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# Coordination Challenges of Production Planning & Control in International Mega-Projects: A Case Study

Luai M. El-Sabek<sup>1</sup>, P.E., P.Eng., PMP and Brenda Y. McCabe<sup>2</sup>, Ph.D., P.Eng

### Abstract

- Questions: 1) How do make ready and weekly work planning features of LPS<sup>®</sup> perform at the scale of international mega-projects? 2) How do coordination challenges of international mega-projects impact LPS<sup>®</sup> features? 3) What are the implications to the LPS<sup>®</sup> application on international mega-projects?
- **Purpose:** The purpose of this case study is to evaluate LPS<sup>®</sup> adaptability in addressing production coordination challenges of international mega-projects' environment.
- **Research Method:** An exploratory approach on an international construction mega-project case study. The project team was trained on LPS<sup>®</sup> implementation 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 8 weeks for milestone I and 15 weeks for milestone II.
- **Findings:** 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). This was then communicated to the entire team at specially held coordination meetings to better understand the progress of the mega-project. Using traditional critical path planning method, key milestones did not appear to be achievable. Implementing LPS<sup>®</sup> helped to pull the project back from the brink of failure and put it on-track towards successful delivery of milestones.
- Limitations: The implementation of LPS<sup>®</sup> was conducted after 70% of the project was completed. The project team did not have any previous LPS<sup>®</sup> experience before implementation. The case study was limited to two milestone stages of the subject infrastructure project. LPS<sup>®</sup> was limited to make-ready and week work planning. PPC was limited to top critical activities defined by the project team.
- **Implications:** This research triggers the need for a new framework for LPS<sup>®</sup> to deal with coordination challenges of international mega-projects. Structuring work for sub-projects that form a mega-project can be treated the same way as is developed for a separate project. The production control aspect of LPS<sup>®</sup> is where coordination requires a different treatment. The complexity associated with international mega-projects appears to increase in a non-linear fashion and it is not scalable.
- Value for Practitioners: From the lessons learned and findings documented in this case study, readers will gain an appreciation for the challenges of international mega-projects and how LPS<sup>®</sup> functions at a complex scale.

<sup>&</sup>lt;sup>2</sup> Professor, Department of Civil Engineering, University of Toronto, Toronto, ON, Canada M5S 1A4. E-mail: Brenda.Mccabe@utoronto.ca



<sup>&</sup>lt;sup>1</sup> PhD Candidate, Department of Civil Engineering, University of Toronto, Toronto, ON, Canada M5S 1A4. Email: Luai.Sabek@mail.utoronto.ca

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Paper type: A case study

### Introduction

The inspiration to initiate this case study originated and was further motivated by the challenges faced in planning and controlling the execution of international mega construction projects (El-Sabek and McCabe 2017). The case study is based on a mega-project worth approximately US\$ 410 million in which the first author was involved as a Senior Project Manager.

Lusail City, located just north of Doha, Qatar, is an immense new urban center planned, designed, and constructed in its entirety in just 13 years. It will cover about 35 km<sup>2</sup> development including 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 giga-project was divided into 105 contracts, of which 8 are mega-projects - the project examined herein, Construction Package 5B (CP5B), is one of them.

Serving about one third of Lusail City, the site of CP5B is spread over an area of approximately 3 km by 3 km. 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 neighboring major district developers, 45 buildings, 10 construction packages, 8 light rail transit (LRT) stations, 17 km of LRT 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 MVA electrical grid stations.

Although the project was designed by a highly reputable international engineering firm, the project experienced significant changes due to design errors and omissions, clashes, and a lack of design coordination at tie in points. This left the construction team with unnecessary layers of complexity in managing coordination challenges on the site along with exponentially increased risks as the project progressed. The duration of the project was initially 912 days, and was eventually extended by an additional 991 days, thereby doubling the time to complete. Unfortunately, completions of mega-projects on time and budget are rare (Flyvbjerg 2007). This reinforces the need for a reform in mega project policy and planning to deal with the extraordinary challenges inherent in mega-projects (Flyvbjerg 2007).

The purpose of this paper is to examine some of the systemic and situational causes of schedule overruns on international mega-projects, and to describe how the Last Planner® System (LPS®) was used on CP5B to bring critical project elements back from the brink of failure. During this effort, LPS® was evaluated to identify its strengths and limitations as it applies to mega-projects. As there are very limited publications addressing LPS® in international mega-project, the authors felt obligated to share their experience and lessons learned to advance LPS® practice at such a complex scale. Furthermore, this paper contributes to the body of knowledge by providing details of how LPS® was used and performed in a mega-project, adding a greater value to the readers. It identifies future work needed to adapt LPS® in international mega-projects.



The first part of this paper covers the literature of mega-projects, LPS<sup>®</sup>, and case study methodologies. The second part presents the case study details, data, results, findings, analysis, and discussion to evaluate LPS<sup>®</sup> compatibility to tackle coordination challenges of international mega-projects. Finally, the conclusion and recommendations for future research is presented.

