AN INVESTIGATION OF THE IMPLEMENTATION OF LEAN PHILOSOPHY WITHIN A SPECIALTY TRADE

by

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Abstract

Construction projects are dynamic and complex systems; their planning, execution and delivery involve considerable collective effort and coordination on the part of multiple individual stakeholders that come together to form a temporary project organization (TPO) for a project’s duration. In contrast, traditional construction project management practices are static. They often rely on inadequate and early assumptions of a handful of individuals in the TPO that try to predict and plan the execution of the project in great detail in the early stages of a project. To manage uncertainties, contingencies and buffers are introduced into the planning process. This static approach to construction management often results in variability which leads to waste and loss of value.

Innovative tools and approaches such as building information modeling (BIM) and Lean construction have emerged over the years and aim to eliminate waste and inefficiency resulting from current practices in the construction industry. These approaches, however, require significant reconfiguration of the interactions within a TPO, among other things, which introduces significant challenges in their adoption and implementation.

This manuscript presents the findings of a 16 month action-research project undertaken with a specialty trade. The research project aimed to investigate the implementation of lean principles within the organization and the potential impact on a complex, mixed-use project. Several performance metrics, such as planned percent complete (PPC) and degree of change in scheduled tasks, were utilized to measure and assess the reliability and efficiency of the planning efforts on the project. Reliance and dependency of following specialty trades on
upstream trades performance was also analyzed. The findings highlight the challenges a specialty trade faces in shielding their production from upstream uncertainties when they have no control over the tasks assigned to them or the preceding tasks to their work. The planning efforts undertaken by the project team were also compared to guidelines of the Last Planner System to uncover differences in planning approaches. Suggestions for further performance enhancement and evaluation such as more collaborative planning and continuous look-back and learning processes are proposed to bridge the gaps uncovered between traditional and novel approaches to planning.
Preface

A condensed, modified version of the findings presented in this research thesis, particularly the findings in chapter 3, is intended to be submitted for possible future publications.

The observations and interactions described in this document were approved by the Behavioural Research Ethics Board at UBC [H15-02907].

The author is responsible for the majority of data collection and analysis presented in this manuscript with direct supervision and input by Dr. Poirier, the research associate on the research project, and research supervisor Dr. Staub-French.
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<th>Description</th>
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<tbody>
<tr>
<td>AEC</td>
<td>Architecture Engineering Construction</td>
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<tr>
<td>BIM</td>
<td>Building Information Model</td>
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<tr>
<td>CPM</td>
<td>Critical Path Method</td>
</tr>
<tr>
<td>DBB</td>
<td>Design-Bid-Build</td>
</tr>
<tr>
<td>GC</td>
<td>General Contractor</td>
</tr>
<tr>
<td>GMP</td>
<td>Guaranteed Maximum Price</td>
</tr>
<tr>
<td>JIT</td>
<td>Just in Time</td>
</tr>
<tr>
<td>LCI</td>
<td>Lean Construction Institute</td>
</tr>
<tr>
<td>LPS</td>
<td>Last Planner System® of Production</td>
</tr>
<tr>
<td>MEP</td>
<td>Mechanical Electrical Plumbing</td>
</tr>
<tr>
<td>NBIMS</td>
<td>National Building Information Modeling Standard</td>
</tr>
<tr>
<td>PMI</td>
<td>Project Management Institute</td>
</tr>
<tr>
<td>PPC</td>
<td>Percent Plan Complete</td>
</tr>
<tr>
<td>RFI</td>
<td>Request for Information</td>
</tr>
<tr>
<td>SI</td>
<td>Site Instructions or Supplementary Instructions</td>
</tr>
<tr>
<td>TPO</td>
<td>Temporary Project Organization</td>
</tr>
<tr>
<td>WLA</td>
<td>Week Look Ahead (eg. 3WLA= 3 Week Look Ahead)</td>
</tr>
<tr>
<td>WWP</td>
<td>Weekly Work Plan</td>
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My life will never be the same because of you; I leave UBC this time feeling accomplished, motivated and excited for the next chapter and what future has in store.

Thank you all from the bottom of my heart.
Dedications

I dedicate this thesis to those close to my heart; my friends and my family. I thank each and every one of you for challenging me, inspiring me and motivating me to be the person I am today. This journey would not have been possible without all your support, love and guidance.
“We are what we repeatedly do. Excellence, then, is not an act, but a habit.” - Aristotle
Chapter 1

Research Outline

1.1 Introduction

Conventional construction project management is notoriously wasteful and inefficient (Ballard 2000 and Koskela 1992). Projects are often behind schedule and over budget. Many scholars (Koskela and Greg Howell 2002) argue that the underlying theory of project management is obsolete and that there is no explicit theory defined for project management. Traditional project planning and control techniques are static and are often based on limited information and inadequate assumptions (Koskela and Greg Howell 2002). Often the project participants try to predict the details of project execution based on these early assumptions and include contingencies to overcome uncertainties. These contingencies all too often result in waste and reduce potential value to a construction project. Novel practices, such as lean construction, aim to eliminate this waste while maximizing the value generated to the client by continuous and consistent planning and control.

These uncertainties are more pronounced for the specialty trades operating in the construction industry. Specialty trades are responsible for delivering projects in a strict timeline, within budget and meeting quality requirements set by owners. In conventional projects, the specialty trades, especially following trades, such as electrical and mechanical contractors
take on much of the risk of delivering the projects even though they are far removed from
the decision-making process in the project conception and planning.

This thesis presents the results of a year-long study carried out as part of an action-
research project conducted on a major commercial project currently under construction in
downtown Vancouver, Canada. The research focuses on how implementing lean construction
principles impacts specialty trade contractors’ performance in a construction project. In this
document, the planning processes and efforts throughout the research project are evaluated
based on the guidelines and metrics of the Last Planner® system of production. In addition,
the impact of the planning processes on the specialty trade’s ability to shield their production
on site is evaluated. Factors impacting the performance of a specialty trade performing on a
conventional project is identified and a theoretical comparison between the observed efforts
and those of a collaborative lean process is carried out. Finally, limitations of the research
are explored and future works are suggested.

1.2 Research Objective

The objective of this research project is to investigate how adaptation and implementation
of lean construction principles and philosophy can impact the performance of a specialty
trade in a traditional construction project. Through an action-research approach, and close
collaboration with the partner organization, the research team aimed to uncover the benefits,
limitations and barriers to the implementation of lean construction principles on a conven-
tional project in the current state of the construction industry and aim to inform the best
practices for developing and integrating these novel approaches in the partner organizations
practices. To gain a better understanding of the current state of project management on
the case study project and achieve the overarching research objective, the following sub-
objectives were introduced:

- Investigate traditional planning means and methods on a complex commercial project
from an electrical contractor’s perspective to understand how the planning process impacts the specialty trade’s performance

- Understand the challenges, limitations and potential benefits of applying Lean principles and tools from the perspective of an electrical specialty trade in the context of a complex project delivered in a traditional procurement mode

1.3 Research Approach

An action research methodology was utilized due to its cyclical, iterative approach and its interventionist nature within the research setting (Lewin 1946). Rapoport 1970’s, definition of action research is: “action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework”. In a simpler language, action research aims to solve a problem in practice, while contributing to knowledge through a joint collaboration between academia and industry (Susman and Evered 1978). Susman and Evered further define six characteristics for action research:

1. Action research is future oriented, as it is designed to deal with a practical problem of people and aims to create a more desirable future for them.

2. It is collaborative, since unlike the traditional type of research where there is zero interaction between researchers and what is being observed, there is a close collaboration between the researchers and the case that’s being studied.

3. It implies system development by aiming to “build appropriate structures, to build the necessary system and competencies, and to modify the relationship of the systems to its relevant environment” (pg. 589).

4. Action research generates theory grounded in action; theory informs action and action informs theories.
5. It is agnostic in that it recognizes that theories and actions are closely related and are generated through processes.

6. It is situational in that it recognizes that plans and actions are functions of the context in which they take form.

Furthermore, according to Susman and Evered (1978), action research can be regarded as a cyclical process; they have detailed five phases for it as outlined below:

1. Diagnosing: analyzing the current practice and identifying the primary problem initiating the desire for change.

2. Action planning: the process of planning the intervention, establishing the desired outcome and selecting a course of action.

3. Action taking: implementing the planned action.

4. Evaluating: evaluating the actions taken; these steps consist of an evaluation of the outcome to determine whether or not the actions taken were successful, and to consider alternative courses of action to solve the identified problem.

5. Specifying learning: generation of new knowledge through continuous reflection on the process and increased understanding of the situation and the depth of problem.

Action research is an established scientific approach that is becoming increasingly popular in the architecture, engineering and construction (AEC) industry; according to Azhar, Ahmad, and Sein 2010, action research is a “reliable, structured, and rigorous research approach” that is very useful to conduct “applied” research in the construction industry.

In order to address the research objectives, an action-research project was set up with an electrical contractor interested in transitioning into a more lean-oriented practice. Houle Electric is one of the largest electrical contractors in British Columbia, Canada. It was founded in 1944, and provides a wide range of services in industrial, commercial, institutional
and residential sectors. The company is greatly invested in enhancing and evolving their operations and was interested in setting up a partnership with the research team at UBC to study one of their upcoming projects. The focus of the study was to investigate the impact of implementation of lean principles and its impact on their performance and operation in terms of planning and executing their work.

In the current state the organization is extensively invested in prefabrication. They operate and run a fabrication shop where all components and material required for their projects are prefabricated or pre-assembled as needed and are ready to install once they arrive on site. The components are then stored in a warehouse close to project site and shipped when needed. Prefabricated items on this project include:

- Temporary lighting (pre-wired and ready to install)
- Conduits
- Cable trays
- Distribution panels and equipment
- Security panels
- Controls
- Support racks
- Fixtures
- Junction boxes

In addition, Houle Electric implements lean 5S (Sort, Set in order, Shine, Standardize and Sustain)- a visual control and management technique used to maintain order and eliminate waste- in their warehouse facilities and on site. An example of such implementation of 5S approach in maintaining their small material storage on site of the project studied can be viewed in figure 1.1 below.
The project is a major mixed-use development currently under construction in downtown Vancouver, Canada. The new construction will house a casino, two hotels in three towers, commercial retail spaces and restaurants and lounges. The research project was set up in the early stages of the multi-year construction on the project site and was carried out over 16 months studying the planning and execution of the work in different areas and stages of the project. During this time period, the focus of the research was on the planning process and different strategies and planning efforts executed on the project. In addition, as part of the research project, collaborative pull planning and the Last Planner® system execution was studied on the project and implemented to the extent possible. Different visual planning tools and techniques were employed to plan, display and track the work. Moreover, a theoretical
comparison was done to compare the planning efforts on smaller time intervals to that of a lean practice, to identify the gaps between the practices implemented on the project and novel approaches such as lean.

The action-research consisted of three cycles spanning over a 16 month period. The first cycle, starting in June 2015, set out the project goals and expectations, consisted in taking preliminary actions, focused on conducting interviews with the project team and observations to get familiar with the organization, the project and identified how the organization could benefit from the research. During this cycle, vPlanner™ was chosen as the primary tool used as part of the research to assist the team in planning and documentation efforts. In addition, a pilot study was carried out, mainly focused on the concrete pour and structural work.

Through discussions with the organization and considering the state of the work, the second cycle was set up to evaluate and plan the interior finishing and fit-out work in the four level of underground parkade (figure 1.2) on the project mainly from the electrical contractor’s perspective.
During this cycle, a production plan in the form of three week short-interval plans were created and plans were refined during weekly meetings with the organization and tracked on a weekly basis on site. The progress was evaluated with respect to the plans, the overall project, and the master schedules. The efforts in this cycle highlighted the interdependencies between different trades and the impact of other participants performance on the planning and execution of the electrical contractors work and their ability to shield their production on site from upstream variations. In addition, this cycle accentuated the importance of having a shared and communal plans that all trades have bought into and follow.

