Last Planner System and the Role of Social Interaction: A Social Network Analysis Perspective

by

Parastoo Eivazi Ziaei

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Department of Civil and Environmental Engineering
University of Alberta

Abstract

Lean construction is a new project management method that focuses on increasing quality and value and, by contrast, decreasing any type of waste. Lean management consists of some principles and concepts that have to be noticed to implement effective Lean management and take advantage of it. Based on the lean concepts and principles, behaviour and culture must be implemented properly to achieve successful lean management. The LPS has been used to increase the reliability of production planning and control. However, a useful health check assessment is needed to understand the level of lean maturity and the implementation level of the last planner system, which is a production planning and control method in lean construction.

Implementing the last planner system (LPS) requires effective communication to collaborate and exchange information. There are a lot of breakdowns in people's communication and information transparency which may cause some planning issues, so to address this concern, there is a need to study the interaction between parties and find the gap to improve the communication and information flow. Besides the literature review, a pilot case study has been chosen to investigate the level of lean in the project and find room to improve weaknesses.

A lean survey was prepared based on the lean success factors. After survey validation by lean experts, the survey was conducted. The lean success factors survey shows that the LPS, communication and collaboration levels are lower than other success factors. In addition, the gathered data from the planning software showed that the Percent Planned Complete (PPC) is low. Therefore, the results prove that the low PPC occurred because of a lack of communication and collaboration and the unhealthy LPS. So, a pilot case study also shows the need for study teams' communication and information transparency.

This study aims to introduce an LPS and social interaction framework to understand the interaction structure, the level of maturity of the lean behaviour, and the effectiveness of the last planner system. Design Science Research (DSR) methodology has been implemented in this research to propose a framework to assess the LPS and social health check. The developed framework includes 1) identifying the LPS success factors, 2) conducting two surveys, 3) gathering LPS metrics, 4) measuring the LPS implementation level, 5) measuring the social network metrics, 6) evaluating team performance, 7) lessons learned and identifying strength and weaknesses.

The LPS survey was designed based on the LPS success factors. The factors have been identified through literature review and interviewing academic and professional experts to prepare the survey. In addition, a social network analysis survey was designed to determine the team members' relationships. After preparing the surveys, three primary case studies have been selected to test the proposed framework and examine the level of LPS implementation and parties' interaction.

Team interaction can be analyzed by Social Network Analysis (SNA) and taking advantage of Gephi software to study the metrics and the outcomes. After analyzing the network and its structure, the correlation test was conducted to find the relationship between SNA and LPS metrics. The results prove that 1) the lookahead planning network has significant importance in impacting PPC, and 2) there is a positive correlation between Graph Density and PPC and a negative correlation between Average Path Length and PPC, which means a well-connected network with faster interaction will have a higher PPC. Finally, a new network structure has been suggested to improve the Graph Density and Average Pathlength, which leads to improving the lookahead planning and having a high PPC.

Preface

This thesis is an original work by Parastoo Eivazi Ziaei. The research project, based on which this thesis is written, received two research ethics approval from the University of Alberta Research Ethics Board, Projects Name:

1. “Lean and Last Planner Health Check Assessment”, Project ID: Pro00115874, approved on March 17, 2022.
2. “Last Planner Health Check Assessment”, Project ID: Pro00119251, approved on March 29, 2022.

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List of Abbreviations

CO	Project Coordinator	CTL	Construction Team Leader
CT1	Construction Team 1	CT2	Construction Team 2
CT3	Construction Team 3	CT4	Construction Team 4
CT5	Construction Team 5	CT6	Construction Team 6
CT7	Construction Team 7	DD	Deputy Director
DEL	Support Department (Electrical)	DSR	Design Science Research
EV	Support Department (Environmental)	GCL	General Contractor Leader
GC1	General Contractor 1	GC2	General Contractor 2
GC3	General Contractor 3	GC4	General Contractor 4
GC5	General Contractor 5	GC6	General Contractor 6
GC7	General Contractor 7	LM	Lean Manager
LPS	Last Planner System	PA	Project Administrator
PM1	Project Manager 1	PM2	Project Manager 2
PPC	Percent Plan Completed	QL1	Support Department (Quality 1)
QL2	Support Department (Quality 2)	QL3	Support Department (Quality 3)
QL4	Support Department (Quality 4)	SCS	Subcontractor (Concrete supply)
SD	Scheduler	SEL	Subcontractor (Electrical)
SF	Support Department (Safety)	SI1	Superintendent 1
SI2	Superintendent 2	SI3	Superintendent 3
SNA	Social Network Analysis	SMP1	Subcontractor (Marine Piling 1)
SMP2	Subcontractor (Marine Piling 2)	SR	Support Department (Survey)