### Background and Literature Review

Mega-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). The authors agree that mega-projects have powerful economic, social, and symbolic roles in societies. However, sky high construction costs should not be the only contributing factor for identifying mega-projects. Besides mega monetary value, the level of complexity in design and construction is a critical qualifying determinant. These are complicated endeavors involving construction coordination, methodology, technology, schedule, finance, governance, resources, organizational behavior, environment, and workflow challenges (Brockmann and Girmscheid 2007; El-Sabek and McCabe 2017).

Mega-projects in an international environment compound increased level of complexity dimensions. An international project is defined as a project undertaken in a region that lacks the technical expertise in engineering, construction, and management to successfully complete the project with local resources. Hence, the owner has the advantage to deploy qualified 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 processing permits for standard local projects. Nevertheless, the undertaking of an international mega-project in the region with its sheer size, complex scope, technical aspects, and an international project team not familiar with local regulations and culture can lead to breakdowns and failures (El-Sabek and McCabe 2017).

Cost overruns, time delays, and benefit shortfalls have been a persistent issue facing mega-projects. It is estimated that nine out of ten mega-projects face cost overruns (Flyvbjerg 2014). Mega-projects include a huge network of engaged stakeholders with conflicting interests, resulting in many participants concentrating on their own benefits. Moreover, stakeholders in international mega-projects have different management systems, diverse organizational behavior, 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 site coordination challenges.

Traditional construction management is based on the transformation concept, converting inputs to outputs (Koskela 1999). The baseline schedule is typically created using the critical path method (CPM) and sequenced according to a lengthy list of



unpredictable but forecasted construction processes, variable productivity, and unknown unknowns (Abdelhamid et al. 2008).

Common practice in international mega-projects in Qatar, and most Middle East countries, is to submit the fully detailed baseline schedule, always in CPM, within 14-28 days of the project commencement date. Such a schedule must be detailed to very short durations of execution activities. For example, the following text is extracted from Appendix F of the CP5B contract document: "Article 4.2.1.1: Contract Administrative Procedures / Detailed Construction Work Schedule: No activity shall have duration exceeding fifteen (15) days except for procurement activities." Undoubtedly, detailing the schedule in the first few weeks of a three year mega-project to a production level with no input from site and trades' teams relies heavily on assumptions and forecasting of all elements of the schedule. This is one of the underlining causes of planning failures.

The resulting baseline schedule does not address how activities will be executed nor does it consider maximizing value or minimizing waste, principles inherent in lean construction (Koskela et al. 2002). It was observed many decades ago that CPM was developed as a management tool for higher planning levels, but it has been morphed and overextended to the production planning level (Peer 1974). As a result, these plans have limited use as tools to manage site operations (Abdelhamid 2004).

The traditional approach to planning assumes that the construction team is capable of handling site production variations and that all the required resources are available. The site operations are driven by a top-down push system, whereby lookahead and weekly plans are filtered from the detailed baseline schedule. This model ignores the actual status of the work at site. Previously developed, often outdated plans are forced on the construction team for execution. This results in an imbalanced system leading to execution failures with unmet commitments and delays (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 what is assigned to the system, the result is also undesired waste due to surplus workers and/or equipment, which negatively affects the overall project performance.

Time, cost, resources, planning, and coordination all naturally loom large in megaprojects. Ensuring execution with sufficient coordination among the fragmented megaproject sections creates a huge challenge due to the large scale of construction operations. Crews in different segments of mega-projects could often be executing out-ofsequence activities with little to no coordination between them. Consequently, no significant gains to the project schedule can be realized and the outcome is more likely to be delays, cost overruns, and waste on one end, with discontented owners on the other.

Our ability to increase the success rate of mega-projects has not improved; the rate of mega-project failures 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 \$2.56 billion in 1992 was dwarfed by the final cost of \$14.8 billion in 2007 (Greiman 2013). Although the Big Dig involved many complex processes and workflow variations, *Integrated Project Management* methods, where all participants are sharing 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 coordination and project performance. However, the project did not adopt continuous



improvement initiatives learned from previous breakdowns, leading to an accumulation of errors and ultimately affecting project delivery (Greiman 2013).

Another important mega-project was Europe's "The Chunnel", a 51.5 km double rail tunnel that crossed the English Channel and connected England and France. Unfortunately, it also suffered schedule and cost overruns. The estimated duration and cost were 5 years and \$5.5 billion which increased to 6 years and \$14.9 billion respectively (Anbari et al. 2005). Forty-six contractors participated in the construction and were selected through competitive bids. 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 of the project during the execution. For example, to maintain the temperature of the tunnel, the design team was required to add a water cooled air conditioning system in the tunnel while construction on the project proceeded (Kirkland 1995). Another major design change was widening passenger doors from 600 mm to 700 mm, which caused another nine month delay (Anbari et al. 2005). These scope changes in the design and construction caused a massive cost surge and escalated the number of project participants, and consequently, the coordination challenges among them.

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

Although not exhaustive of the less-than-successful mega-project cases available, these three examples emphasize our general lack of ability to complete mega-projects according to plan. This planning failure is primarily due to unsatisfied prerequisites, poor coordination, and insufficient planning. All are common delay factors in mega-projects. In other words, traditional construction management methods are not meeting the needs of the people responsible for implementing the plan. LPS® has shown promise in resolving many of the issues experienced on mega-projects.