The third and final cycle was focused on the interior finishes in the first three levels of the podium, which houses the majority of the commercial spaces in the building, including the casino and restaurants (figure 1.3).
During this cycle, lookahead planning and short-term schedules were created for the overall project and followed by all trades. During this cycle, the team was able to build on the knowledge and experience gained from the previous cycles and utilize the planning strategies and lookahead plans to attempt to implement the Last Planner® system and evaluate the plans and processes in accordance to the Last Planner® guidelines (refer to chapter two of this document). The data collected, evaluation, and findings in this cycle of the study are the main focus of this thesis, which will be explored in more depth in chapters three, four and five.

The data collected as part of the research project were mainly focused around the efforts, plans, schedules and execution of the work in the construction phase.
Mixed-method data in the form of both qualitative and quantitative data surrounding the schedules- specifically the short-term schedules- were collected and analyzed over the course of the action-research project.

Qualitative data were collected through direct observations on site, construction coordination meetings, BIM coordination meetings, informal discussions with the project team and semi-structured interviews.

Direct site observations were conducted at least once-a-week with focus on visual tracking of the work progress with respect to the short-term schedules and commitments, identifying constraints and reasons for non-completion of the committed tasks. Additionally, logistics issues and coordination —and any factors or occurrences that could potentially impact the work progression observed either on site or discussed in the coordination meetings— were documented. The observations made during the coordination meetings and data collected were mainly used to feed the progress tracking and evaluation of the short-term schedules to evaluate the team’s performance based on the schedules, and to identify the reasons for failures to meet commitments.

The semi-structured interviews and informal discussions usually involved the senior project manager, foremen, project assistant and the prefabrication manager of the partner organization. These meetings were scheduled regularly on a weekly basis throughout the research study. During these meetings the progress and direction of the research and the project were discussed with the project team, weekly progress tracking and reports were reviewed, and subsequent suggestions on both the research efforts and the work planning were discussed on both sides and implemented.

The qualitative data served to gain an in-depth understanding of the current state of the project organization’s performance and to inform the direction of the research efforts.

The quantitative data collected on the project include:

• Plans and specifications
• Master schedules and short term look ahead schedules

• Request for Information (RFI) and Site Instructions (SI) logs

• Digital progress models

• Budget and cost reports

Plans, specifications and the digital progress models were mainly used to set out the scope of the work and visually assist in planning and tracking the work in terms of optimal flow of material and work forces. RFIs and SIs were used to identify the constraints and bottlenecks of the scheduled tasks or the reasons for their non-completion and, cost reports were occasionally used to study the impact of changes or delays on the project team.

Multiple metrics and measurements were employed to evaluate the effectiveness of the plans and short-term schedules. The metrics used are listed below, and will be explored further in the following chapters:

• Percent Plan Complete

• Reasons for Variance

• Degree of Change

In addition, the impact of the reliability of the plans on the electrical contractor’s ability to shield its production on site is evaluated. Furthermore, the electrical contractors ability to plan their work, their agility, and their ability to react to changes and keep up with the tasks assigned to them are factors evaluated to gauge the impact of lean on the specialty trades performance on the case study. The observations were further employed to understand the challenges and limitations of implementation of lean thinking on the case study project unilaterally by the electrical contractor, and to explore how they could benefit from implementation of lean principles on the project.
Multiple visual planning tools and solutions were utilized to assist the project team with the collection, visualization and analysis of data. The first and primary software used was vPlanner™, a visual planning and control software; this software has become increasingly popular in the United States and is utilized to facilitate collaboration among the project teams. vPlanner is a pull planning solution and supports the Last Planner® system principles. The software was primarily used to document, track and evaluate the short term schedules. The next software used was fieldwire; fieldwire is a mobile collaboration platform used by the overall project organization throughout the project that facilitates real time progress tracking and reporting. Fieldwire was mainly utilized to view and track site instructions and new versions of drawings, communicate the schedules to the field staff, and track defects and progress in certain areas.

1.4 Thesis Outline

This thesis consists of seven chapters; chapter one provides an overview of the research project as a whole by defining the objectives, exploring the research methodology employed and tasks carried out as part of this research. Chapter two aims to set out the foundation for the research by exploring the background and literature related to the subject matter and the research team’s motivation in carrying out this research. Chapter three embodies a detailed research methodology, covering the actions taken in each cycle of the research, exploring the data collection and analysis phases. Chapter four contains all the information with respect to the case study project, defining and providing all the necessary information in regards to the building project context. Chapter five includes a thorough assessment and review of the findings and observations. Chapter six contains a discussion section, evaluating and validating the findings with respect to the research objective and finally, chapter seven serves as a conclusion to this research project, exploring current limitations and setting out future works.
Chapter 2

Background

Construction projects are dynamic and complex systems (Ballard and Gregory Howell 1998, Ballard 2000, Bertelsen 2002). According to PMI’s “A Guide to the Project Management Body of Knowledge” (Guide 2001), projects are temporary endeavours, undertaken to create unique solutions - products or services. They are temporary, in the sense that they have a definite start and end time, and are unique, in the sense that there is no routine operation involved in their realization; a unique set of operations and processes have been designed for the sole purpose of accomplishing a unified goal.

Delivery of projects involve considerable collective effort and coordination on the part of multiple individual stakeholders that have come together to form a temporary project organization (TPO) for the duration of the project delivery (Koskela 1992). These individual stakeholders have different roles on the project, including but not limited to: owner, architect, consultants, prime contractor and specialty trades. The notorious fragmentation in the construction industry has been identified, both by the scholars and in the industry, as one of the core problems with the loss of productivity, cost overruns, delays and lack of quality (Egan Sir 1998, C. Eastman et al. 2011). While fragmentation is the main and overarching cause of waste in the construction industry, the root cause of the issues observed in the construction industry lies in how the projects are planned, managed and executed; as project
management in the construction industry is heavily reliant on bodies of knowledge and transactional contractual arrangements that favour sequential and fragmented approach to project delivery (Daniel Forgues and Koskela 2009).

According to Koskela 2000, the production processes can be conceived in at least three distinctive ways: as a conversion process; converting input to output; as the flow of material, information and workforces through space and time; and lastly as a process of generating value, by identifying and meeting the customers need and requirements. However, the conventional and the most general concept in the AEC (Architecture/ engineering/ construction) industry, seems to be the understanding of construction as a set of activities aimed at a certain output (Koskela 1992). Each building or structure is divided into simpler elements, and the cost of material, labor and resources for each element is estimated. At the heart of the conversion model is the assumption that the production process consists of a group of sub-processes, each converting an input to an output. These elementary processes can be thought of as independent and individual processes that can be managed in isolation, one from the other. The idea of the conversion method, is also observed in the network based Critical Path Method (CPM) and the work breakdown structures, widely used in the construction industry.

The traditional project management practices are static and are often based on limited information and inaccurate assumptions (Koskela and Greg Howell 2002). All too often, the project participants try to predict a project’s execution in great detail and include contingencies to overcome uncertainties. These approaches in project definition and management lead to variability, waste and loss of potential values to the project. Furthermore, looking at project management from the perspective of specialty contractors, they are often required to plan their scope of work and project execution based on the quality requirements and schedules dictated to them by the general contractor or the project managers. Specialty trades, often find themselves in situations where, the predecessors to their task are not completed in the designated timeframe. This is especially observed for following trades, such as electrical contractors; in the sense that, their sequence of work is highly dependent on
completion of critical work by other trades. Variations or failure to complete the predecessor tasks, adversely impacts the performance of the said specialty trades.

With the advent of innovative tools and technologies such as building information modeling and introduction of lean philosophy into construction, novel and innovative approaches to project delivery have emerged that aim at eliminating the existing waste and inefficiencies from the construction projects.

2.1 Building Information Modeling

Building information modeling (BIM) has been defined as tools, processes and technologies focused on development and use of a digital representation of the physical and functional characteristics of a building project to improve the planning, design, construction and operation of the project (C. Eastman et al. 2011, Sacks, C. M. Eastman, and Lee 2004, Messner et al. 2010). According to National Building Information Modeling Standards (NBIMS), “A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder”. The BIM Handbook also states that “BIM provides the basis for new design and construction capabilities and changes in the roles and relationships among a project team. When implemented appropriately, it facilitates a more integrated design and construction process that results in better quality buildings at lower costs and reduced project duration.”

2.2 Lean Construction

Lean construction is the application and adaptation of the underlying theory and principles of lean production from the manufacturing industry into the construction industry. Glenn Ballard and Greg Howell, the co-founders of the Lean Construction Institute (LCI), view
lean, as “a new way to manage construction”, that unlike the current project management
techniques, provides the foundation for an operations based project delivery system. Lean
production, originated from the automotive manufacturing and the Toyota Production Sys-
tem (TPS), developed by Toyota’s lead engineer, Taiichi Ohno, more than half a century
ago, with the focus on reduction in waste, increase in value to the customer and continu-
ous improvement. Ohno 1988 and Dillon and Shingo 1985, identified seven types of waste-
defined as consumption of resources without providing value- in production systems (all of
which could directly translate to the waste observed in the construction industry):

- Defects
- Waiting
- Transportation of goods
- Inventory
- Motion
- Overproduction
- Unnecessary processing

According to the glossary of Lean Construction Institute, Lean is “culture of respect and
continuous improvement, aimed at creating more value for the customer, while identifying
and eliminating waste”. According to Koskela 1992, this new approach, implies another
dimension to production; it consists of conversions and flows. He states, that the overall
efficiency of production is attributable to both the efficiency of the conversion activities or
value adding activities (creating value through conversion of inputs to outputs), as well as
the efficiency of flow activities or non-value adding activities, that bound the conversion
activities together.
2.2.1 Lean Principles

Several scholars and authors have provided lists of lean principles both in the context of the general production and its implementation in construction (Womack and Jones 2010, Koskela 1992). According to Womack and Jones 2010, there are five key lean principles:

1. Identify value
2. Map the value stream
3. Create Flow
4. Establish Pull
5. Seek Perfection

Value is identified by the customer’s need; once the value (end goal) has been identified, the next step, is identifying all the steps and procedures necessary to convert the input into the final outcome. This includes the processes during the design, planning, construction, execution and operation of a project. The objective is to identify the value adding processes and non-value adding processes and explore ways to eliminate those wasteful steps. Once the non-value adding steps have been removed, the next step is to create a smooth and reliable flow among different production units by removing any obstacle or bottleneck. This can be achieved by removing the boundaries around each production unit and keeping the unified goal of the project as a whole in mind. The way that translates into construction is breaking down the silo thinking and fragmented planning of each organization and forming a lean enterprise and create a continuous flow (Womack and Jones 2010). The improved flow makes for a more reliant delivery of a product to a customer as needed (similar to the Just in Time (JIT) delivery); which enables the downstream customers to “pull” or “request” a product when needed (Forbes and Ahmed 2011). The glossary of LCI defines pull as a “method of advancing work when the next in line customer is ready to use it. A request from the customer signals that the work is needed and is pulled from the performer. Pull
releases work when the system is ready to use it”. Finally, as stated, lean is the culture of continuous improvement; the principles stated thus, can be presumed as a continuous cycle, in which, the organization as a whole continuously works towards perfecting the process and creating the most value.