SRB1	Subcontractor (Rebar 1)
SRB2	Subcontractor (Rebar 2)
SRB3	Subcontractor (Rebar 3)
TA	Task Anticipation
TMR	Tasks Made Ready
TP1	Trade Partner1
TP2	Trade Partner2
TP3	Trade Partner3
TP4	Trade Partner4
TP5	Trade Partner5
TP6	Trade Partner6
TP7	Trade Partner7
TP8	Trade Partner8
TP9	Trade Partner9
TP10	Trade Partner10
TP11	Trade Partner11

CHAPTER 1 – INTRODUCTION

1.1. Background and Problem Statement

The construction industry is challenging because of the difficulty in scheduling and budgeting, so planning and scheduling in construction are essential and need to be done precisely to avoid being behind schedule and overbudgeting. Planning helps decrease uncertainties in a project and improve the process' efficiency while better understanding project objectives (Chan et al., 2004).

Modern project management has been developed over the past forty years as companies have realized the necessity of project management (Kerzner, 2017). Lean project management is part of this modern project management that has been developed. The goals and the structure of lean project management are different from traditional project management. The main focus of lean planning is to deliver a product of better quality, maximize value, and minimize waste (Ballard & Howell, 2003). In other words, in lean project management, the objectives for the delivery process are clear, the product and process can be designed simultaneously, and production control applies entirely during the project's life (Howell, 1999).

The last planner system is a tool of lean project management to control the project's production and help to plan better. It also helps to be more thoughtful in production planning and to assist in reducing uncertainty, developing planning foresight, smoothing variation, and improving workflow. In the last planner system, there are four planning processes, which are master scheduling, phase scheduling, lookahead planning, and weekly work planning (Power et al., 2021; Ballard & Tommelein, 2021).

- Master Scheduling: defining the milestones of the project.

- Phase scheduling: Specifying handoffs and collaborative planning.
- Lookahead Planning: Anticipating tasks by breaking down tasks into sub-tasks.
- Weekly work Planning: weekly work assignments that are reliable and promising (Hamzeh et al., 2012).

Different chronological spans help plan in greater detail as you get closer to work. In the look-ahead planning stage, activities are broken down, constraints are identified, and operations are made ready (Hamzeh, 2009). Failure of constraint identification in lookahead planning leads to the emergence of new tasks in the weekly work plan, which adds an extra burden on the planning efforts and causes plan failure (Hamzeh & Aridi, 2013). New tasks are 1) the ones that have not been identified in lookahead planning and appear in the week of execution, and 2) the ones that were not considered critical before but appear as critical tasks at the execution time (Hamzeh, 2009). Other research shows that some new tasks might occur because of a lack of communication and people's behaviour (Rouhana & Hamzeh, 2016).

In construction projects, the decision-making process is influenced by the social interactions and communication between the team members, so miscommunication and involved parties' behaviours throughout the process might lead to creating more new tasks (Hamzeh & Aridi, 2013). In other words, since construction teams are multidisciplinary and temporary, having effective communication to exchange information and collaborate to reach the same goal is crucial. Even though implementing the LPS helps to build relationships among the construction team and strengthen social networks, there are still many breakdowns in people’s communication and information transparency, which may cause: (Priven & Sacks, 2013; Castillo, 2018; Priven & Sacks, 2016; Ghosh et al., 2017)

- Difficulty in constraint identification and removal
- Difficulty in the exchange of communication
- Decreased participant involvement in the decision-making process
- Being behind schedule because the parties could not finish tasks on time.

Each of the abovementioned points leads to partial implementation of LPS, struggle with the planning process, and poor project performance. Priven & Sacks (2016) examined that project performance is influenced by teams' interaction, so finding planning behaviour leads to improving the planning process and finding room to improve the weaknesses. Therefore, there is a need to study planning behaviour by focusing on teams' relationships and finding room to improve the project performance. Hence, this research focuses on studying the social interactions among team members and finding the effect of the interaction on the LPS, and finally proposing a health check framework that helps track the current social interaction and project's performance. To do so, a pilot case study and three primary case studies have been chosen to validate the proposed framework.

