above information
- You voluntarily agreed to participate

☐ Agree ☐ Disagree

Comments (if any):

Signature:_____________________________             Date:________________
Appendix E – Delphi Study (Round I)

Invitation Letter

Subject: Invitation to Participate in a Research Validation Process

Dear Sir,

It is our honour to invite you to participate in one of several validation phases of our ongoing research titled “Integration Challenges of Production Planning and Control in International Mega-Projects: A Framework.” As a practitioner who possesses recent experience with LPS® implementation in mega-projects, you are an ideal candidate to participate in this study to share with us your valuable opinions and suggestions. This study represents one research component of a Ph.D. dissertation in Department of Civil Engineering at the University of Toronto. Your responses and information collected in this study through the Delphi method (a structured questionnaire) will be treated confidentially and reported in aggregate form only. Participation in this research is completely voluntary. However, we hope you will find the engagement in this research interesting enough that you will consider the time well spent. Your participation will be a valuable addition to our research and findings which could lead to greater benefits by improving the performance of international mega-projects. There are no right or wrong answers. What is important is your opinion.

This research is being conducted by the undersigned researchers independently without funding from any organization. More details about this study, you participation, and rights are provided in the attached Consent Form.

If you are willing to participate, please complete the attached questionnaire of Round I and sign the attached Consent Form by January 29, 2017. For your convenience, the questionnaire is provided to you in a PDF and MS Word format.

Regards,

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E-mail : brenda.mccabe@utoronto.ca
Research Objective
The purpose of this study is to evaluate the integration challenges that restrict the use of Last Planner® System (LPS®) in international mega-projects. Since its inception, LPS® has been implemented successfully in many projects. Nevertheless, the application of LPS® to mega-projects is very limited due to major integration challenges, scale, and complexity issues that characterize these projects. Applying LPS® as one of the existing production planning and control paradigm to the construction of international mega-projects would be very challenging due to the difficulty of ensuring a high level of integration among the complex operations involved in international mega-projects. Furthermore, available lean production planning and control solutions cannot be applied directly to address integration challenges in international mega-projects. Therefore, the suitability of LPS® in international mega-projects has not been validated and requires different treatment to overcome these challenges. The results of this study will contribute to developing a framework addressing integration challenges of implementing the LPS® as a production planning and control system in international mega-projects.

International Mega-Projects
In addition to its hundreds of millions of dollars value, mega-projects are extremely complex in engineering and construction. Generally, the legacies of mega-projects and mega-events are remembered far longer than typical projects. They are known for having complex scopes, long durations, difficult logistics, many high-level risks, complicated networks of stakeholders, sophisticated governance issues to navigate through, and challenging interface constraints. Categorized as a complex form of mega-projects, an international mega-project can be defined as one undertaken in a region that lacks engineering, construction, and management companies of the size, proficiency, and technical expertise to successfully complete the project. In the absence of local expertise, the owner has the opportunity to draw from a highly qualified pool of resources from around the world. However, this can result in a project in which the participating companies come from different countries, and have different working cultures, different common practices, attitudes, and organizational cultures. It is unlikely that the team had worked together before. The specifications, building codes, and standards to be achieved by the project team in the host region are often based on international standards, like American and British standards, rather than local standards. Forms of contract are typically derived from FIDIC (International Federation of Consulting Engineers), AIA (The American Institute of Architects), or the British based NEC3 (New Engineering Contract). Within the host country, local authorities are generally well versed in issuing permits and approvals for standard local projects. Unfortunately, the undertaking of an international mega-project in the region with its sheer size, complex scope, technical aspects, and an international project team that lacks local experience, understanding of local regulations, culture, and permitting process can lead to a breakdown of an otherwise well performing system.

Research Methodology: “Modified Delphi Technique”
The Delphi technique is used in obtaining judgment information where statistical methods are not possible or practical due to a lack of data, or when qualitative input from people is required. The Delphi technique is a tool to obtain relevant intuitive insights from practitioners and subsequently use their inputs systematically in combined experts’ opinions (Pill 1971). Delphi’s early applications were primarily focused on forecasting efforts in the defense field. However,
over the decades, Delphi has been widely used in many different domains and industries since its first use including framework development. It provides the platform to check the validity of the cross-disciplinary concepts in various fields such as social, psychological, ethical, managerial, cultural, anthropological, etc. (Linstone and Turoff 1975).

In a Delphi-based study, participants usually go through an iterative multistage communication process designed to aggregate group opinions and arrive at an overall consensus (McKenna 1994; Hasson et al. 2000). The experts go through two or more rounds, answering structured questionnaires anonymously in each round. Two rounds are designed for this:

**Round I (30 min):** This begins with a structured questionnaire (Murry and Hammons 1995; Hsu and Sandford 2007) where participants are asked to edit, rank, and comment upon the ideas embodied in the questionnaire. The researcher will take the responses from round one and calculate summary statistics for each question (Murry and Hammons 1995).

**Round II (30 min):** Participants are provided with the comments from the first round along with the summary statistics, and they asked to review their judgments and revise them as appropriate. The exercise ends once consensus is reached, or it is determined that further rounds will no longer reduce the variance. The researcher can use the second round to present participants with outliers from the first round and their corresponding reasons, affording participants the full opportunity to consider all options (Murry and Hammons 1995).

**Questionnaire Instructions and Consent**

In a previous case-study, we evaluated the implementation of LPS® on a real international mega-project for the delivery of two major milestones. The findings of that case-study will be shared with you in the Delphi survey to validate its outcomes in terms of the importance and ranking of integration challenges causing integration issues among mega-project segments.

The questionnaire is based on the Delphi Technique, as described above. In total, the process will include two rounds of questions. However, there might be a need for a third round. Each round is expected to take approximately 30 minutes to complete.

**INSTRUCTIONS**

Please review carefully the scales used for each question

Please rate each item on the scale provided based on your own opinion

Kindly, explain, defend, and justify your answers in the designated space for each question.

In part II, you may add any missing causes to integration challenges.

You are an expert! Please answer all questions based on your own informed opinion!

**PARTICIPATION**

Without any negative consequences or penalties whatsoever, you are free to decline to participate or not answer any question that you do not feel comfortable answering. Furthermore, you have the right to withdraw at any time before the closure of the survey process.

**BENEFITS**

There is no compensation for participating in this research study.
You will receive no direct benefits from participating in this research study. However, you may benefit indirectly from the insights shared by other experts and by the findings of the whole exercise. A summary of the research findings, conclusions, and recommendations will be shared with you in due course.

**RISKS**

There are no foreseeable risks envisaged due to your participation in this study neither on you nor on your organization other than those encountered in day-to-day life.

**CONFIDENTIALITY**

Responses are anonymous and not binding. No personal information or names will be disclosed. The information you provide will be used for academic purposes related to the study only. Aggregated data will be reported in an article which is expected to be published in a reputable scientific journal, be part of the final thesis of this research, and may be part of a public presentation.

The research study you are participating in may be reviewed for quality assurance to make sure that the required laws and guidelines are followed. If chosen, (a) representative(s) of the Human Research Ethics Program (HREP) may access study-related data and/or consent materials as part of the review. All information accessed by the HREP will be upheld to the same level of confidentiality that has been stated by the research team.

**CONTACT INFORMATION**

If you have any questions or you need additional information about the study or your level of involvement, please do not hesitate to contact us. If you feel you have not been treated according to the descriptions in this form, or that your rights as a participant in research have not been honoured during the course of this study, or you have any questions about your rights as a research participant, concerns, or complaints that you wish to address to someone other than the researchers, you may contact a staff member at the Research Oversight and Compliance Office - Human Research Ethics Program, at the University of Toronto, at +1 (416) 946-3273 or ethics.review@utoronto.ca.