2.2.2 Traditional Planning System Vs. Pull Planning

The traditional construction project planning is based on a push mechanism; where the input (resources, information) or assignments are planned and ordered based on a central schedule and target delivery, irrespective of whether or not the downstream customer or production unit is capable of processing them (Ballard 2000, Ballard and Gregory Howell 2004, Forbes and Ahmed 2011). By contrast, pulling is a method of introducing or allowing materials or information into a process only when the process is ready and capable of performing the work; in other words, the production is prompted at the request of a downstream production unit. Pull is also used in the method of backwards pass team scheduling (Ballard 2000), which creates phase schedules, as an intermediate step between master schedule and the make ready process used for production management (Ballard and Gregory Howell 2004). An instance of pull planning is the Last Planner System® of production (Ballard and Greg Howell 1994, Ballard 2000), where assignments are required to meet certain quality criteria for soundness, definition, sequence and size before being scheduled (Ballard 2000).

2.3 The Last Planner System® of Production Control

The glossary of the Lean Construction Institute defines the Last Planner System® as “system for project production planning and control, aimed at creating a workflow that achieves reliable execution, developed by Glenn Ballard and Greg Howell, with documentation by Ballard 2000. LPS is the collaborative, commitment-based planning system that integrates should-can-will-did planning: pull planning, make-ready, look-ahead planning with con-
straint analysis, weekly work planning based upon reliable promises, and learning based upon analysis of PPC and Reasons for Variance”.

2.3.1 Should-Can-Will-Did

Large and complex projects usually require different people with different levels of authority, to plan and control the planning and execution of the project at different times during the life cycle of the project (Ballard 2000). The planning usually begins with a high-level schedule, governing the contractual obligations and scope of the work with focus on global objectives and constraints (Ballard 2000). These objectives drive lower level plans for the project execution that determine the means for achieving the set goals. What SHOULD get accomplished, is usually stated in the master schedule and look-ahead plans of a project. The lower level assignments are then made ready, so they CAN be performed. Ultimately, the individuals or groups in charge of producing the assignments known as the “Last Planner”, determine what WILL be performed and oversee to ensure the set assignments DID happen (Ballard and Greg Howell 1994). The Last Planner can be viewed as a mechanism for transforming what SHOULD be done into what WILL be done, that eventually becomes what CAN be done (Ballard 2000). The Last Planner System® consists of five distinctive processes:

1. Master Schedule

2. Phase Planning

3. Look Ahead Planning

4. Weekly Work Planning

5. Learning
2.3.2 Master Schedule

Master schedule represents an overall, high level view, that identifies major phases and milestones in a project, such as start-up, mobilization, design completion, contract awards, turn-over, long lead procurement items, etc. and the project timeline. It is usually based on the early information in the contract document and is the basis for contractual agreements between various project stakeholders. It is considered a tool to set the project execution strategy and to check feasibility of project phases, but not necessarily to control the project (LCI, Forbes and Ahmed 2011).

2.3.3 Phase Schedule

Phase schedule is a more detailed work plan that specifies the hand-off between the specialists in each phase of the project (Ballard 2000). Phase schedules are often created in a collaborative setting using a pull technique; working backwards from the target milestone dates for each phase in the master schedule, the team work collaboratively to develop the tasks in each phase. Ballard and G. A. Howell 2003, refer to phase scheduling as “the link between work structuring and production control.” They claim that, without phase scheduling, “there is no assurance that the right work is being made ready and executed at the right time to achieve project objectives.”

2.3.4 Look Ahead Schedule

The look-ahead schedules are short interval plans derived from the phase plan, that identify the potential assignments for the next three to twelve weeks (typically six weeks). According to Ballard 2000, the look-ahead window is dependent on the project characteristics, the planning system and required lead time for information and resources acquisition. Ballard 1997 & Ballard 2000, has identified, 5 functions for the look-ahead planning process:
1. Shape workflow in the best achievable sequence and rate to meet the project objectives to the best of the organization’s abilities in any given time

2. Match workflow to the organization’s capacity

3. Produce and maintain a backlog of ready work to ensure continuous workflow

4. Develop work execution strategies

5. Update and revise high level schedules as needed to maintain a realistic plan

Look-ahead or short term interval schedules are commonly used in the construction industry in order to draw attention to work that needs to get accomplished in a given duration and to encourage steps and actions to be taken to reach a desired milestone. However, seldom efforts are taken to produce sound assignments or to provide instructions to execute the work scheduled. Usually the look-ahead schedules are drop-outs of the higher-level schedules at a greater level of detail, but with no screening of scheduled activities against quality criteria to assure the scheduled tasks can be executed (Ballard 1997). Some features of the Last Planner® that distinguishes it from the conventional look-ahead schedules, are the constraint analysis and make ready processes performed as part of the look-ahead scheduling (Ballard 1997). Constraint analysis, is the process of identifying the constraints or prerequisites of each assignment; typical constraints on construction tasks are design, availability of resources, completion of prerequisite work and information. Once the constraints on each task has been identified, actions are taken to remove the constraints and make the work ready to be performed.

2.3.5 Weekly Work Plans

Weekly work plans or commitment plans, are derived from the lookahead plans and provide a detailed plan of works that will actually be done in a week. Weekly Work Plans (WWP) specify the hand-offs between the trades involved. According to Ballard and Gregory Howell
1998 commitment planning is a “commitment to what will be done, after evaluating “should” against “can”, based on actual receipt of resources and completion of prerequisites”. In order to improve the effectiveness of the weekly work plans and increase the reliability of commitment plans, the weekly work plans need to meet specific quality criteria for definition, soundness, sequence, size and learning (Ballard and Gregory Howell 1998, Ballard 2000).

- Definition: assignments are specific enough, with sufficient detail to determine whether they can be completed
- Soundness: assignments have been made ready to be executed; constraints are removed and the required resources are available
- Sequence: select assignments in a constructability order needed, to release work with respect to the priorities set by the downstream customers
- Size: select the amount and size of activities that match the capacity and capabilities of the crew performing the work, while considering the downstream customers needs and requirements
- Learning: identify assignments that are not completed within a week and the reasons for their non-completion

Applying these quality criteria, increases the plan reliability and with that the crew productivity also increases (Ballard and Howell 1997). In addition, selecting quality assignments, shields production from upstream uncertainty and variation (Ballard and Howell 1995, Forbes and Ahmed 2011). Shielding promotes accountability because expectations can be met, and failure to meet expectations can be investigated and acted upon (Ballard and Howell 1994).

2.3.6 Metrics and Learning

One of the pillars of lean construction is continuous learning and taking corrective measures to continuously improve the process; hence, an important step in the Last Planner® system
of production is a look-back or lessons learned process. A key performance measurement metrics in the Last Planner® system, is Percent Plan Complete (PPC). According to Ballard and Greg Howell 1994, PPC is the measure of how well WILL and DID match in the planning process. Percent Plan Complete, is the number of planned activities completed, divided by the total number of planned activities (commitments), expressed as a percentage (Ballard 2000). The Glossary of Lean Construction Institute defines PPC as “a basic measure of how well the planning system is working”, PPC measures the percentage of assignments that are 100% complete as planned. In addition, PPC measures the extent to which the scheduled activities in a week (weekly work plan or commitments) have been realized. Higher PPC corresponds to doing more and better execution of the scheduled activities and higher productivity and progress.

In addition to measuring the PPC, another process in the Last Planner system is identifying the reasons for non-completion of planned activities that are not completed as planned and tracing the reasons back to their root causes, so improvement can be made in future performance (Ballard and Greg Howell 1994, Ballard 2000). Eliminating reasons for non-conformance, improves the quality of assignments and therefore the plan reliability. Additionally, improving the quality of assignments, automatically shields production flow from uncertainty, increases the lead time and reliability of information needed by the downstream trades for better planning and performing their work (Ballard and Gregory Howell 1998).

Furthermore, according to Ballard 1997 in order to improve the planning process, some type of performance measurement need to be developed to assess the current planning system in place. In his paper “Look-ahead Planning: The Missing Link in Production Control”, he uses different performance measurements to assess the look-ahead planning process implemented on a pilot project. The performance was evaluated through four measurements:

1. Subjective evaluation by the project participants

2. Assignment anticipation through measurement of the extent to which weekly work plan tasks had appeared in the look-ahead plans
3. Measuring the extent to which the assignments that appeared on the weekly work plans, kept their original date as indicated on the look-ahead schedules (prior to moving to weekly work plans)

4. A Time/Time chart to track the change over time of scheduled dates for specific assignments

Inspired by the aforementioned performance measurements, a new metric is developed to assess the predictability and reliability of the short term schedules in this research. This metric measures the degree to which the scheduled dates for the assignments on the look-ahead schedules change from one week to the next. This measurement enables the research team to evaluate the reliability of the look-ahead plans by measuring the percentage of the assignments that are rescheduled each week because the team failed to perform them or their predecessors were not successfully removed as planned. This metric will be further explored in the context of the case study project.

2.4 Motivation

In terms of theoretical motivation, research in construction project management is increasingly exploring the interactions between BIM and Lean Construction (Sacks, Koskela, et al. 2010, D Forgues and Iordanova 2010). Both these innovative approaches aim to improve projects performance and value generated to the customer by better planning, management and execution of projects. However, as explored in this chapter, both innovations require extensive fundamental changes to be made to the temporary multi-organization created as part of each project, their roles and interactions; both approaches, create and foster new opportunities for collaboration, create accountability and mutual trust and respect. While these novel approaches are becoming increasingly popular in the United States, and the empirical evidence available on their implementation, suggest they can create significant value in projects; their implementation in the Canadian construction is lagging. Furthermore,
while some research and work has focused on implementation of building information modeling from a specialty trade’s perspective (Poirier, Staub-French, and Daniel Forgues 2015), research on application of Lean Construction and its impact on specialty trades performance is significantly limited.

In terms of practical motivation in setting up this research project, the research was set up with Houle Electric due to their interest and motivation in transitioning into use of more innovative approaches and integration of lean into their practices.

The identified research gap and interest from the industry partner created a unique opportunity to set up an action-research project to evaluate the impact of implementation of lean on the performance of a specialty trade on a traditional project in the construction industry.
Chapter 3

Research Methodology

Based on the nature of the project, and the research team’s involvement with the partner organization, an action-research was initiated to evaluate the impact of integration of lean philosophy into the organization’s practices on their performance on this project. As covered in the first chapter, the research was set up in part, due to the organization’s interest in transitioning into a more lean oriented practice. As expressed, the organization is extensively invested in prefabrication and operate a prefabrication facility where they prefabcrate or pre-assemble all the material, components and equipment for the project. In addition, they have a warehouse facility close to the project site where the prefabricated components are stored before shipping to site when needed. In order to ensure that they run a smooth operation from prefabrication to installation on site, and that the components are procured and prefabricated in time for installation, especially for long lead procurement items such as luminaires on this project, they require a predictable and reliable schedule.