1.2. Research Objectives

The research aims to understand the social interactions among construction team members and find the relationship between SNA metrics and the LPS metrics. More specifically, the research objectives are:

- Develop an understanding of the relationship between team structure and planning reliability.

- Develop a new framework to measure the LPS maturity level and conduct a LPS and social interaction health check.

- Finally, develop a dashboard to track the current situation in the project and find its weaknesses.

1.3. Research Methodology

This section briefly defines the research methodology used to conduct the dissertation research. The research implements the design science research (DSR) methodology to propose a health check framework for improving the teams' interaction and project performance. DSR aims to develop an artifact to resolve a related problem identified in a specific environment, for which the effectiveness and contribution should be demonstrated and rigorously explained. In this research, the artifact is the LPS and SNA health check framework to improve the project's performance by focusing on parties' relationships and SNA and LPS metrics. Detailed research methodology is described in Chapter 3.

1.4. Thesis Organization

In general, the thesis consists of the following:

Chapter 1 provides background information about this thesis. In addition, Chapter 1 discusses the expected contributions and methodology of the research.

Chapter 2 provides a literature review on the relevant topics, including project planning for lean construction, the Last Planner System and its different phases, and social network analysis and its application in construction.

Chapter 3 presents the methodology, including the design science research approach and social network analysis as the method for this research.

Chapter 4 illustrates the results, a case study, and data analysis.

Chapter 5 describes the conclusions, contributions, and limitations of the study.

CHAPTER 2 – LITERATURE REVIEW

2.1. Project Management and Planning

According to PMI's "*A guide to the Project Management Body of Knowledge*, "project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. Project planning is essential for controlling project success as it gives detailed information about execution time and resources for the project parties (Zwikael, 2009). Project management is accomplished through the appropriate application and five process groups, which are: initiating, planning, executing, monitoring and controlling, and closing. Managing a project includes the management of integration, scope, time, cost, quality, human resources, communications, risks, and procurement (PMI 1996; Ballard, 2000)

In the 19th century, Bar and Gantt charts were used for project planning in industrial management and the construction industry for scheduling construction projects. The Critical Path Method was the developed version of the Gantt charts for production management methods and has been widely used since late 1950 (Henrich & Koskela, 2006). CMP relies on creating construction schedules by breaking the project into activities and assigning them to the task leaders. The main focus of traditional project management is delivering project objectives on the transformational or activity level, and not on flow or value generation. So, measures are taken to reduce the cost and duration or sequence of the activities if they fall behind their critical path (Howell, 1999; Diekmann & Thrush, 1986). Therefore, Ballard and Howell (1997) stated that there is a need to develop a new management system to make good decisions about productivity and project progress.

In addition, decreasing variability was another reason for introducing the new management system. A poor management system leads to fluctuating and unexpected conditions and makes objectives unstable and unachievable (Ballard, 2000; Thomas et al., 2002). Variability in performance is the main reason for having an unstable condition, so having a new management system that could decrease the variability is vital. As a result, lean construction has been introduced, which has been adopted from lean manufacturing principles. According to lean manufacturing principles, construction workflow variables are treated as impeding system performance (Howell, & Ballard, 1994; Tommelein, 1998).

Push and pull are two primary ways of regulating workflow in manufacturing systems that have been identified by manufacturing production control (Ballard, 2000). In the push system, which is the traditional approach, materials or information are released into a system based on a previously assigned due date. By contrast, the "pull" system is the concept of modern planning, and in this system, materials or information are released based on the system's state (Hopp & Spearman, 1996). In summary, a pull system is a lean manufacturing strategy developed to reduce waste and focus on decreasing variability by taking advantage of techniques like the Last Planner System (LPS) (Thomas, 2003).

2.2. Literature review on Lean and Last Planner system

Lean construction begins with the principles of the Toyota Production System, which Taiichi Ohno developed. Customer value identification, waste reduction by identification of non-value-adding activities, creating a continuous flow in production, and continuous improvement are the main concepts of the Toyota Production System (Koskela, 1992; Howell, 1999). Additionally, lean production is an approach to managing a production process by focusing on achieving value efficiency and provides a helpful tool for developing a methodology for managing the construction planning process (Faniran et al., 1997).