**CONSENT**

If you are willing to participate, please complete the attached questionnaire of round one by January 30, 2017. We respectfully appreciate your cooperation to sign the below the designated section of the “Consent Form” and send it to us at your earliest convenience. In the unfortunate circumstances of not being able to participate, please inform us accordingly. Please select your choice below. You may keep a copy of this “Letter of Invitation” and “Consent Form” for your records. Checking the “Agree” box indicates that:

- You read and understand the above information
- You voluntarily agreed to participate

☐ Agree  ☐ Disagree

**Comments (if any):**

Signature:_____________________________     Date:________________
Part 1
In this questionnaire, the following terminology is used:

**Subproject:** It is assumed that mega-projects are subdivided into subprojects to facilitate their management. These subprojects tend to be treated independently but are essential parts of the whole project.

**PPC:** is percent plan complete

**Integration:** means interface of production planning and site operations across subprojects.

Please evaluate the degree to which you believe that the following factors are causes of integration challenges that restrict the use of Last Planner® System (LPS®) in international mega-projects.

<table>
<thead>
<tr>
<th>Integration Challenges of LPS® in international mega-projects</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Integrating multiple LPS® Plans of subprojects of a mega-project:</strong> At a mega scale, it is very challenging to integrate multiple LPS® plans of subprojects. Furthermore, providing the required level of integration among clustered subprojects is the biggest integration challenge of LPS® implementation in mega-projects.</td>
<td></td>
</tr>
<tr>
<td><strong>Poor communication between independent LPS® subproject teams of a mega-project:</strong> It is generally accepted that LPS® performs well in knowledge transfer and information sharing within a subproject. However, communication between subprojects maybe challenging in the complexity of a mega-project environment.</td>
<td></td>
</tr>
<tr>
<td><strong>Massive efforts in developing make-ready and weekly work plans due to the mega scope of the project:</strong> The number of activities in a mega-project is massive. Capturing them in make-ready and weekly work plans is an immense undertaking with respect to time and team effort.</td>
<td></td>
</tr>
<tr>
<td><strong>Moving resources between independent subprojects of a mega-project:</strong> With highly independent delinked subprojects under dedicated site management teams, it is very challenging to share resources on a daily basis in the midst of fast-track operations in the subprojects.</td>
<td></td>
</tr>
<tr>
<td><strong>Interface and alignment of trades within and across subprojects:</strong> The alignment of trades is challenging as the performance of subcontractors can vary greatly in different segments of a mega-project.</td>
<td></td>
</tr>
<tr>
<td>Long weekly LPS® meetings and participation of busy site personnel of a mega-project: <strong>Bringing site personnel (subcontractors and site engineers) to regularly attend the weekly meetings is difficult due to their busy schedules. LPS® meetings tended to be long and exhausting.</strong></td>
<td></td>
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<tr>
<td><strong>Need for Intensive LPS® training:</strong> LPS® implementation in a mega-project requires a massive training program by a highly qualified facilitator much more than training needs in a standard size project. Lean Construction Institute has the patent of LPS® and applied a restricted use of its consultancy services to ensure high standards and quality. However, finding the right LPS® consultant at a reasonable cost is a major obstacle.</td>
<td></td>
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<tr>
<td><strong>Perception of micromanagement:</strong> Some advocates consider that LPS® may lead sometimes to intense micromanagement, which is challenging in mega-project environment.</td>
<td></td>
</tr>
<tr>
<td><strong>Absence of an overall PPC as a single performance indicator for all subprojects of a mega-project:</strong> Given that a mega-project is comprised of multiple subprojects requiring aggregated production control, it was necessary to break down the different, widely spread areas into clusters, each responsible for reporting individual percent plan complete (PPC). With multiple LPS® plans for each subproject, there is no single indicator on project performance like overall project completion percentage generated in traditional practice. In the reality of a mega-project comprising multiple subprojects, there will be multiple PPCs. Some subprojects may perform well with good PPC rates and manageable integration challenges; while others may suffer unmet commitments, delays, and major integration issues. Because each subproject has different denominators of resources, scope, complexity, and challenges, it is not possible to average PPCs from subprojects to generate overall project PPC. In the absence of a single indicator of project progress, it would difficult to determine if the mega-project is on track or not. It is observed that reporting PPC in the weekly work plans are not aggregated in the upper layers of LPS® to the first level of master scheduling.</td>
<td></td>
</tr>
<tr>
<td><strong>Binary nature of PPC calculations where no partial achievement is consider does not fit in mega-projects:</strong> The binary nature of PPC calculations (delivered or not delivered) where no partial achievement is measured does not fit well in a mega scale.</td>
<td></td>
</tr>
<tr>
<td><strong>Absence of rigorous software to develop and update the detailed make-ready plans of the subprojects of a mega-project:</strong> Developing and updating the make-ready plan without the support of sophisticated software is very difficult due to the massive number of activities in a mega-project.</td>
<td></td>
</tr>
</tbody>
</table>
**Measurement of PPC does not recognize complexity factors of subprojects in a mega-project:** A cursory view results in all subprojects displaying the same level of complexity, but the reality is that some subprojects may be more challenging than others. For example, drawings are not normally studied thoroughly during the LPS® process to identify any differences in levels, pipe bends, etc., which are compounding the complexity of the construction activities with possible clashes. A simpler approach is followed by questioning the timeframe and resources for each trade, e.g., what would be the time and resources necessary to lay and backfill the potable water pipe from chamber 10 to chamber 11. This approach likely to miss some of the major difficulties of this activity, like the construction of thrust blocks which requires engineering and concreting works.

**No categorization of the degree of activity criticality of subprojects’ tasks in a mega-project:** Unlike the distinction of critical activities in traditional approach, all tasks in LPS® are treated in equal manner despite the variability in complexity and criticality of site operations in mega-projects.
Part 2
Is this list of contributing integration challenges of LPS® in international mega-projects complete?

☐ Yes  ☐ No

Please use the space below to add any other challenges you believe are missing from the above list.
Part 3

Kindly add to the table below any additional integration challenges of LPS® in international mega-projects you might have considered in your answer of Part 2.

To what degree could the use of LPS® on mega-projects be improved if each problem was resolved? Please rate each factor:

<table>
<thead>
<tr>
<th>Integration Challenges of LPS® in international mega-projects</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrating multiple LPS® Plans of subprojects of a mega-project</td>
<td>0= not at all</td>
</tr>
<tr>
<td>Poor communication between independent LPS® subproject teams of a mega-project</td>
<td>1=minor improvement</td>
</tr>
<tr>
<td>Massive efforts in developing make-ready and weekly work plans due to the mega scope of the project</td>
<td>2=moderate improvement</td>
</tr>
<tr>
<td>Moving resources between independent subprojects of a mega-project</td>
<td>3=good improvement</td>
</tr>
<tr>
<td>Interface and alignment of trades within and across subprojects</td>
<td>4=great improvement</td>
</tr>
<tr>
<td>Long weekly LPS® meetings and participation of busy site personnel of a mega-project</td>
<td></td>
</tr>
<tr>
<td>Need for Intensive LPS® training</td>
<td></td>
</tr>
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</table>
Appendix F – Delphi Study (Round II)

Invitation Letter

Subject: Process Invitation to Participate in a Research Validation Process “Round II”

Dear Sir,

Thank you for participating in Round I of our ongoing research titled “Integration Challenges of Production Planning and Control in International Mega-Projects: A Framework.” As you know, this study represents one research component of a Ph.D. dissertation in Department of Civil Engineering at the University of Toronto.