3.1 Action-Research Phases

The action-research was initiated in the early stages of the construction on site and as depicted in figure 3.1, evolved over the research duration in different stages of the construction
with focus on the work with the most value to the organization. Throughout the research-project, 3 cycles were carried out consecutively. In each phase, as is the cyclical nature of action-research, based on the state of the construction and prevailing conditions, certain areas were identified by the team, certain action plans were proposed and executed, and the outcome was evaluated. The recurring theme of the different phases of the research was however, focused on the work planning and the impact of reliable and predictable work-flow on the specialty trades performance in terms of their ability to plan and execute their work. Mixed-method data collection was conducted to collect related data in each phase. In addition, different tools and measurement metrics were utilized to collect and analyze the data.
Figure 3.1: Action Research Cycles and Breakdown

**Cycle 1**
- Grant Application
- Benchmarking
  - Interviews
  - Project Documentation
  - Observations
- Pilot Study
  - Focused on structural and concrete pour
  - Interviews
  - Observations
  - Software set up
- Set out goals and expectations

**Cycle 2**
- Parkade
  - Focused on interior finishes
  - Weekly meetings and discussions
    - Create production planning: 3WLA (vPlanner)
    - Identify weekly tasks
    - Commit to tasks
  - Regular site visits
    - Track work progression on site w.r.t plans
  - Attend weekly coordination meetings
  - Document project planning efforts
  - Identify shortcomings

**Cycle 3**
- Podium
  - Focused on interior finishes work planning and execution
  - Production planning using visual planning tools (vPlanner, Fieldwire)
  - Identification of constraints
    - Work sequencing
    - Coordination
  - Prepare 3WLA & WWP
  - Regular site visits
    - Track weekly commitments
    - Track PPC and Variance
    - Prepare reports
  - Attend weekly coordination meetings
  - Document project planning efforts
  - Identify shortcomings, make suggestions

*Weekly Work Plan / Look Ahead*

June 2015 - September 2016
3.1.1 Research Phase 1

The first cycle was initiated in June 2015 in the early stages of the construction. This phase was mainly focused on setting out the goals and expectations for the project and taking the preliminary actions to set up the research project. Majority of the time was spent making observations of the project, conducting interviews with the project team and becoming familiar with the partner organization, their culture and their current practices. In addition, a pilot study focusing on the concrete pour and structural work for the parkade was executed to test out and become familiar with vPlanner and its capabilities as the primary visual planning tool to collect and analyze the pull plans.

3.1.2 Research Phase 2

Through discussions with the partner organization’s team and the state of the work, the second cycle was set up to plan and evaluate the interior finishing work from the electrical contractor’s perspective, in the four level of underground parking in the building project (refer to figure 1.2). During this phase, the master schedule was undergoing major changes to reflect the owner’s requirement in terms of level of detail of tasks on the master schedule, therefore an accurate and sufficiently detailed schedule was not available to plan and track the daily tasks on site. To overcome this issue to a certain extent, as part of the research tasks in the second phase, a production plan for the parkade was produced for the electrical contractor. Through a collaborative effort with the electrical contractor’s foremen, the plan was created in form of a pull plan identifying the electrical contractor’s tasks and the predecessor to their tasks and durations. Once the tasks were set up, milestones and logic and resource links were added to the schedule. These plans were refined during the weekly meetings with the organization and activities were tracked on site. An example of a portion of one of the production plans is depicted in figure 3.2 below.
Figure 3.2: An Example of Lookahead Plans Created on vPlanner for the Parkade
The figure is a screenshot of a workflow created on vPlanner; each square represents a task written on a sticky notes in pull planning. Each color represents a different contractor and the lines represent the logical and resource links between activities. The diamond represents a milestone and is set to trigger the activity start in each section.

The progress was evaluated with respect to the plans and measurement metrics such as PPC were used to measure the team’s performance. A major setback in this phase, as can be seen in the figure above, was that the electrical contractor’s work was highly dependent on the rest of the trades and such detailed schedules are mostly effective if developed and followed by all trades, which was not the case in this phase of the project.

3.1.3 Research Phase 3

The third and final cycle during which the research was conducted was focused on the interior work and fit-out in the first three levels of the podium housing the casino, retail spaces, hotel lobbies, restaurants and lounges, kitchens and service areas (refer to figure 1.3). During this cycle was when the general contractor began the implementation of the short-term schedules which facilitated a more rigorous and structured analysis to be performed on the project. Furthermore, during this phase, the author was hired by the partner organization which helped further develop the collaboration between the researchers and the practitioners and created a much richer data collection opportunity. The main focus of the project evaluation and data analysis in this document will be based on the findings in this phase.

During this phase, the general contractor held weekly coordination meetings with the foremen of all contractors responsible for the interior finishing work in the podium. Look-ahead plans were reviewed each week and site logistics, delivery times and work of each trade was coordinated. The look-ahead schedules distributed in this phase were inputted into vPlanner, where weekly commitments were made and tracked on a weekly basis to gauge the performance of the team with respect to the plans. Figure 3.3 below is a screenshot of a portion of one of the look-ahead plans.
Figure 3.3: An Example of Lookahead Plans Created on vPlanner for the Podium
The look-ahead schedules, observations in coordination meetings and in situ activity tracking were the primary information feeding to the analysis in this phase. The data collection and analysis will be discussed further in the following sections.

3.2 Data Collection

The investigation into the impact of implementation of lean processes through creation of predictable and reliable plans and its impact on the performance of a specialty trade presented in this thesis was informed by multiple sources of data collected throughout the research project. As previously stated, the primary data feeding into the findings of this study were data collected and analyzed in the third phase of the study, however, the data collected over the span of the project collectively contributed to the breadth and depth of understanding of the project and the specialty trades performance.

The data collection was continuous throughout the research project and was aimed at evaluation of the organization’s current practices and assist in reduction of waste and inefficiency in the organization through implementation of lean philosophy. The focus was on creating and evaluating the impact of reliable planning on the organization’s ability to shield their production and work planning on site. Throughout the research project, focus was on both the specialty contractor’s organization and the temporary project organization (TPO) operating on the case study project. This multi-level evaluation was proven to be necessary as the specialty trade’s performance on the project was highly dependent on other participants in the project.

As previously noted, the research team’s involvement on this project came at the request of the specialty trades organization to research the impact of lean and its potential to improve their performance and value generation, and to document the benefits, barriers and lessons learned of these efforts.

The action-research was initiated in June 2015 in the early stages of construction on site.
and was consistently carried out for 16 months concluding in September 2016. Throughout the research project a combination of qualitative and quantitative data were collected to study the planning and execution of work in different areas and stages in the construction phase.

The qualitative data collected throughout the project consisted in informal discussions and semi-structured interviews, observations in trade coordination and BIM coordination meetings and in situ observations of the construction activities and progress. The quantitative data collected consisted in different forms of project data surrounding work scheduling and plans, including the master schedules and look-ahead plans, formal communications such as request of informations (RFI) and site instructions (SI), plans and specifications and digital progress models.

Qualitative and quantitative data were collectively utilized to assist the research team and the partner organization with managing their daily tasks, planning their work, procuring and managing resources, tracking the progress on site and evaluating their performance on a weekly basis.

Actions taken to analyze and evaluate the collected data and the performance measures employed will be explored in the next section.

3.3 Data Analysis

As a first step to evaluate the TPO and the specialty contractor’s performance in accordance to the plans in place, the weekly distributed look-ahead plans were documented and inputted into vPlanner. These schedules were further used to identify the activities that were scheduled to be performed in the coming week—ie. the weekly work plan. The weekly work plans acted as each trades weekly commitments. These commitments were tracked in the coordination meetings through information exchange, coordinations and the new schedules. In addition, regular site visits were conducted on site every week to visually track the
progress in each area in accordance to the weekly commitments.

Similar to the guidelines of the Last Planner® system, information were gathered each week to answer the following questions:

1. **(DID)** Work complete (Based on last week’s plan)
   
   (a) What planned activities were completed?
   
   (b) What unplanned activities were completed?
      
      i. Why were they not planned?
   
   (c) What planned work was not completed?
      
      i. Why was it not completed

2. **(CAN)** Three to six week look-ahead
   
   (a) What are the activities that are upcoming in the next three to six weeks?
      
      i. Per Area
   
   (b) Are there any major activities that require extensive lead time?
   
   (c) What are the major activity constraints for the next three to six weeks?
      
      i. RFIs/ Missing information on documents
      
      ii. Submittals
      
      iii. Change Orders

3. **(WILL)** Weekly look-ahead plan
   
   (a) What are the detailed activities that need to happen within the next week?
      
      i. Per area
   
   (b) What are the constraints for these activities?
      
      i. Predecessor activities
      
      ii. RFIs/ Missing information on documents
iii. Submittals

iv. Change Orders

The information feeding to these questions were collectively gathered through discussions with the project team, in addition to in-situ and meeting observations.

A summary of the actions taken each week is listed below;

1. Attend the weekly subcontractor coordination meetings

2. Observe the subcontractors’ and prime contractor’s interactions, their willingness to participate in the weekly coordination meetings and their commitment to the weekly detailed short interval plans

3. Track weekly commitments statuses through in-situ observations

4. Attempt at examining the weekly work plan activity quality in terms of soundness, quality, size and definition

5. Measure PPC and Identify reasons for non-compliance

6. Analyze the reliability of the plans distributed each week and the fluidity of the activities completion dates over time (degree of change)

Both qualitative and quantitative data were collected. The data collected were then employed either individually or in combination with other data to perform different types of analysis.

Similar to the data collection phase, mixed methods were used in examining the collected data.

As briefly explained in the previous section, on this project, the near term schedules were created mainly based on what tasks were expected to happen in what areas according to the master schedule. These schedules were then simply filtered to yield the weekly work expected to be performed in any given week. In other words, no make ready planning process was performed to get the tasks ready to be executed. The tasks scheduled were expected to
get done irrespective of the constraints and obstacles that first needed to be removed for the work to be executed.

In order to analyze the effectiveness and reliability of the said schedules and the accountability of the trades involved, a few performance measurements and metrics were employed.

As stated in chapter 2, three main metrics were utilized to evaluate (1) the team’s performance (the overall interior finishing team and the specialty trade) and (2) the reliability and effectiveness of the planning in the project.

The first performance metric employed was PPC (percent plan complete). As previously noted PPC represents the total number of tasks completed divided by the total number of tasks predicted (commitments). Each week, PPC was measured for the overall interior finishing team in the podium and Houle Electric separately to evaluate the team’s performance with respect to the plans and their commitments.

Throughout the project, it was observed that due to the varying complexity in terms of both design and coordination in different areas, the team’s performance was different in each area. For example, due to the complexity of design and proximity of services, more coordination was needed in the casino (figure 3.4). Therefore, in addition to the overall PPC calculated for each team on a weekly basis, the ratio of the number of completed tasks in each area to the number of commitments in that area (PPC per area) was evaluated.
In addition to PPC, the reasons for variance of the committed tasks not completed in each week was tracked and evaluated. These reasons were identified each week and documented. Similarly, variance charts were created each week for the overall interior finishing team and Houle Electric.

Finally, to evaluate the reliability and effectiveness of the lookahead planning process another metric was utilized. The two above-mentioned metrics focus mainly on the performance of the team with respect to the plans and although the variance analysis highlights some of the shortcomings of the scheduling process, the two do not necessarily speak to the quality and reliability of the planning process. In order to improve the process, some type of performance measurement need to be in place to assess the current system. A new metric, named the degree of change in this research, analyzes the reliability and predictability of the plans. Over the duration of this analysis, the weekly distributed schedules were documented.
and tracked on a weekly basis to evaluate the reliability of the plans in terms of the amount of change to the activities on schedules in two successive weeks. Changes with respect to the start dates, durations and completion dates for activities were compared and the degree of change in form of a percentage was measured each week for both the overall interior finishing team and the electrical contractor.