The Last Planner System (LPS) technique is one of the essential applications of the lean construction concept, which helps to control planning, and minimize uncertainties and complexity by involving subcontractors and lower-level management in the planning and control process (Hamzeh et al., 2019; Viana et al., 2017). Moreover, the LPS production planning and control system increases workflow reliability on construction projects (Ballard & Howell, 1997). To address deficiencies of traditional production planning and control in construction, the LPS contains five planning practices: (Hamzeh, 2009)

1. Planning in more detail as you get closer to performing the work
2. Developing the work plan with those who complete the work
3. Constrain identification and removal to make work ready and increase the work plan's reliability
4. Making reliable promises and active negotiation and interaction with project parties
5. Implementing root cause analysis to learn from planning failures

The LPS has four planning process control levels, which are master scheduling, phase scheduling, look-ahead planning, and weekly work planning, which can be seen in Figure 1.

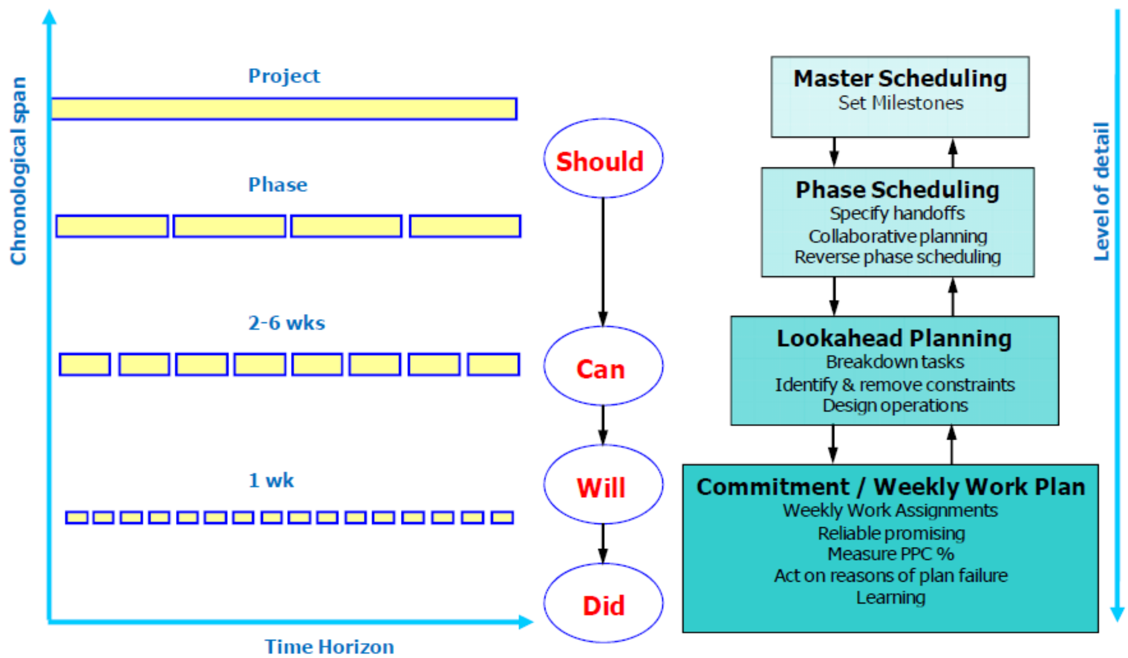

Figure 1. Planning levels in the LPS for production planning (Hamzeh, 2009)

Master scheduling is the first step in planning and defines the identification and planning of the project milestones. A phase schedule is built based on the project milestones that have been set in the master schedule. In this phase, pull planning is used to perform collaborative phase scheduling and define milestone deliverables by adjusting the schedule to meet the available time frame. Look-ahead planning involves breaking down the identified task into smaller and more detailed tasks. In this phase, the tasks are made ready by identifying the constraints and removing them. The weekly work plan is a list of assignments to be completed within a specific week. Therefore, these levels help to plan in greater detail, as getting closer to work improves the overall workflow and allows for better coordination between project participants (Hamzeh, 2009).