Your responses and information collected in this study through Round II of Delphi method (a structured questionnaire) will be treated confidentially and reported in aggregate form only. In Round II, you are given the opportunity to compare your responses from Round I and the modes of the responses from all of the other participants. Please use the designated fields to confirm your responses from Round I or change them. If your final response is higher or lower by more than one rating levels from the mode of other participants’ responses, please provide explanations. In this way, we may better understand your response and gain insights to your expertise. In Parts 1-1 and 2-1 of this round, we ask you to rate the new factors that were newly identified in Round I. **Upon completing the analysis of the second round, there might be a need for a third round to achieve consensus among participants.**

As with Round I, participation in this research is completely voluntary. However, we hope you will find the engagement in this research interesting enough that you will consider the time well spent. Your continued participation will be a valuable addition to our research and findings which could lead to greater benefits by improving the performance of international mega-projects. There are no right or wrong answers. What is important is your opinion.

This research is being conducted by the undersigned researchers independently without funding from any organization. Additional details about this study, your participation, and your rights are provided in the attached Consent Form.

If you are willing to continue your important participation, please complete the attached Round II questionnaire and sign the Consent Form by **February 16, 2017.** For your convenience, the questionnaire is provided to you in a PDF and MS Word format.

Regards,

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Associate Professor  
University of Toronto  
Department of Civil Engineering  
Phone : (416) 9463505  
E-mail : brenda.mccabe@utoronto.ca
Research Methodology: “Modified Delphi Technique”

The Delphi technique is used in obtaining judgment information where statistical methods are not possible or practical due to a lack of data, or when qualitative input from people is required. The Delphi technique is a tool to obtain relevant intuitive insights from practitioners and subsequently use their inputs systematically in combined experts’ opinions (Pill 1971). Delphi’s early applications were primarily focused on forecasting efforts in the defense field. However, over the decades, Delphi has been widely used in many different domains and industries since its first use including framework development. It provides the platform to check the validity of the cross-disciplinary concepts in various fields such as social, psychological, ethical, managerial, cultural, anthropological, etc. (Linstone and Turoff 1975).

In a Delphi-based study, participants usually go through an iterative multistage communication process designed to aggregate group opinions and arrive at an overall consensus (McKenna 1994; Hasson et al. 2000). The experts go through two or more rounds, answering structured questionnaires anonymously in each round. Two rounds are designed for this research as detailed below.

Round I (30 min) “Completed”: This begins with a structured questionnaire (Murry and Hammons 1995; Hsu and Sandford 2007) where participants are asked to edit, rank, and comment upon the ideas embodied in the questionnaire. The researcher will take the responses from round one and calculate summary statistics for each question (Murry and Hammons 1995).

Round II (30 min): Participants are provided with the comments from the first round along with the summary statistics, and they asked to review their judgments and revise them as appropriate. The exercise ends once consensus is reached, or it is determined that further rounds will no longer reduce the variance. The researcher can use the second round to present participants with outliers from the first round and their corresponding reasons, affording participants the full opportunity to consider all options (Murry and Hammons 1995).

INSTRUCTIONS
In Parts 1-1 and 2-1 of this round, we ask you to rate the new factors that were identified by participants in Round I.

In Parts 1-2 and 2-2, please compare your response with the mode for scale. Confirm your response from Round 1 OR change your response.
If you change your response or if your response is falling ±1 from the mode, kindly, explain, defend, and justify your answers in the space at the end of each part of the survey.
You are an expert! Please answer all questions based on your own informed opinion!

PARTICIPATION
Without any negative consequences or penalties whatsoever, you are free to decline to participate or not answer any question that you do not feel comfortable answering. Furthermore, you have the right to withdraw at any time before the closure of the survey process.

BENEFITS
There is no compensation for participating in this research study.
You will receive no direct benefits from participating in this research study. However, you may benefit indirectly from the insights shared by other experts and by the findings of the whole exercise.
A summary of the research findings, conclusions, and recommendations will be shared with you in due course.

**RISKS**
There are no foreseeable risks envisaged due to your participation in this study neither on you nor on your organization other than those encountered in day-to-day life.

**CONFIDENTIALITY**
Responses are anonymous and not binding. No personal information or names will be disclosed. The information you provide will be used for academic purposes related to the study only. Aggregated data will be reported in an article which is expected to be published in a reputable scientific journal, be part of the final thesis of this research, and may be part of a public presentation. The research study you are participating in may be reviewed for quality assurance to make sure that the required laws and guidelines are followed. If chosen, (a) representative(s) of the Human Research Ethics Program (HREP) may access study-related data and/or consent materials as part of the review. All information accessed by the HREP will be upheld to the same level of confidentiality that has been stated by the research team.

**CONTACT INFORMATION**
If you have any questions or you need additional information about the study or your level of involvement, please do not hesitate to contact us. If you feel you have not been treated according to the descriptions in this form, or that your rights as a participant in research have not been honoured during the course of this study, or you have any questions about your rights as a research participant, concerns, or complaints that you wish to address to someone other than the researchers, you may contact a staff member at the Research Oversight and Compliance Office - Human Research Ethics Program, at the University of Toronto, at +1 (416) 946-3273 or ethics.review@utoronto.ca .

**CONSENT**
If you are willing to participate in Round II, please complete and return the attached questionnaire no later than February 16, 2017. We respectfully appreciate your cooperation by signing below and returning it to us with the survey. In the unfortunate circumstances of not being able to participate, please inform us accordingly.

Checking the “Agree” box indicates that:

- You read and understand the above information
- You voluntarily agreed to participate

☐ Agree ☐ Disagree

Signature: ___________________________ Date: ____________________
Part 1-1

Name: ________________________

In this questionnaire, the following terminology is used:

**Subproject:** It is assumed that mega-projects are subdivided into subprojects to facilitate their management. These subprojects tend to be treated independently but are essential parts of the whole project.

**PPC:** is percent plan complete

**Integration:** means integration of production planning and site operations among subprojects.

Please evaluate the degree to which you believe that the following factors identified by other participants in Round I are causes of coordination challenges that restrict the use of Last Planner® System (LPS®) in international mega-projects.