During the final cycle, the following planning cycle was established to collect and analyze the data. The breakdown is depicted in table 3.1 below;
Table 3.1: Breakdown of Weekly Tasks

<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday and Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track weekly assignments from previous week and update statuses</td>
<td>In-situ observation</td>
<td>Plan reliability charts and non-conformance analysis graphs are distributed to the project team (copies sent to the GC)</td>
<td>In-situ observation</td>
</tr>
<tr>
<td>Trades Coordination Meeting- Look ahead schedule V.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracking previous week’s work; close work plans</td>
<td></td>
<td>Look ahead schedule V.2(^1)</td>
<td>Subcontractors one on one breakout scheduling meeting with the GC</td>
</tr>
<tr>
<td>PPC Measurement</td>
<td></td>
<td></td>
<td>Identify constraints and prerequisite work to be performed by other trades</td>
</tr>
<tr>
<td>Non-conformance analysis</td>
<td></td>
<td></td>
<td>Analyze scheduled work for upcoming weeks</td>
</tr>
<tr>
<td>Distribution of weekly assignments to foremen</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Occasionally a new revision of the week’s schedule is distributed to the trades either on Wednesday afternoons or Thursday mornings
Chapter 4

Case Study

4.1 Project Context

The action research was carried out on a complex, mixed-use new development under construction in downtown Vancouver, Canada. The development houses the replacement of an existing casino, as well as a 569-room hotel in three towers with a total budget of approximately 600 million dollars. The prime contract was awarded in December 2013 and the construction on the site began in November 2014. The construction was initially scheduled to be concluded in 28 months, by no later than February 2017.

The partner organization on this research project is the prime electrical contractor on the aforementioned construction project. Founded in 1944, Houle Electric, is one of the largest electrical contractors in British Columbia; they provide a variety of services, ranging from electrical construction contracting on industrial, commercial, institutional and residential projects to security, data network systems and inspection. The research project was set up in part due to the research team’s interest and involvement in innovative practices including among others, Building information modeling, Lean construction and prefabrication and mutual interest of the partner organization in advancing and integrating said practices into their operations.
The original budget for the electrical portion of the project was approximately $40 million dollars; the subcontracted work includes the provision of all necessary and applicable labour, materials, tools, equipment, consumables, engineering, insurance, inclusive of all general requirements, competent and adequate supervision, properly staffed site office and all else required for the execution of work as outlined in the contract. The project is procured under a traditional design-bid-build (DBB) with a joint venture comprising of two large general contractors, providing a guaranteed maximum price (GMP) to the owner.

In addition, being a majorly large project, the contracts are split up within the building and the project team is comprised of a significantly large number of specialty trades, providing services in different components and areas of the building project.

Figure 4.1: Building Project

The project has faced a lot of uncertainties and changes from the beginning. The design that was used as part of the tender documents, was less than 40% complete, followed by major redesign of the structural, MEP services and interior spaces. These late design
development and changes, significantly impacted the project’s overall scope and schedule, to the point that a complete set of new drawings were created, the project contracts were reset over a year into the construction and the schedule was extended for several months. During this redesign phase, the trades were instructed to continue construction according to the original tender documents and supplementary information provided to that phase, with the possibility of having to make changes to the work performed once the new set of drawings were released.

Furthermore, according to the general contractor’s superintendent, due to some owner initiated changes to the design of the hotel towers, there were structural elements added to the design of the structure in the podium levels after the construction had begun that conflicted with the placement of the cranes already in place and crucial to the development of the construction, which led to re-strategizing, re-sequencing the work, in addition to longer temporary structure support than initially planned. (Figure 4.2).
Figure 4.2: Structural Steel Temporary Placement due to the Crane Location- All MEP Services Had to be Relocated/ Re-routed as a Result
Having to comply with strict deadlines or facing hefty penalties, the general contractor and trades have been forced to work in very heavily reshore loaded areas which significantly hinders the performance of the project team.

In addition, due to the complexity of design, up to this point in the project, there has been some constructability issues associated with the structural, architectural and MEP services in the building in many aspects and with respect to other services in terms of spatial limitations that has impacted the work progression in the affected areas. These will be covered in more details in the following sections.

4.2 BIM Submissions and Process Requirements

In terms of BIM use, the original mandate by the owner was to have a fully coordinated multi-disciplinary model used for visualization, clash detection and conflict resolution for the entire project. Initially all contractors had agreed to comply with this requirement, however, considering the complexity, scale of the project and the constant changes to the design, the amount of effort required for modeling proved to be out of the participating contractors capabilities and scope of BIM was scaled back.

As part of the coordination efforts on the project, regular BIM coordination meetings were held by the general contractor. In these coordination meetings, the general foremen of each specialty trades, their modeller and the consultant in charge of each MEP services design was present. Progress models were uploaded by each trade to a central network every week and were linked to the structural and interior design models and the clashes were detected. Major clashes were reviewed in the coordination meetings and the foremen and consultants worked together to resolve the conflicts.

As mentioned previously, due to the complexity of the design and mixed-use scope of the building, in some heavily MEP service loaded areas, some major clashes between the mechanical, electrical and plumbing services and the structural or architectural elements
were detected. An example of spatial conflicts between MEP services is illustrated in figure 4.3 below;

Figure 4.3: Mechanical Ducting and Plumbing Clash with Electrical Conduits and Cable Trays- Progress Model Screen-shot

The constructability issues were discussed in the BIM coordination meeting and the trades discussed alternative solutions to rectify the issues. As an example of the coordination results some services were relocated or re-routed or in some cases, resized to fit the confined space.

Due to the accelerated speed of construction, a notable portion of the clashes were detected on site while services were being installed. The detected issues were then discussed in the coordination meetings, RFIs were issued to respective consultants, the necessary instructions were provided and the design was modified in accordance with the instructions.
4.3 Scheduling Efforts

As part of the owner’s requirements, the general contractor has been required to present and report on a very detailed master schedule that dictates the overall project milestones, sequence and flow of work. Considering the significant changes to the scope and construction of the project, there has been several revisions of the master schedule distributed to trades. The current master schedule has grown to be over 300 pages with more than 20,000 activities, with a new schedule being issued every month.

With constant changes to the master schedule and the level of detail dictated by the owner, the general contractor and trades were forced to create a new set of look-ahead schedules to plan and include the day-to-day tasks on-site.

Several iterations and planning strategies were implemented and the planning sessions evolved over the course of the research time. Initially the planning sessions were mostly focused on the structural/ concrete and related work such as, rebar and, in-cased electrical and mechanical rough-in; however, over time, a separate weekly planning meeting for interior works was created. The interior finishing works, including but not limited to framing, electrical and mechanical rough in, board, tape, sand, installation of overhead ducting, ceiling framing, mechanical and electrical drop in, etc. were discussed and planned during these meetings.

4.3.1 Master Schedule

To comply with the owner’s requirement, a detailed master schedule comprised of over 300 pages, with over 20,000 activities, was created. The master schedule is broken into phases to reflect every task taking place on the project since the day the contract was awarded to the general contractor; the master schedule contains all the design processes milestones, permitting activities and dates, tendering process for the specialty trades, and so forth. In addition to the procurement tasks, the master schedule is broken down to reflect the tasks
and completion dates for the structural elements of each component of the building: ie. parkade, podium, tower A, tower B and tower C (figure 4.4) and, the finishing activities and hand off for each component including every activity in every room in each level.

Figure 4.4: Building Components

Furthermore, as part of the scheduling efforts, the specialty trades were obligated to meet with the general contractors scheduler every two weeks and report on their progress based on the latest version of the master schedule to be reported to the owner.

4.3.2 Short-Term Schedules

In order to better manage the scope of work and sequence of activities in the podium- ie. the first 6 levels of the building, housing the retail spaces, hotel lobbies, restaurants, bars and the casino, each floor has been divided into 6 zones or areas as depicted in figure 4.5 below.
The team had to adhere to the master schedule to plan the day to day work on site with the level of detail mandated for the master schedule, which has proven to be a challenging task; in order to overcome this issue and to create a more straightforward plan for the trades to follow, near-term or look ahead schedules broken down per each area in each level of the podium, were created.

Over the course of this study, the general contractor implemented a few different approaches in creating the look ahead plan. These approaches are briefly described below;

Initially, the look ahead plans were created in coordination meetings with all trades involved in pull planning format using post it notes on the wall. The plans were then documented in Microsoft Excel spreadsheets and communicated to the project team via e-mail. An example of the planning boards used in the look-ahead planning sessions can be
seen in figure 4.6 below.

![Look-ahead Planning Board](image)

Figure 4.6: Look-ahead Planning Board

The general contractor’s next attempt, was to create three week look-ahead plans in the same format as the master schedule, i.e critical path method, but with a different level of granularity- outlining the activities in each area in contrast to each room. These three week look-ahead plans were created on Microsoft Project and reviewed in the coordination
meeting with the trade contractors (figure 4.7).

In addition to the two main approaches outlined above, there were a few odd weeks, where the meetings were replaced with coordination site-walks with the trades foremen to review the progress on site.

4.4 Scheduling Complications

As was briefly touched on in the previous sections, the scheduling efforts on this project have had its fair share of complications and uncertainties. Some of the factors impacting the scheduling efforts both in terms of the master schedule and the near-term schedules discretely and with respect to each other- are described in this section.

4.4.1 Design

Over two years into the construction, the project has faced many uncertainties and changes associated with the design of the structure and interior spaces of the building. In addition
to the owner initiated changes on the project, being a complex commercial project many
changes have been made to the restaurants and or retail spaces that have impacted the
schedules and work advancement. Additionally, late developments in the design and the
constructability issues covered earlier have led to over 1250 Request for Informations (RFI)
and more than 650 Site Instructions (SI) which further impact the project schedule.

4.4.2 Commercial and Contractual Issues

The podium, encompassing the first 6 levels in the building, houses the commercial retail
spaces, the restaurants and lounges, the casino, hotel lobbies, as well as kitchens and back
of house service areas. On account of the size and scope of the project, the podium has been
divided into several categories including back-of-house and front-of-house, and restaurants
and base building spaces. These segments are in some instances contracted and managed
separately.

During the short-term planning in the podium, some unanticipated commercial issues
was brought to the project team’s attention. In the case of the sheet metal contractors, the
podium was managed as base building, containing about 60% of their scope of work and
restaurants the remaining 40% of their work. It was revealed that the restaurants HVAC
ducting work was not originally included in the agreements made with the sheet metal
contractor and therefore they were not contractually responsible or prepared to perform the
work assigned to them in the said areas. Being one of the contractors leading the work,
the delays caused by this issue impeded the work progression in the restaurant’s areas and
impacted the following trades workflow and schedules.

Furthermore, the project being set up in a traditional design-bid-build contract did not
foster a collaborative environment among the trades. With the constant changes and the
short timelines and deadlines assigned to tasks, each trades workflow was reactive to the
site conditions. In addition, the trades were not contractually obligated to follow the short-
term look ahead schedules, and were not incentivized to participate in the planning sessions;
therefore, there was a very low percentage of buy-in from the trades in terms of keeping up with the short-term plans and fulfilling their commitments.

4.4.3 Complexity and Size of the Project

Another project characteristic that is consistently highlighted by the project team as a major factor impacting the scheduling efforts is associated with the size and complexity of the project; remarks such as “the project is too large and complex” are often made by different project participants to justify the issues arising in project execution in terms of planning the work and procuring resources.

4.4.4 Correlation Between Master Schedule and Near-Term Schedules

The near-term plans were initiated by the general contractor in an attempt to plan the day to the day work on site and coordinate and direct various trades working in different areas.

As expressed, the short-term schedules presented the work scheduled per area in the podium levels (refer to figure 4.5), whereas, as per the owner requirements, the master schedule included activities in every room in the building. To put this into perspective, each level of the podium is broken down to -on average- over 100 rooms, in comparison to 6 areas in each level. The notable difference in the level of granularities in the activity breakdowns created a disconnect between the two schedules.
Chapter 5

Findings

5.1 Percent Plan Complete (PPC)

One of the main measurement metrics utilized as part of the performance assessment on this research project is the Percent Plan Complete (PPC). PPC was measured based on the weekly scheduled work on two levels;

1. For the overall interior finishing team; containing the overall work scheduled each week for all parties involved, and

2. For Houle electric; for tasks only assigned to them each week and their performance based on the assigned work

The PPC charts below illustrate the measured PPC during three months on a weekly basis for the interior finishing team and Houle electric.