Several metrics have been developed for the LPS environment, and among these metrics, Percent Planned Completed (PPC) is the most common metric. PPC measures the reliability of weekly work planning and tracks the performance of a reliable promise. It is the number of planned activities completed at the end of a short future period divided by the total number of activities promised to be completed at the beginning of that period. Besides PPC, there is a need to have other metrics to measure the overall reliability of the lookahead process (El Samad et al., 2017). Lookahead planning relies on anticipating the tasks by breaking them into sub-tasks and making these tasks ready by constraint identification and removal; so, the reliability of the lookahead plan increases by focusing on identifying and removing constraints (Hamzeh et al., 2015).

Although the LPS increases planning reliability by identifying and removing constraints and ensuring reliable commitment of labour resources, there are still some challenges in the LPS's implementation, like the existing unreliable relationship between main contractors and subcontractors (Viana et al., 2017). To address this challenge, the authors used the language-action perspective to understand construction planning and control systems, and the results revealed that formal procedures are rarely followed, especially at the look-ahead planning level.

Rouhana and Hamzeh 2016 examine three types of causes that lead to the emergence of new tasks that have not been identified before. The authors categorized these causes as reasons within the realm of planning, ongoing construction, and uncertainties. The planning behaviour contains five families: social network and communication, making ready, construction as a production system, safety management and risk analysis, learning and continuous improvement. The authors stated that project performance needs to be improved by focusing on planning behaviour (Rouhana & Hamzeh, 2016).

Liu et al. (2020) stated that in implementing the LPS, there might be some barriers because of the transition from a traditional culture to a lean construction culture. The authors categorized the barriers into socially driven and production-driven processes. The socially-driven category has two critical barriers: resistance to change and lack of cooperation (Liu et al., 2020). They also stated that LPS controls the production system by focusing on conversation, relationships, and commitment among participants, so individuals are affected by each other's social behaviour. Lastly, the authors mentioned that successful LPS implementation and training require efficient social management and technical dynamics (Liu et al., 2020).

Alarcón et al. 2005, and Asadian and Leicht (2022) examine that there is still room to maximize the benefits of LPS by identifying the barriers and missing parts in the implementation process. Asadian and Leicht (2022) stated that there was not enough study in LPS concerning the human aspect and participants' interactions to show the technique's effectiveness. Asadian and Leicht 2022 stated that improving project coordination and workflow requires effective social interactions among project participants. Therefore, there is a need to study social interactions and team dynamics within the LPS meeting to examine effective LPS implementation.

LPS aims to achieve the lean goals of increasing productivity and decreasing waste and variability through a social process of continuous improvement and collaborative planning (Seppänen et al., 2010). The research shows that reasons for low reliability were mostly related to the social process of using the information. In other words, the lack of proper team interaction and slow information flow are the other reasons for variability in the planning process (Seppänen et al., 2010). According to Koskela (2000), information flow is a critical issue from the lean production point of view; therefore, there is a need to focus on information flow to decrease variability in the planning process.

2.3. Literature review on last planner system and social network analysis

Chih Lin (1998) and Bresnen et al. (2005) stated that there is a need to bridge the positive and interpretive approach with more qualitative methods in a construction project to face key social issues. Loosemore (1998) mentioned that SNA is a quantitative tool that is able to be applied within an interpretive context in construction research. According to Pryke (2012), "Social network analysis involves the representation of organizational relationships as a system of nodes or actors linked by precisely classified connections, along with the mathematics that defines the structural characteristics of the relationship between the nodes", like Figure 2.