<table>
<thead>
<tr>
<th>Integration Challenges of LPS® in international mega-projects, as identified by other participants in Round I</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>The use of LPS® in mega-projects requires additional Organizational Change Management (OCM) that deals with the human aspects to facilitate change and reduce associated resistance. Many of the OCM components are already covered in different integration challenges identified earlier by the researchers in Round I, such as, communication, training, and key stakeholders’ involvement and engagement. Nevertheless, other OCM elements may also impose major integration challenges to the use of LPS® in international mega-projects. These include the scientific stakeholders’ analysis to detect and manage resistance, organizational structural design, readiness assessment, marketing, expectations management, and stakeholders’ support especially if they are coming from different international backgrounds. No doubt that the contribution of all stakeholders is important for production planning and control. However, engagement of stakeholders varies with their interest, degree of influence, and project phase. Buy in and benefits’ realization of stakeholders of a mega-project and accepting the involvement in LPS® implementation are challenging. To summarize, OCM of stakeholders’ resistance (particularly governmental authorities, operator, and contractors/subcontractors) can also be a major integration challenge to the use of LPS® in international mega-projects.</td>
<td></td>
</tr>
<tr>
<td>Lack of LPS® process know-how, understanding, and building LPS® competency. The process is often misapplied and then LPS® is accused of under-delivering.</td>
<td></td>
</tr>
<tr>
<td>Developing a training program and a clear governance plan which are well understood by all stakeholders of a mega-project is key challenge.</td>
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<tr>
<td>Absence of leaders (champions), in subprojects of a mega-project, who are change agents convinced with the benefits of LPS® and can influence others.</td>
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<tr>
<td><strong>Sustaining the level of effort by all stakeholders.</strong> Lack of KPI to monitor attendance and reward scheme to sustain engagement.</td>
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<tr>
<td><strong>Sharing the priority list of each subprojects needs.</strong></td>
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</tr>
<tr>
<td><strong>Unforeseen risks</strong> that may delay the pre-requisites of the weekly work plans.</td>
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</tr>
<tr>
<td><strong>LPS®</strong> rely heavily on partnership with the contractors of a mega-project. <strong>Any commercial disputes</strong> will impact the contractor and/or subcontractor(s) cooperation. The results will be more challenges to the owner to enforce the LPS® implementation since it requires constant updates to run site operations.</td>
<td></td>
</tr>
<tr>
<td><strong>Linking LPS® with the contractual terms</strong> in regards to the Extension of Time (EOT) entitlement, progress monitoring, and producing s-curve with cash-flow.</td>
<td></td>
</tr>
<tr>
<td><strong>Absence of commercial incentive</strong> to collaborate on making commitments</td>
<td></td>
</tr>
<tr>
<td><strong>Fixing incomplete design</strong> during construction to ensure design integration of various subprojects and building an agile approach among subprojects to capture operational requirements and end-user (operator) needs which may had been disregarded at design stage.</td>
<td></td>
</tr>
<tr>
<td><strong>Integration</strong> and implementation of <strong>design changes</strong>. Any design modification in one subproject may impact the adjacent subprojects</td>
<td></td>
</tr>
<tr>
<td><strong>Commitment of Design and Construction Team</strong> to work together</td>
<td></td>
</tr>
<tr>
<td><strong>Integration for testing and commissioning</strong> activities must be very well defined and <strong>integrated</strong> between subprojects in order to ensure proper tie-in interface and avoid any gaps or duplications.</td>
<td></td>
</tr>
<tr>
<td><strong>Scope changes</strong> by the owner at different stages of the mega-project lifecycle.</td>
<td></td>
</tr>
<tr>
<td><strong>Integration challenges related to the procurement strategy</strong> of the owner. The flexibility of the LPS® to changes throughout the relatively long development duration of mega-projects where the changes are introduced by internal and external factors (i.e. financial crisis).</td>
<td></td>
</tr>
<tr>
<td><strong>Lack of daily monitoring</strong> at site to track the delayed activities and update the delays on the LPS® plans.</td>
<td></td>
</tr>
<tr>
<td><strong>Incompatibility and connection with existing schedule software program.</strong> Relationship of the critical path of the project and how to deal with.</td>
<td></td>
</tr>
</tbody>
</table>
Part 1-2

Please confirm or change your evaluation of the degree to which you believe that the following factors are causes of coordination challenges that restrict the use of Last Planner® System (LPS®) in international mega-projects. Your responses from Round I and the modes of all other participants are provided for your consideration. If your response is higher or lower by one rating level from the mode of other participants’ responses, please provide explanations.

<table>
<thead>
<tr>
<th>Integration Challenges of LPS® in international mega-projects</th>
<th>Your Rating from Round I</th>
<th>Mode Rating of Other Experts Round I</th>
<th>Confirm Rating Round II</th>
<th>Change Rating Round II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrating multiple LPS® Plans of subprojects of a mega-project: At a mega scale, it is very challenging to integrate multiple LPS® plans of subprojects. Furthermore, providing the required level of integration among clustered subprojects is the biggest integration challenge of LPS® implementation in mega-projects.</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor communication between independent LPS® subproject teams of a mega-project: It is generally accepted that LPS® performs well in knowledge transfer and information sharing within a subproject. However, communication between subprojects maybe challenging in the complexity of a mega-project environment.</td>
<td>3</td>
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<tr>
<td>Massive efforts in developing make-ready and weekly work plans due to the mega scope of the project: The number of activities in a mega-project is massive. Capturing them in make-ready and weekly work plans is an immense undertaking with respect to time and team effort.</td>
<td>3</td>
<td></td>
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<tr>
<td>Moving resources between independent subprojects of a mega-project: With highly independent delinked subprojects under dedicated site management teams, it is very challenging to share resources on a daily basis in the midst of fast-track operations in the subprojects.</td>
<td>2</td>
<td></td>
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<tr>
<td>Interface and alignment of trades within and across subprojects: The alignment of trades is challenging as the performance of subcontractors can vary greatly in different segments of a mega-project.</td>
<td>3</td>
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</tbody>
</table>
### Integration Challenges of LPS® in international mega-projects

<table>
<thead>
<tr>
<th>Your Rating from Round I</th>
<th>Mode Rating of Other Experts Round I</th>
<th>Confirm Rating Round II</th>
<th>Change Rating Round II</th>
</tr>
</thead>
</table>

#### Long weekly LPS® meetings and participation of busy site personnel of a mega-project:
Bringing site personnel (subcontractors and site engineers) to regularly attend the weekly meetings is difficult due to their busy schedules. LPS® meetings tended to be long and exhausting.

#### Need for Intensive LPS® training:
LPS® implementation in a mega-project requires a massive training program by a highly qualified facilitator much more than training needs in a standard size project. Lean Construction Institute has the patent of LPS® and applied a restricted use of its consultancy services to ensure high standards and quality. However, finding the right LPS® consultant at a reasonable cost is a major obstacle.

#### Perception of micromanagement:
Some advocates consider that LPS® may lead sometimes to intense micromanagement, which is challenging in mega-project environment.

#### Absence of an overall PPC as a single performance indicator for all subprojects of a mega-project:
Given that a mega-project is comprised of multiple subprojects requiring aggregated production control, it was necessary to break down the different, widely spread areas into clusters, each responsible for reporting individual percent plan complete (PPC). With multiple LPS® plans for each subproject, there is no single indicator on project performance like overall project completion percentage generated in traditional practice. In the reality of a mega-project comprising multiple subprojects, there will be multiple PPCs. Some subprojects may perform well with good PPC rates and manageable integration challenges; while others may suffer unmet commitments, delays, and major integration issues. Because each subproject has different denominators of resources, scope, complexity, and challenges, it is not possible to average PPCs from subprojects to generate overall project PPC. In the absence of a single indicator of project progress, it would difficult to determine if the mega-project is on track or not. It is observed that reporting PPC in the weekly work plans are not aggregated in the upper layers of LPS® to the first level of master scheduling.
<table>
<thead>
<tr>
<th>Integration Challenges of LPS® in international mega-projects</th>
<th>Your Rating from Round I</th>
<th>Mode Rating of Other Experts Round I</th>
<th>Confirm Rating Round II</th>
<th>Change Rating Round II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Binary nature of PPC calculations where no partial achievement is consider does not fit in mega-projects:</strong> The binary nature of PPC calculations (delivered or not delivered) where no partial achievement is measured does not fit well in a mega scale.</td>
<td>2</td>
<td></td>
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<tr>
<td><strong>Absence of rigorous software to develop and update the detailed make-ready plans of the subprojects of a mega-project:</strong> Developing and updating the make-ready plan without the support of sophisticated software is very difficult due to the massive number of activities in a mega-project.</td>
<td>3</td>
<td></td>
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<tr>
<td><strong>Measurement of PPC does not recognize complexity factors of subprojects in a mega-project:</strong> A cursory view results in all subprojects displaying the same level of complexity, but the reality is that some subprojects may be more challenging than others. For example, drawings are not normally studied thoroughly during the LPS® process to identify any differences in levels, pipe bends, etc., which are compounding the complexity of the construction activities with possible clashes. A simpler approach is followed by questioning the timeframe and resources for each trade, e.g., what would be the time and resources necessary to lay and backfill the potable water pipe from chamber 10 to chamber 11. This approach likely to miss some of the major difficulties of this activity, like the construction of thrust blocks which requires engineering and concreting works.</td>
<td>2</td>
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<tr>
<td><strong>No categorization of the degree of activity criticality of subprojects’ tasks in a mega-project:</strong> Unlike the distinction of critical activities in traditional approach, all tasks in LPS® are treated in equal manner despite the variability in complexity and criticality of site operations in mega-projects.</td>
<td>3</td>
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</table>