5.1.1 Interior Finishing Team PPC

Over a certain period of time the PPC varied from the initial PPC of 48%, dropping to below 20% and then fluctuating in the 20% and 30% range. The maximum PPC value during the
study was 48% and the minimum value was as low as 18%. As can be seen in graph 5.1 below, the PPC variation did not follow any particular trend.

![Interior Finishing Team PPC](image)

Figure 5.1: Interior Finishing Team PPC

In order to gain a better and a more in depth understanding of the Percent Planned Complete variation, and factors contributing to the fluctuations, chart depicted in figure 5.2 was prepared. This figure, illustrates the total number of commitments in a week, number of completed, on going and not completed tasks.

As illustrated, from week 3 to week 4, over one week, the number of tasks scheduled to be performed by the team was more than doubled; this abrupt and noticeable growth in the scope of work, did not give trades enough advance notice to plan for the additional labour force or in general resources needed to perform the work or plan out their work execution strategy.

In addition, as previously stated, due to the size of the project and the segmented
management of different components of the project, the availability of work spaces was not properly communicated to the project team.
Figure 5.2: Weekly PPC
On the other hand, the mandated characteristics for the master schedule, differing level of granularity of activities on the two schedules and the difficulty of maintaining the dates on the master schedule, meant that the master schedule was not a reliable or effective tool to plan the day to day work on site; and therefore, the look ahead schedules were the only documents assisting the trades in planning their work and resources.

5.1.2 Houle Electric PPC

Similar to the Percent Plan Complete (PPC) calculated for the overall interior finishing team, PPC was measured for Houle Electric separately. As depicted in the two graphs below, the PPC for Houle Electric follows the same general trend that was observed for the overall interior finishing team (figure 5.3).

![Houle Electric PPC](image)

Figure 5.3: Houle Electric PPC

As shown in figure 5.3 above, there is an evident jump in PPC on week 3; however, taking a closer look at figure 5.4 below, a possible explanation for the jump and the subsequent
decline is that a very small number of assignments were actually assigned to Houle in that
particular week in comparison to the number of tasks assigned to Houle over the duration
of the study in other weeks.

Similarly, in comparison to the number of tasks scheduled for the overall interior finishing
team, a relatively small number of tasks were assigned to the electrical subcontractor each
week, and therefore, a small number of non completion tasks registered as a relatively large
percentage of failure. PPC is a ratio and in the absence of quality data selection and matching
the amount of work scheduled to the capabilities of the said trade, does not fully speak to
the performance of the team, and hence, other factors and means need to be considered.
Figure 5.4: Weekly PPC for Houle Electric
5.2 Percent Plan Complete Per Area

In addition to the general PPC charts created on the weekly basis, to gain a more in-depth understanding of the impact of coordination and interdependencies between the trades performance, a separate graph illustrating the Percent Plan Complete in each area of the building was created.

5.2.1 Interior Finishing Team PPC Per Area

The two graphs below are different representations of these PPC values per area, each week, over the study period. Figure 5.5 shows the break up per area over the weeks of the study with the percentages listed below.
Figure 5.5: Interior Finishing Team Weekly PPC Per Area
In addition, figure 5.6 depicted below shows the stacked percent of completed tasks in each area over the duration of the study. As observed, during the 10 weeks period depicted, the maximum stacked percentage of commitments completed in different areas was less than 500%, which means that the team performed less than half of the activities they committed to over the 10 week period.
Figure 5.6: Stacked PPC Over 10 Weeks of Study
There are many factors contributing to the low percentage of planned work completion overall and the observed variation in different areas. Factors such as site logistics and coordination issues including heavy loads of reshore and temporary structure, excess material storage on site and trade stacking, in addition to failure to meet commitments by other trades greatly impacted the overall performance of the interior finishing team over the duration of this study. Figures 5.7a & 5.7b below are examples of some of the conditions that impacted the performance of the team in keeping their commitments. The contributing factors to variance, and the trades failure to perform as planned will be explored in more details in the following sections.

![Example 1](image1.png) ![Example 2](image2.png)

Figure 5.7: Temporary Structures and Scaffolding on Site

5.2.2 Houle Electric PPC Per Area

Furthermore, a similar analysis was performed for Houle electric separately and its results are demonstrated in the two following charts. Comparable outcome to the overall interior finishing team were again observed here. The similarities between the results of the overall team and a single entity as part of the whole organization, highlights the interdependency between the tasks and different trades. This topic will be assessed further in this chapter.

Figure 5.8 & 5.9 are two different representations of the PPC variations during the study
period in different areas. Factors such as number of tasks assigned to Houle in each area, their reliance on upstream trades completing the prerequisites to their tasks, and availability of resources are some root causes for the variation which will be explored further.
Figure 5.8: Weekly PPC Per Area (Houle Electric)
Similarly, as illustrated in figure 5.9 below, over the 10 weeks depicted, the maximum stacked PPC for Houle was just about 300% which translates to an average of 30% in the 10 week period; which correlates to the overall low PPC observed in the study period.
Figure 5.9: Stacked PPC Over 10 Weeks of Study
5.3 Variance Analysis

One of the important steps in the Last Planner System process, is the variance analysis. Planned Percent Complete, measures the extent to which the weekly work plans are realized each week. Analysis of the non conformance, on the other hand, can identify the reasons why the tasks were not realized and lead back to the root causes. Identification of the reasons why planned work was not completed, can be used to improve PPC, the planning process and consequently the project performance.

On this project, the performance of the previous week was not reviewed during the coordination meetings. One action initiated by the research team, was to evaluate the weekly schedules and compare the progress on site to the scheduled tasks. The assignments statuses were then updated on vPlanner- the visual planning software utilized- as completed, ongoing or not complete and the reason for variance of tasks were documented.

There is a list of pre-populated reasons for variance in vPlanner that can be assigned to tasks marked as not complete (table 5.1).
Since there was no explicit look-back on the work performed, the reasons for non-completion were not usually discussed in the meetings. In order to simplify the process and pinpoint the main recurring reasons for variance, through discussions with the partner organizations superintendent, the list was tailored and six simplified categories (table 5.2), were assigned to the tasks identified as not complete.
Table 5.2: Reasons for Variance Used on the Project

<table>
<thead>
<tr>
<th>Reasons for Variance Used on the Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-requisites work not completed</td>
</tr>
<tr>
<td>Design, information, approvals incomplete</td>
</tr>
<tr>
<td>Lack of resources (material, labour force, equipment)</td>
</tr>
<tr>
<td>Coordination and site related issues</td>
</tr>
<tr>
<td>Scheduling errors</td>
</tr>
<tr>
<td>Commitments not met</td>
</tr>
</tbody>
</table>

5.3.1 Interior Finishing Team

The reasons for non-compliance were evaluated on a weekly basis and eventually for the overall project in the duration of the study. These reasons were communicated to the electrical contractor’s executive team.

As graphically shown in figure 5.10 below, of the 698 activities that were not completed, 367 (52%) were not completed due to prerequisite work not being completed. These prerequisites were either explicitly scheduled in the look-ahead plans, had been left out of the plans or were not properly communicated to the project team.

The outstanding RFIs, pending approvals or incomplete design processes were not discussed or reviewed during the coordination meetings and were not reflected on the schedules. Therefore, the prerequisites restraining work realization also includes information, design, change order approvals and predecessors not scheduled.
The next two categories are commitments—assignments with no explicit outstanding prerequisite assigned—to a trade, whom failed to meet the commitment, and scheduling reliability are evident scheduling errors such as wrong dates, missing or wrong logic links.

Coordination and resources were the next two reasons for variance. Coordination includes any site logistics issues such as excess material blocking access to workspace and trade stacking in confined spaces forcing one trade to pause their work. Figure 5.11, is an example of coordination putting work in an entire area on hold. The glazing subcontractors failure to
complete its assignment as planned and the oversized panels stored in the area, meant that the rest of trades were unable to perform their assigned tasks according to the schedule.

Figure 5.11: Excess Material Storage on Site

Another example of coordination issues caused by multiple trades working in one confined space, was between the sheet metal and electrical contractor; in this case, the HVAC work took priority over the electrical work and not only did the electrical crew have to stop their work, but they also had to make room for the oversized ducts by removing the cable trays already installed (figure 5.12).
And lastly, resources are attributed to assignments that were not executed as planned due to unavailability of the resources needed; this includes any material, workforce or proper equipment required to execute a work.

By examining the reasons for noncompliance and the PPC charts, it can be concluded that the fundamental causes of the low performance and non-compliance were failure to apply quality criteria to the assignments as defined in the literature in terms of soundness, definition, size and quantity. Additionally, failure to evaluate the weekly performance and failure to learn from plan failures means that the reasons the schedules were not executed as planned, were not identified, and its consequent impact on the existing commitments were not evaluated. As a result, the PPC on the project did not improve and assignments were simply rescheduled from one week to the next.
5.3.2 Houle Electric

In addition to the evaluation performed on the overall project, the reasons for non-compliance was examined separately for Houle electric. As shown in figure 5.13 below, a substantial percentage of work that Houle failed to accomplish was because of the prerequisites not completed by other trades.

![Figure 5.13: Reasons for Variance for Houle Electric](image)

<table>
<thead>
<tr>
<th>Reasons for Non-Completion Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduling Reliability</td>
</tr>
<tr>
<td>Design, Information, Approvals</td>
</tr>
<tr>
<td>Coordination</td>
</tr>
<tr>
<td>Resources (labour/material)</td>
</tr>
<tr>
<td>Commitment</td>
</tr>
<tr>
<td>Prerequisite Work by other trades</td>
</tr>
</tbody>
</table>

Figure 5.13: Reasons for Variance for Houle Electric
These graphical representations signify the dependency of specialty contractors, especially a following trade, on the upstream trades. In fact, as delineated, over the three month duration of the study, and as suggested by Houle electric’s senior superintendent they had control over about 10% of their entire scope of work. This further highlights the importance of having a predictable, reliable and comprehensive schedule created and followed by all trades across the board.

5.4 Degree of Change

Another action taken to analyze the reliability and quality of the short interval schedules, was to measure and analyze the degree of change of scheduled dates for tasks on each schedule to its successor. Based on the relatively low percent of planned work completion, and through a closer examination, it was observed that many tasks on the look aheads were continuously being rescheduled. In order to examine the degree of the variations, gauge the reliability of the schedules, and to further assist the research team in identifying the reasons for the overall low performance of trades based on the short term plans, this metric was introduced.

5.4.1 Interior Finishing Team

As shown in figure 5.14 below, the degree of change of scheduled dates for the activities that have been repeatedly re-scheduled on the short interval schedules during the study period was on average over 50%. This change, does not represent the activities that are added for the first time to a schedule or tasks that have been completed and therefore crossed off the schedule; it simply depicts the percentage of tasks that their scheduled date have shifted from one schedule to the next.

It is worth mentioning that, due to the size of the project and the rapid growth in the areas of concurrent work; the short interval schedules grew to over 10 pages and more than 600 activities in a very short amount of time; which in turn, made the process of updating
and keeping as-built or as-expected dates for all activities an onerous task for the general contractor. The noticeable drop in the degree of change from over 50% to less than 10% from week 8 to 9, was because the schedule was not updated during that period and the PPC values of 26% and 20% on weeks 8 and 9 respectively, suggest that the trades failed to perform their assigned tasks as scheduled.