### Last Planner® System

In 1994, LPS<sup>®</sup> was introduced as a new production planning and control method to address the shortcomings of CPM and its inability to build consensus amongst project stakeholders and support the site's day to day project execution efforts. LPS<sup>®</sup> 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 prior to initiation of any activity. This results in reducing variation by better predicting production workflows (Ballard 2000).

Unlike the traditional construction management CPM-based approach described earlier, LPS<sup>®</sup> is a philosophy that embraces pull planning to manage the project by incorporating flow and value generation theories (Abdelhamid et al. 2008; Koskela 1992). Resources are pulled in the system depending on the status of work. LPS<sup>®</sup> pulls works back from project milestones and works are executed at the last responsible moments (Ballard 2000). In a bottom-up grassroots approach, LPS<sup>®</sup> integrates the inputs of the "last



planners", i.e. the field engineers and trades, 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. LPS<sup>®</sup> is structured in four phases (Ballard 2000):

Master Schedule (Needs to be done): Phase Schedule (Should be done):

Make Ready Plan, MRP (Can be done): Weekly Work Plan, WWP (Will be done):

- Major milestones are defined
- Detailed plan of one phase of master schedule showing dependencies between activities
- Rolling plan from 3 to 6 weeks
- Commitments are made and measured

Master and phase schedules are typically developed using CPM - a function for which CPM was developed (Peer 1974). Make ready and weekly work plans, however, need a more proactive and collaborative method. The traditional practice of developing work plans to run site production too detailed and too early requires a major shift in construction industry. The practical perspective in LPS<sup>®</sup> is limiting the high level planning to the master and phase scheduling steps, leaving the deep details to make ready and weekly work planning steps. This is a critical aspect in LPS<sup>®</sup> transformation journey.

Figure I provides the detailed framework behind LPS<sup>®</sup> as a pull production planning and control system designed to assist site teams to run construction operations in a continuous improvement cycle.



Figure 1: Framework of LPS<sup>®</sup> (Ballard and Tommelein 2016) "Reprinted/Adapted with permission of the Lean Construction Journal (LCJ), a publication of the LCJ."



Mega-projects involve many complex processes and some of the major challenges at the Big Dig, The Chunnel, and Denver International Airport projects involved underestimation of those complexities. Complexities could be related to 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 LPS<sup>®</sup>, 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 to 6 weeks are analyzed so that the path is clear and can be executed without any unnecessary hurdles (Ballard 2000).

The percent plan complete (PPC) is based on the actual activities completed for that week over the total activities planned. This new metric is a core principle of the LPS<sup>®</sup> (Ballard & Howell 1994). PPC is calculated using the following equation:



A repeated PPC score of 100% sometimes indicates that the team is either under committing or being very conservative. It's the responsibility of the LPS® facilitator to detect such an unfavorable behavior and work with the team to prevent it. From the experience gained in this study, a typical PPC score in the complexity of international mega-projects is between 85-95% as the construction crew should be motivated to "push the envelope" by increasing productivity. If PPC falls below 80%, an investigation must be conducted to identify 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 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:

Number of Tasks Anticipated in MRP for a week and confirmed in WWP TA (%) = x 100 Total Number of Tasks in WWP for the same week

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:

Number of Tasks Anticipated in MRP for a week and confirmed in WWP TMR (%) = x 100 Total Number of Anticipated Tasks in Make Ready Plan for the same week



**Frequency of Plan Failures:** Uncompleted assignments of 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.

### LPS® Implementation in Mega-projects

LPS<sup>®</sup> has been successfully implemented in many projects. However, its use in megaprojects has been very limited. Three case studies were found in the literature: 1) the \$151 million Temecula Valley Hospital (Do et al. 2015), 2) \$5.5 billion Sutter Health Program (Lichtig 2005), and 3) the \$8.5 billion Terminal 5 of Heathrow Airport (Davies et al. 2009). From these very few examples, no information was found explicitly documenting the details, or confirming the success and the limitations of implementing LPS<sup>®</sup> as a lean production planning and control system in mega-projects. Therefore, in the absence of documented applications, the adaptability of LPS<sup>®</sup> to fully engage in international megaprojects has yet to be explored.

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 works 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 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-assessment and knowledge management, each team recorded the 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 in Heathrow Terminal 5, 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.

## **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 is collected or observed over a certain period of time (Creswell 2003). In conducting a case study research, there is a tendency by researchers to include too many objectives or attempt to answer questions that are too broad. To avoid this, a methodology to conduct case study research was presented as: 1) determining when to use a case study approach; 2) what is to be analyzed; 3) circumscribing the case study, i.e. drawing boundaries; and, finally 4) determining the type of case study to be used (Baxter and Jack 2008).



When a researcher conducts a case study, the method used in defining, exploring, or comparing the phenomenon or a case object mainly depends on the psychology of the researcher. The result is a function of one's perspective, that is to say, the outcome is subjective. In case studies, there are two participants - the researcher and the case object (Baxter and Jack 2008), and the relationship between the researcher and the case object 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 that are used less often include: 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 the problems for which little or no research has been carried out to bring possible insights like familiarity, feasibility, direction for future research, techniques, and formulation of new research questions. Exploratory research typically aids in diagnosing a situation, screening of alternatives, discovering new ideas, and clarifying 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. Its format is flexible. To start research on new or little-researched topics, one should start with exploratory research (Tellis 1997).