**Explanations /Justifications**
Part 2-1

To what degree could the use of LPS® on mega-projects be improved if each new challenge below identified by other participants in Round I was resolved? Please rate each challenge:

<table>
<thead>
<tr>
<th>Integration Challenges of LPS® in international mega-projects, as identified by other participants in Round I</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>The use of LPS® in mega-projects requires additional Organizational Change Management (OCM) that deals with the human aspects to facilitate change and reduce associated resistance. Many of the OCM components are already covered in different integration challenges identified earlier by the researchers in Round I, such as, communication, training, and key stakeholders’ involvement and engagement. Nevertheless, other OCM elements may also impose major integration challenges to the use of LPS® in international mega-projects. These include the scientific stakeholders’ analysis to detect and manage resistance, organizational structural design, readiness assessment, marketing, expectations management, and stakeholders’ support especially if they are coming from different international backgrounds. No doubt that the contribution of all stakeholders is important for production planning and control. However, engagement of stakeholders varies with their interest, degree of influence, and project phase. Buy in and benefits’ realization of stakeholders of a mega-project and accepting the involvement in LPS® implementation are challenging. To summarize, OCM of stakeholders’ resistance (particularly governmental authorities, operator, and contractors/subcontractors) can also be a major integration challenge to the use of LPS® in international mega-projects.</td>
<td></td>
</tr>
<tr>
<td>Lack of LPS® process know-how, understanding, and building LPS® competency. The process is often misapplied and then LPS® is accused of under-delivering.</td>
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<tr>
<td>Developing a training program and a clear governance plan which are well understood by all stakeholders of a mega-project is key challenge.</td>
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<tr>
<td>Absence of leaders (champions), in subprojects of a mega-project, who are change agents convinced with the benefits of LPS® and can influence others.</td>
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<tr>
<td>Sustaining the level of effort by all stakeholders. Lack of KPI to monitor attendance and reward scheme to sustain engagement.</td>
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<tr>
<td>Sharing the priority list of each subprojects needs.</td>
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<tr>
<td>Unforeseen risks that may delay the pre-requisites of the weekly work plans.</td>
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</tr>
<tr>
<td>Integration Challenges of LPS® in international mega-projects, as identified by other participants in Round 1</td>
<td>Rating</td>
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<tr>
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</tr>
<tr>
<td>LPS® rely heavily on partnership with the contractors of a mega-project. Any commercial disputes will impact the contractor and/or subcontractor(s) cooperation. The results will be more challenges to the owner to enforce the LPS® implementation since it requires constant updates to run site operations.</td>
<td></td>
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<tr>
<td>Linking LPS® with the contractual terms in regards to the Extension of Time (EOT) entitlement, progress monitoring, and producing s-curve with cash-flow.</td>
<td></td>
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<tr>
<td>Absence of commercial incentive to collaborate on making commitments</td>
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<tr>
<td>Fixing incomplete design during construction to ensure design integration of various subprojects and building an agile approach among subprojects to capture operational requirements and end-user (operator) needs which may have been disregarded at design stage.</td>
<td></td>
</tr>
<tr>
<td>Integration and implementation of design changes. Any design modification in one subproject may impact the adjacent subprojects</td>
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<tr>
<td>Commitment of Design and Construction Team to work together</td>
<td></td>
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<tr>
<td>Integration for testing and commissioning activities must be very well defined and integrated between subprojects in order to ensure proper tie-in interface and avoid any gaps or duplications.</td>
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<tr>
<td>Scope changes by the owner at different stages of the mega-project lifecycle.</td>
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<tr>
<td>Integration challenges related to the procurement strategy of the owner. The flexibility of the LPS® to changes throughout the relatively long development duration of mega-projects where the changes are introduced by internal and external factors (i.e. financial crisis).</td>
<td></td>
</tr>
<tr>
<td>Lack of daily monitoring at site to track the delayed activities and update the delays on the LPS® plans.</td>
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<tr>
<td>Incompatibility and connection with existing schedule software program. Relationship of the critical path of the project and how to deal with.</td>
<td></td>
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</tbody>
</table>
Part 2-2

Please confirm or change your previous assessment of the degree to which the use of LPS® on mega-projects could be improved if each challenge was resolved? Your responses from Round I and the modes of responses of all other participants for each challenge are provided for your consideration. If your response is higher or lower by one rating level from the other participants’ responses, please provide explanations.

<table>
<thead>
<tr>
<th>Integration Challenges of LPS® in international mega-projects</th>
<th>Your Rating from Round I</th>
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<tbody>
<tr>
<td>Integrating multiple LPS® Plans of subprojects of a mega-project</td>
<td>3</td>
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<tr>
<td>Poor communication between independent LPS® subproject teams of a mega-project</td>
<td>4</td>
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<tr>
<td>Massive efforts in developing make-ready and weekly work plans due to the mega scope of the project</td>
<td>2</td>
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<tr>
<td>Moving resources between independent subprojects of a mega-project</td>
<td>3</td>
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</tr>
<tr>
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<td>4</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Need for Intensive LPS® training</td>
<td>2</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Perception of micromanagement</td>
<td>2</td>
<td></td>
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<tr>
<td>Absence of an overall PPC as a single performance indicator for all subprojects of a mega-project</td>
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<td>Absence of a rigorous software to develop and update the detailed make-ready plans of the subprojects of a mega-project</td>
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<td>Measurement of PPC does not recognize complexity factors of subprojects in a mega-project</td>
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</tbody>
</table>

Comments/Justifications
Appendix G – Comments of Delphi Participants

Expert No. 3

Comments/Justifications of Part 2-2
2) Increased to 4 due to high importance of communication.
3) Reduced to 3 because it can be managed if leadership is willing to implement LPS
12) Increased to 3 due to complexity factors influence the Rate of progress

Expert No. 4

Explanations/Justifications of Part 1 –2
5) rating change to 2 as performance of subcontractors will differ and accordingly will complicate the integration process.
7) Training is a core requirement and the lack of local expertise in this area. Definitely impact the successful implementation of LPS. However, rating is change assuming external trainers will be made available.
9) I agree that an overall PPC is required. First rating was provided with the assumption that other tools/means are being used to assess the overall PPC.

Comments/Justifications of Part 2-2
6) Reducing the weekly LPS or finding another mean to achieve the same will greatly improve use of LPS.
9) rating changed as the overall PPC is critical for the overall team perception and appreciation at their collective achievement.