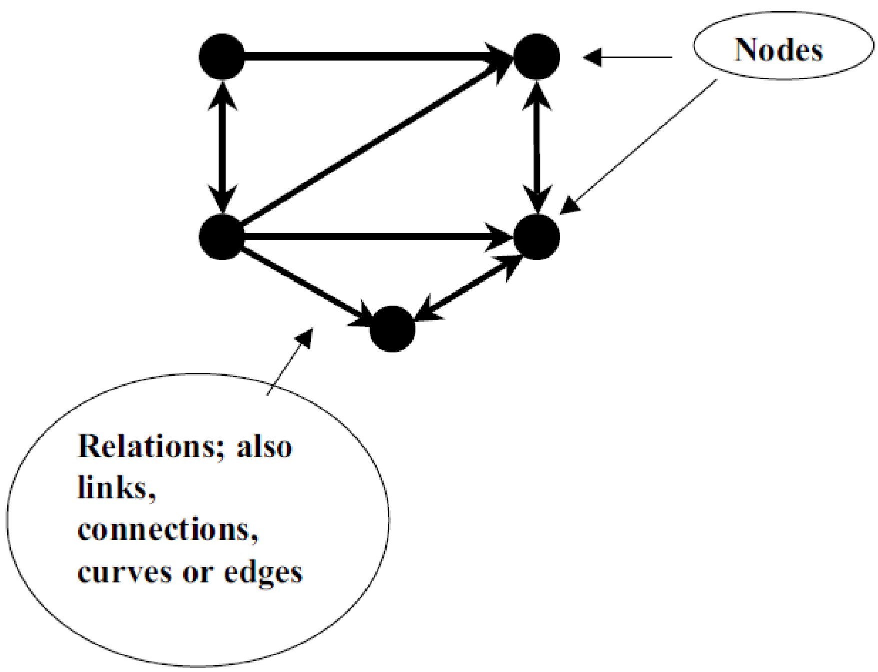

Figure 2. Nodes and actors (Pryke, 2012)

Decision-making is an ongoing process, and it is influenced by social interaction, communication, and exchanging information among group members. Decision-making is embedded in larger goals in the construction industry and requires more effective decision-making to accomplish the related tasks. The LPS is a commitment management system that helps to manage construction flow through relationship development, creating conversation, and securing promises to accomplish the tasks at the right level and time (Ghosh et al., 2017; Priven & Sacks, 2016). Even though the LPS helped to build relationships among the construction team and strengthen social networks, there is still some limitation in the LPS implementation that is related to social interaction (Ghosh et al., 2017).

According to Rouhana and Hamzeh (2016), the performance of an organization is affected by the behavioural responses of team members, so a lack of communication and existing different patterns of planning behaviours could cause planning failure by creating new tasks that have not been identified in the planning process. The authors found that the level of problem-solving and making reliable promises is higher in cases with higher interaction and communication because of greater transparency and a higher level of information exchange. As a result, studying the team's interaction and finding the planning behaviour in the team improves the planning process and leads to more reliable planning (Rouhana & Hamzeh, 2016).

According to previous research, since parties' relationships influence project performance, there is a need to study and measure the levels of communication among participants in project organizations (Priven & Sacks, 2016; Castillo et al., 2018). Pryke (2005), Nohria and ECCles (1992) also highlighted the need for SNA as a suitable method to investigate the relationship among construction teams as follow:

- All organizations are social networks, so a set of nodes linked by social relationships requires analysis of the interactions
- Actors' actions in organizations can best be described in terms of their position within networks of relationships; and

- The comparative organizations' analysis must consider their network characteristics

SNA is applied in several construction cases as a sociological tool to make information flow visible inside an organization, and it is divided into two major levels: company and project levels (Alarcón et al., 2013). Pryke (2004) stated that SNA is critical in investigating interrelationships within construction companies like subcontractors and general contractors. Priven and Sacks (2013) have used SNA to investigate the behavioural patterns at the project level between subcontractors and general contractors. The authors found that social networks among subcontractors became stronger after implementing the LPS management system.

Other research shows that in LPS projects, the level of giving suggestions and opinions is higher than the level of asking for information, which shows the success of LPS in creating a better environment to communicate with participants (Ghosh et al., 2017). The authors have used SNA as a methodology. They discovered that the exchange of information, positive relational interactions, and participant involvement in decision-making is higher in the project in which LPS was implemented.

Priven and Sacks (2016) studied the effectiveness of the LPS on coordination between stakeholders. The authors selected 12 LPS projects to analyze the social impact of taking advantage of SNA. In this study, comparing SNA analysis and the best practice index score shows that 1) the LPS has a social impact on building relationships between construction teams; and 2) the social networks are more robust where the LPS is more thoroughly implemented. Other researchers study the relationship between general contractors and subcontractors using SNA and the lean workflow index as the methodology (Priven & Sacks, 2016). In this study, the authors suggested a new pathway to more effective social interaction for the relationship. The authors stated that the lean workflow index is complex and hard to implement; therefore, there is a lack of easily implementable methods (Priven & Sacks, 2016).