Figure 5.14: Percentage of Change Per Week (Interior Finishing Team)

5.4.2 Houle Electric

In a similar fashion to the previous measurements, in addition to the overall schedule assessment, a separate analysis of the scheduled dates for tasks solely assigned to Houle was performed. In addition, the analysis was utilized to gain a more in-depth understanding of the standing of a downstream following trade and the impact of workflow variation on their ability to shield their production.
A illustrated in figure 5.15 below, the same movement can be observed for tasks solely assigned to Houle. However, on a closer review, it can be noted that the fluctuations in the degree of change from one week to the next are somewhat more pronounced. Being a following specialty trade, the electrical contractor is not prioritized as a trade; often times, they have to make way for other trades that lead the work in a specific area, eg. the sheet metal subcontractor. In addition, being a following trade, the majority of their work is dependent on the other trades and their progression. If one trade fails to meet their commitment, its impact extends along the production and impacts all the downstream trades.

![Percentage of Change Per Week (Houle)](image)

Figure 5.15: Percentage of Change Per Week (Houle Electric)

### 5.5 Degree of Change Per Area

Similarly, to further analyze the significance of coordination and mutual reliance among the trades, similar to the analysis performed for Percent Plan Complete per area, the degree of
change in scheduled dates for activities planned was analyzed in each area. Two different representations of the measurements are illustrated.

As shown in figure 5.16, the results of these analyses did not yield a smooth and uniform flow; the percentage of change varies across different locations. A possible explanation for this variation is that the work performed in each segment of the building is incomparable in terms of complexity, effort and resources. Due to the mixed-use nature of the project and all the different facilities in the podium, and the expected differing design complexity in different areas, the work complexity and efforts vary significantly across the project. These variations, instigate different results in terms of performance, and quality of schedules.
Figure 5.16: Weekly Degree of Change Per Area for the Interior Finishing Team
For example, as shown in figure 5.17, a noticeably larger percentage of change is observed in areas 2, 3 and 4 on both levels 2 and 3, which also correlates with the relatively lower PPC values measured in those areas. This was, in part due to the complex ceiling and coving design in those areas and the trade and GC’s inability to accurately predict a realistic duration for the work, which in turn impacted the other trade’s assigned tasks in those areas.

In addition, as was discussed earlier, due to complexity of design of the structure and the mechanical, plumbing and electrical services, and the resultant constructability issues identified on site, the work was either put on hold or carried on at a much lower pace in the affected areas. Issues of similar nature were not necessarily reflected in the work scheduling decisions and tasks were rescheduled every week, until the work was eventually executed on site.
Figure 5.17: Examples of Degree of Change Observed Per Area Per Week
5.6 Observations

During the data collection period, different strategies and attempts were employed by the project team to rectify the scheduling delays. One of the attempts, was to test out some variation of the Last Planner® System and pull planning. A handful of meetings were held with the project team as an introduction to the Last Planner system, however, the approach was soon abandoned; it was brought up on several occasions by the GC’s superintendents that the project was too large and too complex to implement the planning strategy; the scheduling effort was burdensome, time consuming and there was not enough interest from the trades. In addition, the trades were not contractually obligated to attend the meetings or follow the schedules created in these meetings and some were not familiar with the approach. Furthermore, GC’s superintendent or the trades foremen attending these meetings were not given authority to make any decision when it came to the project execution.

Another attempt was aimed at creating look ahead schedules (typically 3 or 6 weeks). However, these schedules were developed without the trades input and were done using the traditional CPM method- irrespective of the workflow on site or the spatial and temporal constraints. In addition, as observed through the data collected and analyzed, no efforts were put into selecting quality assignments. Oftentimes, there were outstanding RFI or coordination drawings awaiting approval for the tasks assigned, or a long string of incomplete prerequisite work, hindered trades performance. Measurement of the PPC on the project, revealed a very low plan reliability. As observed through this study, the plan reliability is of vital importance because it has a direct impact on trades performance and their downstream customers.

The primary factors contributing to the low plan reliability observed on this project are described in the table below:
Table 5.3: Primary Factors Contributing to Low Plan Reliability

<table>
<thead>
<tr>
<th>Design</th>
<th>• incomplete design</th>
<th>• constructability issues</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• missing information</td>
<td></td>
</tr>
<tr>
<td>Coordination</td>
<td>• excess storage of material on site</td>
<td>• spatial conflict between different trades and systems</td>
</tr>
<tr>
<td></td>
<td>• trade stacking in confined</td>
<td></td>
</tr>
<tr>
<td>Schedules</td>
<td>• plans, did not include a detailed definition of assignments,</td>
<td>• plans often missed logic or resource linkages</td>
</tr>
<tr>
<td></td>
<td>• trades often were unsure, which trade was in charge of what activity</td>
<td>• duration assigned to activities were often unrealistic</td>
</tr>
<tr>
<td>Learning</td>
<td>• absence of a look-back or learning process</td>
<td>• no action was taken to avoid such failures from recurring</td>
</tr>
<tr>
<td></td>
<td>• work not accomplished was not reviewed</td>
<td>• impact of plan failures on the upcoming tasks and commitments was not evaluated</td>
</tr>
</tbody>
</table>
Chapter 6

Discussions

One objective of setting up this action-research with a specialty contractor was to study the extent of their control on a conventional, yet very complex project, in terms of shielding their production on site from upstream uncertainty and variations and improving their efficiency and flow of work. As explored earlier, shielding requires that certain quality criteria and rules be applied to the assignments selected to be performed as part of the short interval planning and weekly work plans. As was evident from the various data collected and analyzed throughout this project it became apparent that the main focus of the project team had been put on starting work in whichever area available as soon as possible without any consideration to the conditions in that area, availability of resources and whether or not the prerequisite work was satisfied. These uncertainties and variations, as was observed, led to unreliable work scheduling and loss of productivity. On many occasions, time was wasted on site waiting for or looking for work to become available; many crews either had to be sent home or work on small areas in confined spaces that significantly impacted their efficiency.

In addition, the extremely low level of plan reliability observed on this project over the course of the study period may have in part resulted from it being an extremely complex project both in terms of design and technical complexity as well as organizational and operational complexity. As mentioned, the project team is comprised of a relatively large number
of subcontractors and many are required to work in confined spaces in a very close proximity spatially and temporally. In addition, due to complexity of design, many services—especially MEP services—require close coordination, communication, and collaboration among the parties involved. Considering the large number of key players involved, getting everyone into one space at the same time to coordinate the closely related work or to make decisions on issues at hand, proved to be an extremely difficult task.

The project—granted an extreme case—helps magnify the challenges, barriers, and limitation with traditional project management and delivery methods and the limited control of following trades on their scope of work and their ability to shield their production from uncertainties on a project.

Reflecting on the process observed over the course of the research action and comparing the process with the guidelines of the Last Planner® system described in the second chapter; the first sub-objective of this research can be addressed: “Investigate traditional planning means and methods on a complex commercial project from an electrical contractor’s perspective to understand how the planning process impacts the specialty trade’s performance.”

As expressed, even though on the surface, the project team had attempted to create short term interval plans to develop a more reliable and efficient flow of work, the proper steps and actions were not taken and the mentality of the conventional management overruled these attempts.

Lean practices are based on collaborative efforts focused on elimination of waste and optimized value generation to each downstream customer and the ultimate customer (owner), while continuously improving the processes in place. Looking back on the process observed on the project studied, the planning process was not performed in a collaborative setting; the trades did not have much say in the work assigned to them; therefore, the look-ahead plans were not as realistic, comprehensive, or efficient. In addition, the activities were not scheduled at the request of downstream trades (i.e., pulled), on the contrary, the contractual expectations and obligations included in the detailed master schedule took priority over the
downstream trades’ requests and conditions on site (eg. activities and assignments were pushed).

Furthermore, another focus of lean projects is on creating reliable and predictable workflow and schedules; as identified, factors such as design, coordination, scheduling efforts and learning, contributed to unreliable near term schedules that overall did not assist the project team with planning or project execution and ultimately led to the low PPCs observed and trades failure to meet their commitments.

Utilizing this assessment and the results observed over the study period, the second sub-objective can also be addressed: “Understand the challenges, limitations and potential benefits of applying Lean principles and tools from the perspective of an electrical specialty trade in the context of a complex project delivered in a traditional procurement mode”. As explored throughout this document, the overarching challenge with implementation of lean by a specialty trade on this project is embedded in the traditional approach of project delivery employed on the project. As observed, the one-sided planning on the project meant that the trades did not have much say in the creation of the look-ahead schedules which significantly limited their ability to efficiently plan their daily work. Reflecting on the shortcomings observed in the planning process, taking a more collaborative approach to creation of the said short term schedules, keeping track of the constraints, prerequisite and predecessor tasks to each trades assignments, ensuring trades understand their commitments and are prepared to uphold their assignments are some lean strategies that could improve the outcome and overall project performance.

In additions, steps such as tracking the previous week’s commitments, updating the assignment statuses and identifying the reasons for variance, could enable the team to find the root cause for such failures and take corrective measures to improve their planning strategies, as opposed to the overall downhill trend observed on this project.

The findings and results of this case study speak to the inadequacy of the conventional project management techniques and highlight the current industry’s need for a more collab-
orative, holistic and integrated approach to project deliveries from inception to delivery.

Based on the observations made, implementation of lean in a lonely setting for a following trade with such a limited control on their scope of work and their interdependency with other stakeholders in the project is viewed as being not effective. Shielding their production is possible if they have control on the work assigned to them and have an input on the preceding tasks to their work. This was not the case in the project that was studied.

That said, the partner organization’s commitment to improving their efficiency by: (1) taking advantage of their prefabrication capabilities, (2) innovative, clear and organized storage solutions on site, and (3) their incorporation of visual planning software and research team’s input into their practice, enabled them to enhance their agility and efficiency within their limited control and stay on task on the limited unrestricted assignments they had.

Validity of findings in action-research could be viewed in terms of the retroactions taken by the partner organization; in terms of this research project, the artifacts and reports produced as part of the weekly tasks undertaken in the action-research were shared with the partner organization on a weekly basis. Data were collected and analyzed in real-time and were reviewed by the project team. Suggestions made by the research team were implemented to the extent possible, and the findings were evaluated and validated by the organization. Sample of the weekly reports are appended to this research thesis.

Limitations of this research could be viewed in terms of the action-research approach taken and degree of involvement of the author with the organization which could potentially introduce some bias through observations in the meetings and discussions with the project team. Additionally, while the single case study used informed the research team of the common practices in the construction industry and the challenges faced as a result of approaches taken, there is an issue with generalizability of the findings.

Lastly, recommendations that can be formulated as part of this action-research project are:
In terms of organization formation and delivery approaches, taking more integrated approaches to project deliveries by involving key project participants in early stages of project pre-planning and design; incorporating their input in planning and execution of projects and motivating the team to work together collaboratively towards a unified goal while sharing risks and rewards on novel, innovative project delivery approaches such as Integrated Project Delivery (IPD); this is still achievable to some extend on traditional projects by addition of design-assist roles and collaborative planning.

In terms of use of technology and innovative tools, as was observed, 3D models were used as part of coordination and high level clash detection on the overall project; incorporation and integration of modeling with scheduling efforts, in addition to use of visual planning software could significantly assist the project team with visualization of the scheduled tasks to create and maintain a more efficient flow on site.

Finally, in terms of processes, as mentioned, incorporation of the Last Planner® system of production guidelines, such as make-ready planning, constraint analysis and look-back processes can assist the project team in creation of more reliable, predictable and efficient plans; having more reliable plans, in turn, adds to accountability of stakeholders and fosters a more collaborative team environment. However, this requires the appropriate organizational context to fully implement.
Chapter 7

Conclusion

An action-research was carried out over a 16 month period to assess the performance of a specialty trade on a traditional construction project and investigate the potential impact of implementation of lean philosophy within the organization.