Expert No. 6

Explanations/Justifications of Part 1 –2
4) Moving resources could be challenge especially when subprojects are carried out by different subcontractors. Driving this understanding on a daily basis could be a major challenge in my opinion.
7) Finding the right LPS Consultant is a challenge especially when mega projects are carried in geographies where LPS is now well known like developing world China, Vietnam, Laos, Indonesia, and Middle East as well.
8) Binary nature of PPC calculations can remain challenge as a # of tasks may have been partially done and starts may be moderately affected by this consideration.

Expert No. 8

Explanations/Justifications of Part 1 –2
5) Previous rating incorrect. The alignment of trades between subproject is a moderate challenge that requires careful planning.

Expert No. 11

Explanations/Justifications of Part 1 –2
7) Having reviewed this again, same training is required to understand the steps to implement LPS, although intensive training of a highly qualified facilitator isn’t necessary.

Comments/Justifications of Part 2-2
5) Previously misinterpreted the question. Having reread it would be a good improvement.
12) it would be a good improvement if LPS and the PPC could show complexity factors. Currently a high PPC doesn’t guarantee important work or complex work is completed as all items get the same weightage.
Expert No. 13

Explanations/Justifications of Part 1-2
1) This is a fundamental challenge. A mega project can be viewed as a program and the subprojects are components within the big program. These components are interrelated by nature and coordinating their plans is a critical factor for the success of the overall program.
9) This is a fundamental challenge because key stakeholders and especially owner requires to see a bottom-line performance indicator and a single consolidated measure of all subprojects.
10) When no partial achievements are measured and reported, an inaccurate picture is given about the real actual progress of the subproject. For example, if you can only claim a progress for a task only when it is completed, you are not giving the true picture that you have spent a significantly large amount of efforts and money on it if it is a large task. Hence, partial achievement is necessary to give the closest accurate picture of real performance.
11) This is one of the biggest challenges of LPS because if there is a suitable complex software in the market, we will see more use of LPS in mega-projects. With the absence of this software, it will be more difficult to apply LPS in mega projects.

Comments/Justifications of Part 2-2
6) Due to its nature, LPS will require long weekly meetings. They may be shortened after achieving better learning curve, but they will remain relatively long because they are planning events that need time. Hence, limited improvement can be introduced here.
9) If we are able to produce a single consolidated KPI, many stakeholders will have clear visibility of the true accurate performance of the mega project and they can take informed decision. Hence, they will be more satisfied especially the customer.
10) Producing more accurate performance picture that truly reflects reality can enhance confidence of all stakeholders in the generated performance reports, become more satisfied, and can take appropriate informed decisions based on true accurate facts of performance.

Expert No. 14

Explanations/Justifications of Part 2-2
3) The effective preparation of weekly work plans is leading to a good improvement.
6) Misjudgment of rating. The resolving of this big obstacle for the contractor and stakeholders will be resulted in a good improvement.

Expert No. 15

Explanations/Justifications of Part 1-2
4) In highly independent delinked subprojects under dedicated site management teams it is almost impossible to share resources on daily basis. Thus I considered this is major degree.
10) PPC not reflected partial achievement could give different signal from actual one if they are much aggregated.
11) Because it needs intense micromanagement and much more resources and efforts for LPS, it is very challenge to develop and update the make ready plan without sophisticated software.
13) Because all task in LPS are treated as critical activities, Contractor could not distribute resources efficiently to the more critical works wherein it may increase cost.

Comments/Justifications of Part 2-2
2) Should it is proven that benefit is bigger in every aspects compare to the efforts input, efforts will be followed for use of LPS.
6) Should it is proven that benefit is bigger in every aspects compare to the efforts input, efforts will be followed for use of LPS.
12) This factor is same challenge to other progress management system as well.
Expert No. 17

Explanations/Justifications of Part 1 -2
8) I can see how it seems micro management, it creates responsibility and accountability which is challenging to people.
11) If a process is developed using sticky notes and not software it creates a better environment for team support, team building collaboration. I agree that developing a software which sits in the background would be a good tool to have; I don’t believe it would make a vast difference if no software.

Comments/Justifications of Part 2-2
6) the meetings should not be long timed as in Lean manufacturing. Talking about the problem items not everything. (Clear Time Agenda)
11) Software would not improve to a vast level – it is about all taking an active part – Visual management to see what is happening and where things are, we do this now without software.
12/13) An activity is an activity – complexity should be taken into account when activity duration measured and planned.

Expert No. 19

Explanations/Justifications of Part 1 -2
8) Sometimes the micromanagement and the deep searching for the root causes is exposing confidential issues which leads usually to bad impressions and losing trust.

Need for intensive LPS training: the good understanding is required for the correct implementation.

Perception of micromanagement:
The very deep search for the root causes leads to exposing some confidential issues which leads as well to bad impressions ruined the trust.

Expert No. 20

Explanations/Justifications of Part 1 -2
7) Based on my personal experience with LPS, training did not really took much of time which also simple and not intensive, I believe LPS is somehow self-training while practicing the method.

Comments/Justifications of Part 2-2
3) This is an important component of LPS, accordingly if the solution is found to save the massive efforts spent on developing the make ready and weekly program plan, this effort can be allocated for another integration challenge which I believe is a great improvement.

Expert No. 21

Explanations/Justifications of Part 1 -2
4) Subprojects are implemented by different contractors. There is no contractual framework for moving resources among subprojects. From Client and consultants point of view, it is possible.
6) It’s a culture of management to use LPS. If the will and commitment is there, stakeholders will get used to it, and meetings will become shorter with time.
7) Due to magnitude of activities and complexity, very good training and software is must. Otherwise results will be wrong and misleading.
8) Construction Professionals have high ego. They won’t accept being under daily inspection.

Comments/Justifications of Part 2-2
3) In the absence of properly sophisticated software and process to derive weekly work plans, arranging a subproject plan is a challenge on its own. Therefore, it is even more complex at the mega level. I believe that fixing this area will greatly improve the appetite and efficiency of implementing LPS.

7) The current practice at mega level. Collating, compiling and analyzing data to reach at meaningful results is key, therefore intensive training is required to replace current with standardized approach/process.

8) Discussing with every team member his/her work activities in presence of all other team members at the level of the hour and day and for every activity and resources might be conceived as kind of micromanagement hence source of professional’s resistance and avoidance. This is directly related to human behaviour specially in construction. If this can be fixed by any alternative means, great improvement and buy in are expected.

10) Since the same binary system is used in calculating the PPC (the indicator) at the subproject and the mega level, it will not make a big difference to account for the partial achievements.

**Expert No. 22**

**Explanations/Justifications of Part 1 -2**

6) Severe sure, it’s impacting all the plan if one site personnel didn’t attend.

10) Some activities require less weightages than the others.

11) I see integrating Primavera is so useful.

**Expert No. 23**

**Explanations/Justifications of Part 1 -2**

3) What is the alternative? How else will the production work be controlled? This myth of massive effort is debunked once the team is properly divided into sub-teams managing clusters of work. This is a defeatist and victim mentality in my opinion.

9) I am not convinced this is a major issue. This wouldn’t be the issue making a team shy away from implementing the LPS. I am not convinced an averaging scheme would not work to reflect an overall project PPC from the different

10) This is a problem in application of the LPS and not an issue in the concept of PPC being binary. In setting up my assignment, I commit to completing the ‘size’ I declared to the team. The key is on whether I completed work that allows others to begin work. If they can’t then the task is not done. If executor sizes their task incorrectly, that is their problem.