The *descriptive approach* describes people, products, and situations. It describes the phenomenon possessed 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 aid the reader in understanding the data distribution. Descriptive statistics are very important in reducing the data to the manageable form (Baxter and Jack 2008).

The *explanatory approach* is conducted for a problem that has not been clearly defined. Explanatory case study research focuses on "why" questions (Tellis 1997). This method is about explaining a phenomenon or a situation. Often there is confusion between explanatory and descriptive case study research. The descriptive approach addresses the behavior itself while the explanatory method addresses why a particular behavior is such (Yin 1993).

Increased coordination challenges of international mega-projects coupled with the super-sized project scope, risk, cost, and schedule provide many and compounding factors to delay or halt construction progress. However, mega-projects have the opportunity to reap the greatest benefit from implementing novel practices, like LPS<sup>®</sup>, that ensure delivery with project objectives and benefits. However, little is known about the adaptability of LPS<sup>®</sup> on an international mega-project scale (El-Sabek and McCabe 2017). For this reason, CP5B as a mega international project was selected as a testing ground for LPS<sup>®</sup> application. This case study is based on an exploratory approach and follows recommended guidelines of Baxter and Jack (2008), which were described earlier. Being one of the CP5B execution team and has access to project information, all data were collected with permission by the first author at the project. Participants were asked to identify the challenges of applying LPS<sup>®</sup> in two evaluation sessions. Given that they were relatively new to the system, this gave them a unique perspective.



# Case Study - CP5B at Lusail City

At 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 in this case study is Infrastructure Construction Package 5B (CP5B). Valued at \$410 million, CP5B is focused on the major roads that will serve as a centerpiece of the Lusail City transportation system, and mainly comprises of:

- Roads: 11,400 m and 15 junctions (J)
- Structural Works: 2 Major Underpasses (UP): 1,018 m and 440 m in length
  - Utility tunnel (cut & cover): 3,200 m
- Utilities: Potable water pipes: 16,583 m
  - Foul sewer pipes: 5,090 m
  - Stormwater pipes: 34,761 m
  - $\circ~$  Irrigation pipes: 17,085 m  $\,$

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

Upon the award of the construction contract on January 15, 2012, the winning bidder, an international general contractor (GC), started mobilizing resources and manpower over a period of six months. The owner allocated six professionals to oversee project progress and monitor the performance of the CP5B consultants and 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 international mega-project was very diverse with personnel from 36 countries around the world.

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. 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.

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 with the GC an unbinding strategy to monitor progress commitments by measuring PPC of enabling works. Only two major construction activities were in progress at the site at that time, namely: 1) the excavation of 1.8 million cubic meters 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 that the GC was required to measure PPC. Over a period of three months, PPC results were extremely poor, falling in the range of 20 to 40 percent, revealing that the GC was achieving only 30% of their 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 factors contributing to the failure to meet their 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 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, it was observed that the real physical progress could not be determined most of the time. This is due to the magnitude of the project and complexity of the software used. Projects of this size and such challenging horizon windows will always have a high degree of unpredictability that no project team can properly and sufficiently consider during the planning stage. Therefore, the baseline schedule failed to consider such unpredictability resulting in complications to the anticipated progress. The project situation became increasingly complex due to coordination challenges driven by delays, cost overruns, and scope changes. The schedule suffered and the project setbacks compounded upon each other, rendering the baseline schedule obsolete as a tool for production planning and control purposes. Hence, the owner demanded a recovery and mitigation program to regenerate 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.

Looming ahead were critical sections of the project, 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 both the owner, as a master developer, and the GC. Under these stressful mandates, demanding conditions, stringent evaluations, and careful consideration, the GC decided to reinstitute LPS® to help them track the key contractual milestones and practically plan site operations. The owner welcomed and supported this idea. The situation provided an excellent opportunity to evaluate the adaptability of LPS® in addressing production coordination challenges in the complex atmosphere of an international mega-project, such as CP5B.

The master baseline schedule was revised five times during the contract period. Table 1 shows the chronology of the revisions of the baseline program and how it evolved to be an outdated monitoring program, rather than being an effective planning tool. With the commencement 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 still ongoing to date, and the project team is striving to close punch list items, nonconformance reports, minor remaining works, and the overall testing and commissioning to handover the project. The project is expected to be completed by March 31, 2017.