Castillo et al. (2016) stated that there is a positive correlation between LPS implementation and SNA strength in planning, knowledge management, learning, and problem-solving. Other researchers discovered a positive correlation between SNA strength and performance indicators (Herrera et al., 2018). In spite of these studies, lean and LPS health checks have not been studied for the way they are implemented. Accordingly, this study tries to use SNA to better understand how a more mature LPS implementation might promote better collaboration. As a contribution to this discussion, the research evaluates human behaviours and social interactions in an LPS meeting by focusing on lean implementation and different phases of LPS. In this regard, the social interaction is divided into three phases to explore the weekly plan, look-ahead plan, and PPC interactions among team members.

CHAPTER 3 – Research Methodology

3.1. Introduction

This section describes the research approach, data collection, and the main objectives of the research. Figure 3 shows an overview of the methodology.

3.2. Design Science Research

According to Van Aken (2004), scientific disciplines can be classified into formal sciences, explanatory sciences, and design sciences depending on the mode of producing scientific knowledge. In design sciences, knowledge is created through the implementation of a solution that is able to employ or alter a particular occurrence (Vaishnavi and Kuechler, 2007); therefore, according to Alsehaimi et al. (2012), design science (or constructive research) can assist in developing and implementing innovative managerial tools and tackling different managerial construction problems. So, this approach seems to be an appropriate approach for conducting research in construction management. March and Smith (1995) state that the design science research process has two fundamental activities: creating artifacts that can address real-world issues and evaluating their performance in use.

According to Hevner (2007), DSR contains three primary cycles, which are:

1. The relevance cycle involves the development of an artifact to resolve a relevant problem identified in a specific environment.
2. The design cycle facilitates iterations in the design and assessment of the artifact until a satisfying product is obtained.
3. The Rigour cycle uses existing past knowledge, skills, and artifacts in the application area to ensure innovation beyond the known.

This research implements the DSR methodology to develop a framework for LPS and social health checks. Three main stages of the research are shown in Figure 3, which are: the need for a framework, solution development, testing the framework.