11) Software is available – BIM 360; Touch Plan; and V-Planner.

12) Why do I need to recognize the complexity if the work needing to be completed is identified and in fact completed (WWP conversations will uncover these detailed interactions, and PPC is just a measure). What would complexity add to the PPC that would help a team want to adopt or not adopt the system?

13) This is why we have ‘workable backlog.’ This is a nuanced and advanced aspect of the LPS that may not be clear to all users.

The team, in their rich conversations during the Make Ready Planning and the Weekly Work Planning process focus on the critical path activities anyway. The team knows!!! And this can be gleaned easily from the nature of the phase the project is in, or by referring to the Master/Phase schedule.

**Comments/Justifications of Part 2-2**

11) Software is not absent. Maybe making teams more aware of it will help.
Appendix H – Invitation Letter for Nominal Group Technique (NGT) Study

Invitation Letter

Subject: Invitation to Participate in a Research Validation Process

Dear Sir,

It’s our honour to invite you to participate in a research validation process engaging 5-7 experts, as a part of our ongoing research titled “Integration Challenges of Production Planning and Control in International Mega-Projects: A Framework.” As a practitioner possesses a recent experience of LPS® implementation in mega-projects, you are an ideal candidate to participate in this interview to share with us your valuable opinions and suggestions. The study is a part of thesis for Doctorate of Philosophy in Civil Engineering, at the University of Toronto. Your responses and the information collected through the Nominal Group Technique (NGT, a structured interview method) will be treated confidentially and reported in aggregated form only. NGT is a structured interview process involving multiple numbers of selected experts in one room.

Your participation will be a valuable addition to our research and findings which could lead to greater public benefits to improve the performance of international mega-projects. Participation in this research is completely voluntary. However, we hope that you will find the engagement in this research interesting enough that you will consider the time well spent. There are no right or wrong answers. What is important is your opinion.

This research is being conducted by the undersigned researchers independently without any funding from any organization. More details about this study, your participation, and your rights are provided in the attached Consent Form.

Regards,

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Department of Civil Engineering
35 St George Street; Room 134
Toronto, ON M5S 1A4
Phone: (647) 800-4664
E-mail: Luai.Sabek@mail.utoronto.ca

Brenda McCabe, PhD, PEng, FCSCE
Associate Professor
University of Toronto
Department of Civil Engineering
35 St George Street
Toronto, ON M5S 1A4
Phone: (416) 9463505
E-mail: brenda.mccabe@utoronto.ca
Research Objective:
Since its inception, Last Planner® System (LPS®) has been implemented successfully in many projects. Nevertheless, LPS® application in mega-projects is very limited due to major integration challenges, scale, and the complexity issues of international mega-projects. Applying LPS® as a new production planning and controlling paradigm to the construction of international mega-projects would be very challenging due to the difficulty of ensuring a high level of integration in complex operations of international mega-projects. Furthermore, available lean production planning and control solutions cannot be applied directly to address integration challenges in international mega-projects. The suitability of LPS® in international mega-projects has not been validated and requires different treatment to overcome these challenges. Therefore, a framework is necessary to address integration challenges of implementing the LPS® as a production planning and control system in international mega-projects.

The results of this study will contribute to developing a framework addressing integration challenges of implementing the LPS® as a production planning and control system in international mega-projects.

The purpose of this part of the research is to evaluate the validity of the proposed framework in addressing integration challenges of implementing the LPS® in international mega-projects. Evaluating validity and practical relevance of the framework will be primarily based on the following criteria:

- Correctness
- Usefulness
- Effectiveness

Research Methodology: “The Nominal Group Technique (NGT)”
The Nominal Group Technique (NGT) was developed by Andre L. Delbecq and Andrew H. Van de Ven in 1968 (Delbecq et al. 1975). It is a highly structured meeting process, done by prescribed steps, to reach consensus on a solution to a problem, an idea, or prioritizing interests for the researcher. The number of participants in an NGT group has ranged in the literature from two to fourteen.

**Step I (25 min):** The participants are placed in the same room, but do not speak to each other in the first step. Participants are given questions to answer and are allotted a specified amount of time to record their answers on a paper.

**Step II (25 min):** The facilitator asks each participant, in turn, to share one idea from their list. During this second step of NGT again there is no discussion amongst the participants.

**Step III (60 min):** The third step is a clarification phase in which the ideas are discussed and can be altered, excluded, supported, modified, and further clarified. The discussion is structured so that each idea is addressed, one by one.
**Step IV (10 min):** The facilitator then asks the participants to rank the ideas according to their own respective preference. This step is recorded on a paper and is done anonymously. Finally, the decision of the group is the calculated rank of the ideas from the individual votes.

**Questionnaire Instructions and Consent:**
The interview is based on the Nominal Group Technique (NGT) described above and it is expected to take around two hours. The interview is scheduled at the Boardroom at Executive Lounge (22nd Floor), Hilton Doha, on Monday (January 23, 2017 at 5:00 pm). Valet parking and refreshments will be provided complementary.

**INSTRUCTIONS**
Please review carefully the questions asked during the interview before answering them. Kindly, explain, defend, and justify your answers in the designated space for each question. In Step IV of the interview, please rank each idea on the scale provided based on your opinion. Full respect to the structured process of this study and to the opinion of other participating expert fellows to be maintained.

You are an expert! Please answer that all questions are based on your own informed opinion!

**PARTICIPATION**
Without any negative consequences or penalties whatsoever, you are totally free to decline to participate or not to answer any question that you do not feel comfortable answering. You may choose to withdraw from this study at any time before the closure of Step IV. However, if you choose to withdraw after the closure of Step IV, your inputs cannot be isolated from the data collected, due to the nature of this study.

A summary of the research findings, conclusions, and recommendations will be shared with you in due course.

**BENEFITS**
There is no compensation for participating in this research study. You will receive no direct benefits from participating in this research study.

**RISKS**
There are no foreseeable risks envisaged due to your participation in this study neither on you nor on your organization other than those encountered in day-to-day life during external meetings with individuals from external organizations in a public venue.

**CONFIDENTIALITY**
Final responses are anonymous and not binding. No personal information or names will be disclosed.

The information you provide will be used for academic purposes related to the study only. Aggregated data will be reported in an article which is expected to be published in a reputable journal, be part of the final thesis of this research, and may be part of a public presentation. The research study you are participating in may be reviewed for quality assurance to make sure that the required laws and guidelines are followed. If chosen, (a) representative(s) of the Human
Research Ethics Program (HREP) may access study-related data and/or consent materials as part of the review. All information accessed by the HREP will be upheld to the same level of confidentiality that has been stated by the research team.

**CONTACT INFORMATION**

If you have any questions or you need additional information about the study or your level of involvement, please do not hesitate to contact us.

If you feel you have not been treated according to the descriptions in this form, or that your rights as a participant in research have not been honoured during the course of this study, or you have any questions about your rights as a research participant, concerns, or complaints that you wish to address to someone other than the researchers, you may contact a staff member at the Research Oversight and Compliance Office - Human Research Ethics Program, at the University of Toronto, at +1 (416) 946-3273 or ethics.review@utoronto.ca.

**CONSENT**

If you are willing to participate, please confirm your acceptance at your earliest. In the unfortunate circumstances of not being able to attend after confirmation, a reasonable advance notice is appreciated to avoid wasting the time of other invited experts.

We respectfully appreciate your cooperation to sign the below the designated section of the “Consent Form” and send it to us at your earliest convenience.