	Tal	ole 1: Revisio	ons of Maste	er Baseline Schedule									
	Project Commen	cement Date	January 15, 2012										
	Original Comp	letion Date	July 14, 2014										
	Revision 5 Com	pletion Date	March 31, 2017										
	Original Projec	t Duration	912										
	Revision 5 Proje	ect Duration		1903									
Revision Number	Date of Submission	Date of Approval	Completio n Date	Remarks									
Revision 0	22-Mar-2012	16-Apr-2012	14-Jul-2014	First Baseline submission incorporating original contract parameters.									
Revision 1	11-Jul-2012	4-Sep-2012	14-Jul-2014	Approved with comments. 1 <sup>st</sup> revision of the schedule was submitted 3 months after Rev. 0 approval due to major delays in mobilization									
Revision 2	28-Feb-2013	21-Mar-2013	14-Jul-2014	In 2 <sup>nd</sup> revision, GC trying to recover in response to schedule slippage									
Revision 3 (EOT 1)	10-Jul-2014	5-Aug-2014	31-Dec-2014	Approved with comments. 3 <sup>rd</sup> revision incorporated excusable delay events that resulted in 170 days extension of time (EOT 1)									
-	Start of LPS <sup>®</sup> Case Study: Milestone I (30-Oct-2014) & Milestone II (01-Mar-2015)												
Revision 4 (EOT 2)	15-Jul-2015	15-Dec-2015	25-Mar-2016	Due to lengthy disagreement, completion date of Rev. 3 elapsed by 285 days before Rev. 4 was granted EOT 2 with additional 450 days									
Revision 5 (EOT 3)	7-Aug-2016	17-Jan-2017	31-Mar-2017	5 <sup>th</sup> revision incorporated excusable delay events with an additional 371 days to the Completion Date.									

### LPS<sup>®</sup> Case Study: Milestone I & II

On October 4, 2014, the senior management of the owner and the GC agreed on the importance of finding a solution for the ongoing project delays and to complete contractual milestones I & II on December 31, 2014 and June 30, 2015, respectively. The scope of these milestones is detailed in Table 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.

Given the previous challenging complications witnessed in CP5B, and as incredible as it sounds, the task seemed impossible to many 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, were left with no choice except to deliver the project within the required timeframe. Failure to achieve these milestones would inevitably result in catastrophic consequences and unaffordable damages to all involved organizations, along with public inconvenience.



	Table 2	2: Scope of	fWork					
	Discipline	Unit	Milestone I (Dec. 31, 2014)	Milestone II (Jun. 30, 2015)				
	Road Length	М	6,300	5,100				
	Number of Lanes	No.	8	8				
Roads	Number of Junctions	No.	8	7				
	Highway Traffic Signal & Road Lighting duct	m	5,648	4,918				
	Storm Water Pipelines	m	11,102	3,869				
	Foul Sewer Pipelines	m	4,445	645				
	Potable Water Pipelines	m	11,562	2,011				
	Irrigation Pipelines	m	13,174	2,179				
litilition	Gas Network	m	8,363	2,782				
Utitities	District Cooling Pipes	m	1,831	907				
	Pneumatic Waste Collection	m	204	378				
	Telecommunication Ducts	m	27,664	5,433				
	11 & 66 kV Cabling	m	4,296	9,479				
	Security System Ducts	m	7,238	2,785				

The project team participated in a planning workshop to define the best strategy to deliver these very important 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 vast majority of the team members selected LPS<sup>®</sup> as the tool with the greatest potential to get the project back on track. As such, it was to be tested on the 1<sup>st</sup> 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 to 29, 2014, an intensive professional training program was organized towards official launching of LPS<sup>®</sup> implementation on October 30, 2014 for Milestone I covering a period of 8 weeks; while milestone II continued to follow the traditional planning approach awaiting the evaluation outcomes of LPS<sup>®</sup> in milestone I. Some photos of the LPS<sup>®</sup> training workshops and weekly work planning sessions are provided in Figure 6 of Appendix A.

Because of the magnitude and scale of this international mega-project, the work was divided into smaller more manageable subprojects, where activities could be more easily monitored and controlled. Individually, each subproject had its own resources and ran independent LPS<sup>®</sup> sessions to report 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 was delegated to a section manager who was responsible to complete the works in accordance with the agreed make ready plan.

The site team faced many coordination and integration issues. As reflected in Figure 2, road junctions have a significant number of utility lines under the pavement. To better demonstrate the complex site conditions, photos from site are provided in Figure 7 of Appendix A. The challenge was to sequence the works so as to optimize the clash resolution, ensure high coordination among project segments, keep construction production in full operation, and advance tasks by getting the work done right the first time. Another major factor that made coordination more challenging was driven by 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 chamber



dimensions and reroute all pipelines allocated under the roads to outside of the pavement areas.



Figure 2: A Sample of Design Complexity at Junctions Showing Combined Utilities

The results of LPS<sup>®</sup> workshops were transferred into make ready plans. Senior management of all parties, including the trade subcontractors, endorsed their approval by signing the make-ready plans to demonstrate their firm commitment, coordination, and full collaboration. The trade 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 of the other project stakeholders to commit to an unconventional collaboration agreement outside of their original contractual obligations was indeed a remarkable achievement.