In order to gain a better understanding of current project management practices on a large commercial project in Canada, an assessment of the efficiency of the planning and execution of a project over the course of the research was carried out. The planning efforts and project control practices were documented and analyzed in depth; the scheduling efforts, effectiveness and reliability of the schedules were evaluated using different metrics such as Planned Percent Complete (PPC) and degree of change observed in the weekly distributed schedules. In addition, the reasons for variance of weekly commitments were evaluated based on simple categories defined by the project team.

Through the analysis performed the fundamental contributing factor to such a low observed PPC was identified as the team’s failure to select quality assignments in terms of soundness, definition, sequence and size. Oftentimes, assignments were scheduled irrespective of the trades capability of executing them in terms of having the needed material on site and/or available work force to perform the tasks. Additionally, many of the assigned tasks on the weekly work plans had long strings of prerequisites that were not yet satis-
fied. Moreover, lack of a learning, or look back process through identification of reasons for plan implementation failure meant that the root causes were not identified and therefore, corrective measures were not taken to improve the plan reliability during the study period.

The processes observed over the course of the study period were then evaluated and compared to the guidelines of lean construction principles and practices. Furthermore, guidelines and processes of The Last Planner® system of production and quality criteria suggested and implemented on lean projects were explored, and their potential impact on the project studied was evaluated.

Additionally, the impact of reliability and predictability of construction planning on a following trade in terms of their ability to shield their production and increase their productivity and efficiency was evaluated. It was found that variations in the scheduling reliability, the upstream trades’ performance, and their ability to keep their commitments greatly impacted the electrical contractor’s performance. As observed the electrical team’s work is highly dependent on the upstream trades and about 89% of assignments that Houle failed to perform was because of the prerequisites not completed by other trades. These recursive issues and uncertainties adversely impacted the team’s ability to shield their production on site and repeatedly time and resources were wasted on site looking for work to become available.

Furthermore, despite the limitations of the research in terms of the prevailing conventional project management mentality and control on the project, and the project team’s resistance to change; the research project was able to investigate the impact of implementation of lean within the specialty trades organization, implement and test visual planning tools to support such approaches and document the benefits, challenges, and lessons learned in the context of the Canadian construction industry.

Further action-research cycles could be implemented to potentially refine the findings over longer periods of study. In addition, similar studies could be replicated on similar case studies to evaluate consistency of the findings. Another string of study could also be imple-
mented to evaluate the efforts and effectiveness of planning processes on more collaborative projects of similar scope and complexity.
Bibliography


Bertelsen, Sven (2002). “Bridging the gap–towards a comprehensive understanding of lean construction”. In: IGLC-10, Gramado, Brazil.


Appendix: Sample Progress Report
<table>
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<tr>
<th>Date Recorded</th>
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<td>level 3</td>
<td>Area 2</td>
</tr>
<tr>
<td>2016-08-11 1:18 AM</td>
<td>14289</td>
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<td>board/lam &amp; plywood UPS room 3-GT1-04 and electrical room 3-B1-07</td>
<td>Podium</td>
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<td>Area 2</td>
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<td>14432</td>
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<td>wall framing (walls not dependent on HVAC)</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 2</td>
</tr>
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<td>2016-08-11 1:19 AM</td>
<td>14465</td>
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<td>OH &amp; In wall M&amp;E RL (wells not dependent on HVAC)</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 2</td>
</tr>
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<td>2016-08-11 1:19 AM</td>
<td>14531</td>
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<td>Podium</td>
<td>level 3</td>
<td>Area 2</td>
</tr>
<tr>
<td>2016-08-11 1:22 AM</td>
<td>14417</td>
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<td>Vault/chip room block work</td>
<td>Podium</td>
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<td>Area 3</td>
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<tr>
<td>2016-08-11 1:23 AM</td>
<td>14227</td>
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<td>Frame wall (Balcony-HVAC Completion Main North)</td>
<td>Podium</td>
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<td>Area 3</td>
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<tr>
<td>2016-08-11 1:23 AM</td>
<td>14514</td>
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<td>resources</td>
<td>Frame balance of wall (not dependent on HVAC)</td>
<td>Podium</td>
<td>level 3</td>
</tr>
<tr>
<td>2016-08-11 1:23 AM</td>
<td>14402</td>
<td>Constraint Not Complete</td>
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<td>Podium</td>
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<td>Area 3</td>
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<tr>
<td>2016-08-11 1:23 AM</td>
<td>14448</td>
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<td>Podium</td>
<td>level 3</td>
<td>Area 3</td>
</tr>
<tr>
<td>2016-08-11 1:23 AM</td>
<td>14232</td>
<td>Other</td>
<td>Commitment not met</td>
<td>FCLAVAV installation</td>
<td>Podium</td>
<td>level 3</td>
</tr>
<tr>
<td>2016-08-11 1:24 AM</td>
<td>14153</td>
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<td>resources</td>
<td>Frame wall IDF Room 3-B1-10, 11</td>
<td>Podium</td>
<td>level 3</td>
</tr>
<tr>
<td>2016-08-11 1:24 AM</td>
<td>14368</td>
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<td>OH &amp; in wall M&amp;E (Electrical Early rooms 3-B2-01A, B,C)</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 3</td>
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<tr>
<td>2016-08-11 1:24 AM</td>
<td>14492</td>
<td>Constraint Not Complete</td>
<td>Board/lam &amp; plywood Electrical Early rooms 3-B2-01A, B,C</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 3</td>
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<tr>
<td>2016-08-11 1:24 AM</td>
<td>14434</td>
<td>Constraint Not Complete</td>
<td>OH &amp; in wall M&amp;E (Electrical Early rooms 3-B2-01A, B,C)</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 3</td>
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<td>2016-08-11 1:24 AM</td>
<td>14486</td>
<td>Constraint Not Complete</td>
<td>Inspections (Electrical Early rooms 3-B2-01A, B,C)</td>
<td>Podium</td>
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<td>Area 3</td>
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<td>2016-08-11 1:27 AM</td>
<td>14155</td>
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<td>Podium</td>
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<td>Area 3</td>
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<td>2016-08-11 1:27 AM</td>
<td>14035</td>
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<td>OH &amp; in wall M&amp;E Electrical rooms 3-B2-01A,B,C</td>
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<td>Area 3</td>
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<tr>
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<td>14242</td>
<td>Vascular Delivery</td>
<td>HVAC Delivery Date</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 4</td>
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<td>2016-08-11 1:29 AM</td>
<td>13821</td>
<td>Unavailable Material</td>
<td>Material Delivery date changed resources</td>
<td>OH HVAC work West</td>
<td>Podium</td>
<td>level 3</td>
</tr>
<tr>
<td>2016-08-11 1:30 AM</td>
<td>14167</td>
<td>Unavailable Labor</td>
<td>Resources</td>
<td>Frame walls (not HVAC dependent)</td>
<td>Podium</td>
<td>level 3</td>
</tr>
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<td>2016-08-11 1:30 AM</td>
<td>14260</td>
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<td>OH &amp; in wall M&amp;E</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 4</td>
</tr>
<tr>
<td>2016-08-11 1:30 AM</td>
<td>14246</td>
<td>Constraint Not Complete</td>
<td>OH &amp; in wall M&amp;E</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 4</td>
</tr>
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<td>2016-08-11 1:30 AM</td>
<td>14282</td>
<td>Unavailable Labor</td>
<td>Resources</td>
<td>Frame walls</td>
<td>Podium</td>
<td>level 3</td>
</tr>
<tr>
<td>2016-08-11 1:30 AM</td>
<td>14285</td>
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<td>OH &amp; in wall M&amp;E</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 4</td>
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<td>2016-08-11 1:30 AM</td>
<td>14283</td>
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<td>Podium</td>
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<td>2016-08-11 1:30 AM</td>
<td>14281</td>
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<td>Pre-board inspection</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 4</td>
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<tr>
<td>2016-08-11 1:30 AM</td>
<td>14533</td>
<td>Constraint Not Complete</td>
<td>B/T/G and Plywood</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 4</td>
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<td>2016-08-11 1:30 AM</td>
<td>14482</td>
<td>Constraint Not Complete</td>
<td>Paint</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 4</td>
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<tr>
<td>2016-08-11 1:31 AM</td>
<td>14244</td>
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<td>Commitment not met</td>
<td>FCLAVAV installation</td>
<td>Podium</td>
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<tr>
<td>2016-08-11 1:32 AM</td>
<td>14162</td>
<td>Unavailable Labor</td>
<td>Resources</td>
<td>Top track and opening layout</td>
<td>Podium</td>
<td>level 3</td>
</tr>
<tr>
<td>2016-08-11 1:32 AM</td>
<td>14511</td>
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<td>resources</td>
<td>Frame walls (Elec Closet 3-ELEC-01, 3-KR-13, 3-K-01)</td>
<td>Podium</td>
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</tr>
<tr>
<td>2016-08-11 1:32 AM</td>
<td>14307</td>
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<td>OH &amp; in wall M&amp;E (Elec Closet 3-ELEC-01, 3-KR-13, 3-K-01)</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 5</td>
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<tr>
<td>2016-08-11 1:32 AM</td>
<td>14500</td>
<td>Constraint Not Complete</td>
<td>OH &amp; in wall M&amp;E (Elec Closet 3-ELEC-01, 3-KR-13, 3-K-01)</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 5</td>
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<tr>
<td>2016-08-11 1:32 AM</td>
<td>14164</td>
<td>Unavailable Labor</td>
<td>Resources</td>
<td>Frame walls</td>
<td>Podium</td>
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<td>2016-08-11 1:33 AM</td>
<td>14176</td>
<td>Constraint Not Complete</td>
<td>OH &amp; in wall M&amp;E</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 5</td>
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<td>Date Recorded</td>
<td>Task ID</td>
<td>Variance Reason</td>
<td>Description (vPlanner)</td>
<td>Component</td>
<td>Floor</td>
<td>Zone</td>
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<tr>
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<td>2016-08-11 1:33 AM</td>
<td>14180</td>
<td>Constraint Not Complete</td>
<td>OH &amp; in wall M&amp;E</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 5</td>
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<tr>
<td>2016-08-11 1:34 AM</td>
<td>14174</td>
<td>Other</td>
<td>Chinese Rest. wall framing</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 5</td>
</tr>
<tr>
<td>2016-08-11 1:34 AM</td>
<td>14172</td>
<td>Constraint Not Complete</td>
<td>Chinese Restaurant OH Electrical</td>
<td>Podium</td>
<td>level 3</td>
<td>Area 5</td>
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<tr>
<td>2016-08-11 1:37 AM</td>
<td>14294</td>
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<td>Masonry @ Vertical Duct Shaft (Fuel Fill)</td>
<td>Podium</td>
<td>level 1</td>
<td>Area 5</td>
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<tr>
<td>2016-08-11 1:44 AM</td>
<td>14485</td>
<td>Unreliable Reporting – Status Unknown</td>
<td>Frame wall (Electrical Early rooms 3-B2-01A, B,C)</td>
<td>Podium</td>
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<td>Area 3</td>
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</tbody>
</table>

| Constraints | 60 |
| Commitment  | 16 |
| Resources   | 26 |
| SL & Changes| 3  |
| Coordination| 0  |
| Status unknown/unreliable | 2 |

Total commitments: 207
Completed: 54
On going: 46
Not Complete: 107

Complete, ongoing, not complete

| Completed | 26.1% |
| On going  | 22.2% |
| Not Complete | 51.7% |