Please select your choice below. You may keep a copy of this “Letter of Invitation” and “Consent Form” for your records.

Checking the “Agree” box indicates that:

- You read and understand the above information
- You voluntarily agreed to participate

☐ Agree  ☐ Disagree

I am willing to participate in further surveys to reconfirm the validity of the proposed framework.

☐ Agree  ☐ Disagree

**Comments (if any):**

Signature:_____________________________             Date:________________


NGT Step I:

1) Do you suggest any modifications to the proposed framework

2) Anything Missing?

NGT Step IV:

To what degree could the following changes / suggestions improve the proposed framework in addressing the integration challenges of implementing LPS in international mega-projects?

0= not at all  1=minor  2=moderate  3=good  4=great

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<th>Idea</th>
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Appendix I – Invitation Letter for Focus Group Technique

Invitation Letter

Subject: Invitation to Participate in a Research Validation Process – Focus Group

Dear Sir,

It’s our honour to invite you to participate in a research validation process based on Focus Group technique (a semi-structured group interview process involving multiple numbers of selected experts in one room) engaging about 10 experts, as a part of our ongoing research titled “integration Challenges of Production Planning and Control in International Mega-Projects: A Framework.” This study represents the final research component as part of a Ph.D. dissertation in Department of Civil Engineering at the University of Toronto.

As a practitioner possesses a recent experience of LPS® implementation in mega-projects, you are an ideal candidate to participate in this interview to evaluate the correctness, usefulness, and effectiveness of our proposed framework in addressing integration challenges of LPS® in international mega-projects.

Your responses and the information will be treated confidentially and reported in aggregated form only. Your participation will be a valuable addition to our research and findings which could lead to greater public benefits to improve the performance of international mega-projects. Participation in this research is completely voluntary. However, we hope that you will find the engagement in this research interesting enough that you will consider the time well spent. There are no right or wrong answers. What is important is your opinion.

This research is being conducted by the undersigned researchers independently without any funding from any organization. More details about this study, your participation, and your rights are provided in the attached consent form.

Regards,

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Phone : (647) 800-4664
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Brenda McCabe, PhD, PEng, FCSCE
Associate Professor
University of Toronto
Department of Civil Engineering
35 St George Street
Toronto, ON M5S 1A4
Phone : (416) 9463505
E-mail : brenda.mccabe@utoronto.ca
Research Objective:
Since its inception, Last Planner® System (LPS®) has been implemented successfully in many projects. Nevertheless, LPS® application in mega-projects is very limited due to major integration challenges, scale, and the complexity issues of international mega-projects. Applying LPS® as a new production planning and controlling paradigm to the construction of international mega-projects would be very challenging due to the difficulty of ensuring a high level of integration in complex operations of international mega-projects. Furthermore, available lean production planning and control solutions cannot be applied directly to address coordination integration challenges in international mega-projects. The suitability of LPS® in international mega-projects has not been validated and requires different treatment to overcome these challenges. Therefore, a framework is necessary to address integration challenges of implementing the LPS® as a production planning and control system in international mega-projects.

The results of this study will contribute to developing a framework addressing integration challenges of implementing the LPS® as a production planning and control system in international mega-projects. The purpose of this part of the research is to evaluate the validity of the proposed framework after going through multiple improvement and development iterations. Evaluating the validity and practical relevance of the framework in addressing integration challenges of implementing the LPS® in international mega-projects will be primarily based on the following criteria:

- Correctness
- Usefulness
- Effectiveness

Research Methodology: The Focus Group Technique
Focus group can be defined as: “a carefully planned discussion designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment” (Krueger 1988; Sink 1991). They are essentially group interviews except that unlike individual interviews, focus group relies on the interaction of the group. The group discussion is guided by a skilled interviewer who provides the topics. The qualitative data provided explicitly by the group interaction is the defining feature of focus groups.

At the end of the discussions, participants will be asked to anonymously vote on the validity of the framework based on the described evaluation criteria.

Instructions and Consent:
The interview is based on the Focus Group Technique described above and it is expected to take around two hours. The interview is scheduled on Wednesday, March 8, 2017, at 4:00 pm, at Lusail Plaza Meeting Room G42 in Lusail Hub Office CP07 ZONE B.

INSTRUCTIONS
Please review carefully the questions asked during the interview before answering them. Full respect to the opinion of other participating expert fellows to be maintained. You are an expert! Please answer that all questions are based on your own informed opinion!
PARTICIPATION
Without any negative consequences or penalties whatsoever, you are totally free to decline to participate or not to answer any question that you do not feel comfortable answering. You may choose to withdraw from this study at any time before the closure of the Focus Group session. However, if you choose to withdraw afterwards, your inputs cannot be isolated from the data collected, due to the nature of this study.

A summary of the research findings, conclusions, and recommendations will be shared with you in due course.

BENEFITS
There is no compensation for participating in this research study.
You will receive no direct benefits from participating in this research study.

RISKS
There are no foreseeable risks envisaged due to your participation in this study neither on you nor on your organization other than those encountered in day-to-day life during external meetings with individuals from external organizations in a public venue.

CONFIDENTIALITY
Final responses are anonymous and not binding. No personal information or names will be disclosed.

The information you provide will be used for academic purposes related to the study only. Aggregated data will be reported in an article which is expected to be published in a reputable journal, be part of the final thesis of this research, and may be part of a public presentation. The research study you are participating in may be reviewed for quality assurance to make sure that the required laws and guidelines are followed. If chosen, (a) representative(s) of the Human Research Ethics Program (HREP) may access study-related data and/or consent materials as part of the review. All information accessed by the HREP will be upheld to the same level of confidentiality that has been stated by the research team.

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CONSENT
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We respectfully appreciate your cooperation to sign the below the designated section of the “Consent Form” and send it to us at your earliest convenience. Please select your choice below. You may keep a copy of this “Letter of Invitation” and “Consent Form” for your records.

Checking the “Agree” box indicates that:

- You read and understand the above information
- You voluntarily agreed to participate

☐ Agree  ☐ Disagree

Comments (if any):

Signature:_________________________ Date:_________________
**Focus Group:**

Kindly, evaluate the practical relevance of the proposed framework in addressing coordination challenges of LPS® in international mega-projects based the correctness, usefulness, and effectiveness using the scale provided below.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Attributes</th>
<th>Rating</th>
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<td><strong>Correctness</strong></td>
<td><strong>Diagnosis:</strong> Accuracy of identified processes and coordination challenges</td>
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<td><strong>Treatment:</strong> Suitability of suggested components in the framework in practice</td>
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<td><strong>Execution:</strong> Conformity of proposed processes, tools, and techniques in addressing coordination challenges of LPS® in international mega-projects</td>
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<td><strong>Usefulness</strong></td>
<td><strong>Applicability:</strong> Appropriateness of the proposed framework in international mega-projects</td>
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<td><strong>Practicality:</strong> Ease of use of the proposed framework in terms of simplicity and clarity</td>
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<td><strong>Flexibility:</strong> Adaptability of the proposed framework for improvements and customization in practice</td>
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<tr>
<td><strong>Effectiveness</strong></td>
<td><strong>Efficacy:</strong> Ability of the proposed framework to achieve the intended results</td>
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<td><strong>Measurability:</strong> Ability of the implementation to be quantified</td>
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<td><strong>Acceptability:</strong> Ability of the proposed framework to inspire trust in its value to practice</td>
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Do you have any suggestions or comments on the proposed framework?

☐ No  ☐ Yes, please explain