The team agreed to meet weekly to monitor progress, calculate PPC, and document events that may have caused interruptions and delays. During regular LPS<sup>®</sup> weekly work plan meetings, potential delays and significant setbacks were detected. The progress was measured at the selected activity level every week. Factors considered in choosing an activity are weight of a work item, typical durations of activities for a work item, and the degree of ease in determining an accurate progress rate in each activity. During the LPS<sup>®</sup> workshops, key stakeholders defined the characteristics of PPC activities:

- Limited in number, to save time in recording data on a weekly basis
- Measurable that identifies delivery in a "yes" or "no" level, without uncertainty.
- Tangible, representative, informative, and have significant weight or relevance to the overall physical progress

With the extensive knowledge of the site and the experience gained by the stakeholders from the LPS® exercise, activities to monitor the physical progress in each subproject were optimized and mutually agreed. Examples of selected activities are listed



J2 - UP2 (Junction 3)						۷	Vk	1,	P	20	; =	0	%		V	Vk	2,	PI	ъС	0	%	W	k (	3, I	PP	С	0%	, V	Vk	4,	P	PC	0%
Potable Water (2 lanes) Road crossing - 1																																	
				Des De milaites		00	:t-14		Nov-14																								
Location	Activity	Start	Finish	Pre-Requisites Dependencies	Status	Week 1									V	Vee	k 2					W	eek	3			Week 4						
						30	31	1	2	3	4	56	7	Y/N	8	9	10 <sup>·</sup>	11 1	2 13	3 14	Y/N	15 <sup>-</sup>	16 1	7 18	3 19	20	21 Y/	N 22	2 23	24	25 2	6 27	28 Y/N
	Europation	29-Oct-14	12-Nov-14		Planned																												
	EXCAVALION				Actual																												
	Geotextile & Bedding	13-Nov-14	15-Nov-14		Planned																												
					Actual																									$\square$			
2-95 &	Pipe laying	16-Nov-14	17-Nov-14		Planned																												
DCP 3					Actual																												
	Surrounding	10 Nov 14	20-Nov-14		Planned																											Τ	
	backfilling	10-1101-14			Actual																											Τ	
	Dookfilling	21-Nov-14	25-Nov-14		Planned																												
	Dackilling				Actual																											Τ	
<u>Cummanı</u>				Total Weekly Proposed							Total Weekly Proposed							Total Weekly Proposed						Тс	Total Weekly Proposed								
	Summary						Completed weekly						Completed weekly							Completed weekly						Completed weekly							

in the template of a weekly work plan summary in Figure 3 which is variable based on time and location.

Figure 3: Weekly Work Plan Summary Template

The team opted to use Microsoft Excel<sup>®</sup> 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<sup>®</sup> does not require professional planners and a lot of training to generate PPC calculation charts and reports. The use of Excel<sup>®</sup> worksheets was an effective facilitation and communication tool with site crews for the LPS<sup>®</sup> implementation in multiple locations with massive construction / production operations.

Gradually, the LPS<sup>®</sup> workshops facilitated the overall goal of delivering the milestones into a real production plan for site crews to practically perform well coordinated tasks within each segment of the project. However, the design interface and tie in points remained a big challenge for coordination. Unlike the practice and project culture prior to initiation of LPS<sup>®</sup> workshops, it was realized that subcontractors' involvement represented a significant share of the planning effort. To assist in resolving coordination challenges, it was crucial to ensure that they actively participated 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 by the subcontractors in the planning stage. Such a plan often failed.

Although the team had informally used PPC to track progress at the beginning of CP5B, this was the first time for them to implement LPS<sup>®</sup>. Hence, most of them were very conservative when giving commitments, like J2, J2-J3, and JP1-JP2, as shown in Figure 4. Others like J1-GD1 and JP5-UP1, were overconfident by over committing on an assignment they could not accomplish. However, over a period of three to four weeks, all crews began to be more familiar with LPS<sup>®</sup> with more training and explanations during weekly work plan meetings. With increased familiarity with the system, 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, the 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 was more



congested with limited access for equipment, materials, and workers. Photos in Figure 7 of Appendix A provide further evidence of the site conditions. PPC in J1-GD1 was 0% in the fifth week due to a delay in authority inspection approval, which was outside the sphere of control of the project team. Nonetheless, the delay caused the construction production to be paralyzed. The team identified many other contributing factors of the delay and revisited the plan by making necessary adjustments.



Figure 4: Percent Plan Complete Charts for Milestone I

With the success of milestone 1 using the LPS<sup>®</sup>, the owner hosted a big event to celebrate the first achievement of CP5B and to recognize the outstanding team efforts. Some photos of the LPS<sup>®</sup> celebration events are provided in Figure 6 of Appendix A.

Starting on March 1, 2015, the project team continued to use this tool to complete the rest of CP5B road network by milestone II of June 30, 2015 with a second LPS<sup>®</sup> 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, the critical control points consuming the biggest efforts were the road junctions where all utilities are congested in confined areas. Therefore, the team decided to focus the full attention of LPS<sup>®</sup> workshops on the junctions of milestone II. The team, including all subcontractors, focused on a typical junction, identified each utility, numbered them, discussed work sequence among the trades, and developed make-readyplan by identifying pre-requisites, securing directives, and ensuring resource availability. 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 problematic coordination challenges, the trend continued to improve, lifting PPC every week until the successful delivery of the second milestone, as reflected in Figure 5.



		Start wee	Start week			5											
		Week	Neek W1 W		W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
		JP6	100%	100%	90%	89%	56%	40%	52%	62%	89%	89%	76%	56%	60%	76%	89%
		J5	100%	100%	20%	67%	20%	33%	43%	51%	89%	89%	95%	93%	94%	93%	95%
Project	CP5B Road Construction	FH1	80%	86%	100%	22%	30%	62%	81%	97%	78%	78%	79%	78%	80%	91%	95%
Location	Road Completion (June 30, 2015)	FH2	100%	100%	67%	40%	33%	65%	85%	95%	94%	94%	100%	100%	100%	97%	97%
	Percent Planned Complete (PPC)	FH3	100%	100%	75%	75%	25%	50%	65%	78%	75%	75%	100%	100%	100%	100%	100%
		J3	100%	100%	100%	100%	78%	60%	50%	60%	33%	33%	29%	67%	67%	73%	73%
		J4	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	73%	67%	62%	77%	95%



Figure 5: Percent Plan Complete Charts for Milestone II

Out 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 to west and south to north. Such complex design requires very careful construction phasing to prevent access problems to other works inside the complex junctions. The challenging nature of the sequence of works required close coordination between all subcontractors on a daily basis to make adjustments to the activities as necessary in order to prevent delays with 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 the breaking down of equipment and lengthy backfilling operations of deep excavations with massive internal and external coordination issues. Necessary resources were deployed to recover the backlog during the following weeks of the plan. As illustrated in Figure 5, the plan recovered successfully allowing the curb installation and asphalt pavement works to begin on time to coincide with the paving operations at the adjacent segments.

The project team invested a great deal of time keeping track of and measuring weekly progress, identifying root-causes of the problems, and finding appropriate solutions. In the absence of a single metric in LPS® to measure mega-project status like overall progress percentage, the LPS® team communicated PPC status to the entire team at specially held coordination 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.

## Findings, Analysis, & Discussion

As specified in the contract, the detailed project master baseline schedule was developed in electronic CPM format; however, it was found on CP5B 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 enough, 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 LPS® implementation in CP5B was limited to make-ready and weekly work planning levels and the project was about 70% completion status, aggressive milestones were successfully delivered on time without the same frustrations witnessed in the past. A summary of evaluation findings from the LPS® exercise for CP5B are listed below, as observed by the authors and discussed with the project team in two evaluation sessions.

### Things that performed well:

- Developing a detailed sequence of works for each task minimized the waste in production rates by preparing make ready plans and preventing the occurrence of work waiting for workers and workers waiting for work incidents.
- 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 of their subcontractors and potential threats of penalties. This eventually changed as progress improved, benefits realized, and successes were achieved.
- One of the challenges to complete the milestones was managing the activities being carried out by three different 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 existing prior to the implementation of LPS® was closed. The value of trades' contribution was materialized and unexpected events that could cause delays were minimized. For example, one of the key subcontractors executing all wet utilities noted that "before LPS® workshops, we were not given a chance to speak out about our problems and why we are failing." This important testimonial is undoubtedly a sign of the collaboration benefits of LPS®.
- With its great incremental and sustainable value, LPS® allowed for a much more accurate way to monitor progress and develop practical plans to maintain the PPC above 80%.
- LPS® transformed the organizational behavior of the mega-project to a higher tier of excellence. The commitment driven aspect of LPS® proved to be invaluable as it clearly defined the responsibilities for 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.
- 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 LPS® in their future projects.

### Things that needed improvement:

- At a mega scale, it was very challenging to integrate multiple LPS® plans of subprojects. Furthermore, providing the required level of integration among clustered subprojects was the biggest coordination challenge of LPS® implementation in international mega-projects.
- LPS® performed well in knowledge transfer and information sharing within a subproject. However, communication among subprojects was challenging.
- It was noted that reporting PPC on the weekly work plan was not aggregated in the upper layers of LPS® to the first level of master scheduling. There is no single indicator on project performance like overall project completion percentage generated in traditional practice. As CP5B is a mega-project comprising multiple subprojects, there were multiple PPCs. Some subprojects were performing well with good PPC rates and manageable coordination challenges; while others were suffering unmet commitments, delays, and major coordination issues. Because each subproject had different denominators of resources, scope, complexity, and challenges, it was not possible to average PPCs from subprojects to generate overall project PPC. In the absence of a single indicator of project progress, one construction manager said "we could not identify if we are on track or not." However, this comment is applicable strictly to this case study where the team implemented LPS® for the first time with no previous LPS® experience.
- The number of activities in mega-projects is enormous. Capturing them in make-ready and weekly work plans is an immense undertaking with respect to time and planning efforts. Obviously, the project team was not used to such undertakings in a traditional approach.
- The binary nature of PPC calculations (delivered or not delivered) where no partial achievement is measured was faced with a strong resistance from the project team.
- Moving resources between different zones was challenging in the mega scale of the project.
- Developing and updating the make-ready plan without the support of sophisticated software was very difficult due to the enormous number of activities in a mega-project.
- Alignment of trades was challenging as subcontractors performance varied to a great extent in different segments.
- Bringing site personnel (subcontractors and site engineers) to regularly attend the weekly meetings was difficult due to their busy schedules. Meetings tended to be long and exhausting.
- It was found that sometimes LPS® lead to intense micromanagement, which was challenging in mega-project environment.
- Measurement of PPC does not recognize complexity. A cursory view results in all subprojects displaying the same level of complexity, but the reality is that some subprojects were more challenging than others. For example, drawings were not 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 was 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 missed some of the major difficulties of this activity, like the construction of thrust blocks which require engineering and concreting works.

- A planner participating in LPS® critiqued the system saying "in LPS® everything is critical."
- LPS® implementation in a mega-project requires a mammoth training program by a highly qualified facilitator until the organizations build a strong internal capacity. The 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 was a major obstacle.

These findings collectively point to a need for LPS® to expand its standard practices to fit in the context of international mega-projects. With the experience gained in this study, authors believe that LPS® cannot be applied directly on a mega-project unless it is divided to multiple subprojects. Applying production planning and control system on scattered sections belonging to the same mega-project resulted in increased challenges to ensure site coordination during construction among subprojects, neighboring developers, and adjacent construction packages. We do not believe that these findings will be much different if the LPS® was fully implemented from the beginning of CP5B given that the mega scope dictating to split the mega-project to smaller manageable segments is the same. No doubt that because there are no guidelines or available framework for implementing LPS® in international mega-projects, the outputs of this study may be considered critical findings.

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 received a shorter duration of LPS<sup>®</sup> implementation compared to milestone II, it is not possible to simply say that milestone II was less complex than milestone I. There are many factors contributing to the degree of complexity due to the nature of international mega-projects which was explained earlier.

## **Implications & Limitations**

This study contributes to the body of knowledge by providing details of how LPS<sup>®</sup> was used and performed in a mega-project, adding a greater value to the readers. It identifies future work needed to adapt LPS<sup>®</sup> in international mega-projects. Moreover, we shared our experience and lessons learned of implementing LPS<sup>®</sup> in an international mega-project to contribute to the very little literature in this respect and to enhance practice. All practitioners in this field are highly encouraged to join us in this endeavor by documenting their professional practice results and lessons in the body of knowledge.

This study was limited to two milestone stages of CP5B project, due on December 31, 2014 and June 30, 2015. LPS<sup>®</sup> implementation in CP5B was limited to make-ready and weekly work planning levels. Because it is not specified in the contract, LPS<sup>®</sup> implementation could not be enforced from the beginning. When the project team willingly elected to utilize LPS<sup>®</sup>, after careful consideration, the project was about 70% completed. The project team had no previous experience in LPS<sup>®</sup>. PPC measurement was limited to key critical activities determined by the project team. LPS<sup>®</sup> impact on construction cost of CP5B, whether positive or negative, was not part of the scope of work



of this study. Therefore, to draw a conclusion of commercial impacts of LPS<sup>®</sup> implementation, further investigation is required.

# **Conclusions & Recommendations**

LPS<sup>®</sup> was introduced as a tool to assist in ensuring the completion of two critical milestones for the CP5B project. Before the original completion date of CP5B was reached, the GC had submitted its 3<sup>rd</sup> baseline schedule revision and implementation of LPS<sup>®</sup> was just a few months away. With a realistic view to satisfy site production requirements, LPS<sup>®</sup> assisted the CP5B team to bring the program to a substantial completion. The 1<sup>st</sup> milestone was set for completion by December 31, 2014 which consisted of finishing the construction of major roads serving VIP developers. The 2<sup>nd</sup> 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 mega-project team members. Several participants were skeptical at the start of implementation, 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, LPS<sup>®</sup> is a production planning and control philosophy that currently exists to improve predictability and reliability of construction workflows. A critical advantage of LPS<sup>®</sup> is the collaboration of the "last planners" and decision makers at the execution level. It is still undergoing further enhancements and vetting on the mega-project scale as LPS<sup>®</sup> has been implemented on a limited number of international mega-projects. There is no doubt that implementation of LPS<sup>®</sup> in international mega-projects is a serious undertaking due to the difficulty in integrating coordination challenges among scattered subprojects. To make it more adaptable on a mega-project scale, the CP5B team introduced some changes to LPS<sup>®</sup> by splitting the mega-project to subprojects and selected a few critical activities in the weekly work planning to measure and monitor PPCs. However, it was concluded that the production control aspect of LPS<sup>®</sup> is where coordination requires different treatment. Therefore, future research is needed to develop a new framework for LPS<sup>®</sup> to deal with coordination challenges of international mega-projects. Finally, LPS<sup>®</sup> impact on construction cost of mega-projects, whether positive or negative, requires further investigation.

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# **Appendix A - Photos**



Figure 6: LPS® Training Workshops, WWP Sessions, and Celebration Events





7-1:Aerial Photo for road works



7-2: Multiple disciplines in the limited space



7-3: Stormwater installation crossed under and above existing utilities



7-4: District Cooling system installation at the junction crossed underpass and stormwater



7-5: Stormwater system installation nearby underpass crossed under district cooling system



7-6: Potable Water & Irrigation installations crossed under stormwater and foul sewer nearby 220KV cable

#### Figure 7: Site Photos



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