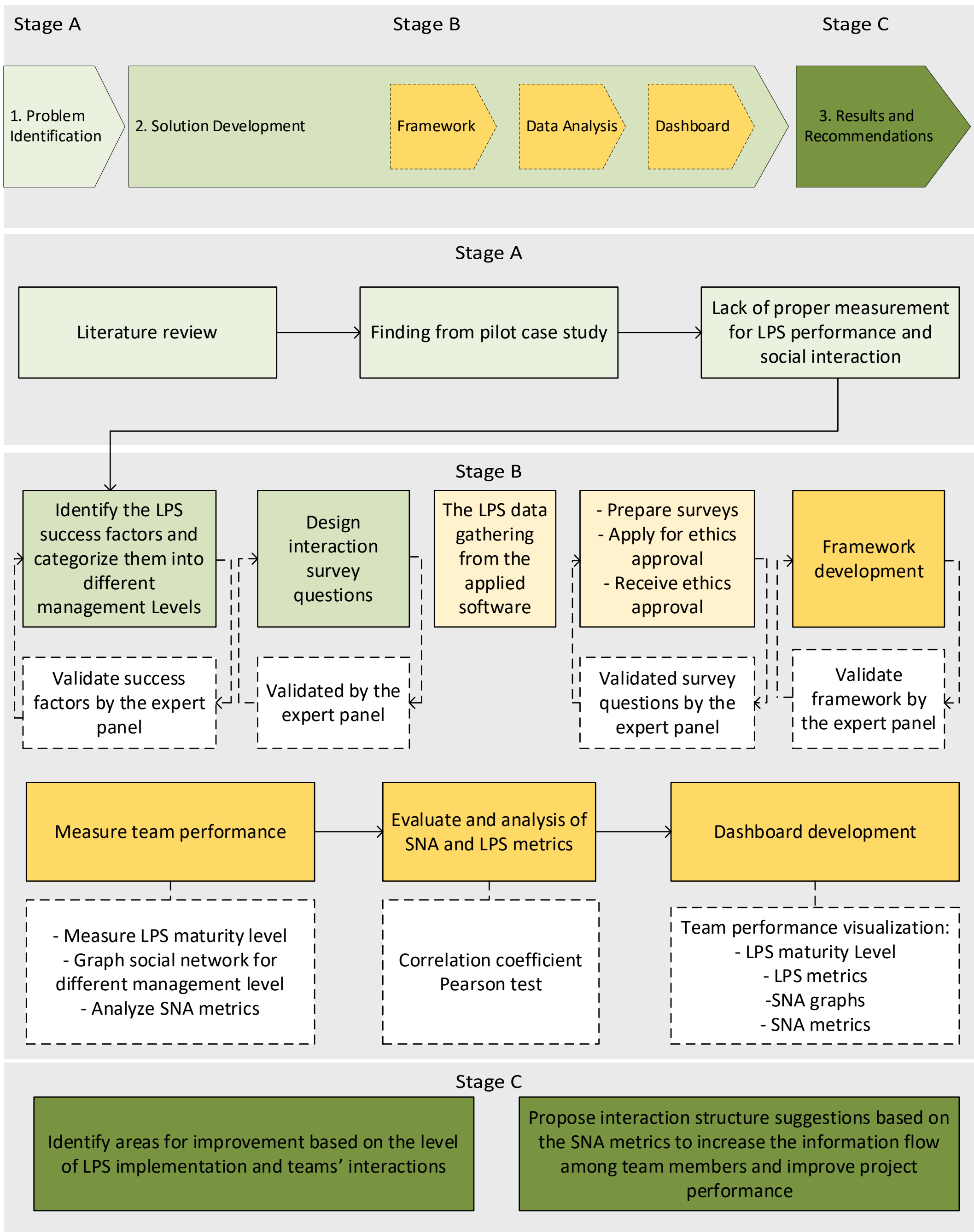

Figure 3. Research Methodology Flowchart

3.3. The Need for a Framework

Step 1. Literature Review: Even though the LPS is widely used all around the world, it is still new to many construction professionals, and partial implementation of lean and LPS leads to a decrease in their potential (Porwal et al., 2010; Lagos et al., 2017; Pozzi et al., 2021; Nesensohn et al., 2014). Therefore, there is a need to focus more on implementing it properly and addressing the previous gap. This part has been broadly discussed in the literature review (Chapter 2).

Step 2. Pilot Case Study:

In addition to the literature review, a pilot case study has been done to find the gap between communication and project performance. For that purpose, a lean survey was conducted to analyze the lean maturity level of the project. The survey was designed based on the lean success factors, which have been identified through the literature review and interviews with lean experts. After collecting the success factors, the factors have been organized into eleven categories. In order to capture the lean maturity level, some questions have been designed by focusing on the factors. In other words, each category contains some questions, and then the maturity level can be captured based on the answers. To answer the survey questions, the respondents have to rate each question from 1 (low) to 5 (high). This stage will be discussed in detail in chapter 4, section 4.2.1.

Step 2.1. Survey Approval:

Before conducting the survey, the survey got two approvals. 1) Approval from the industry: the factors and the questions were validated by lean experts, and after modifying the questions, the survey got the industry's approval. 2) Ethics approval from the University of Alberta: the ethics application has been submitted (ID: Pro00115874) to the research ethics office, and after modifying the questions, the application has been approved.

Step 2.2. Conducting Survey and Data Collection:

After survey approval, the designed survey was uploaded to the LimeSurvey platform (Appendix A) and was accessible for one month to collect the results.

Besides the lean survey, some other information has been drawn from the company's planning software, like PPC and constraint log information.

Step 2.3. Data analysis:

In order to analyze the data, the average of the answers for each category has been used to create a lean maturity level graph. After designing the lean maturity level, the constraint analysis was done to find how many tasks were ahead of and behind schedule and the reasons behind them.

Step 2.4. Finding from Pilot Case Study:

Proper implementation of the LPS is one of the key success factors asked in the survey. The lean survey results show that the team members were optimistic about how they were implementing the LPS, but the actual data, which has been driven from the planning software, show that the PPC level is low and they are struggling with constraint identification and removal. Comparing the other success factors reveals that the communication and collaboration levels needs improvement. Existing low LPS implementation levels and low communication and collaboration level show that there could be a relationship between the LPS implementation and teams' interactions.

By considering these needs for the study and the existing gap, team interaction and LPS implementation, which have been broadly mentioned in the literature review, the objectives of this research are:

- Understanding the correlation between social networks and planning reliability.
- Develop a new framework for measuring and assessing LPS implementation and team interaction

3.4. Solution Development

To address the need for the study, the DSR approach has been implemented to propose a framework for LPS and social interaction health checks. The LPS and SNA health check frameworks require collecting some data about the LPS implementation level and also social interaction. Therefore, two surveys need to be conducted in order to collect the required information. The proposed framework contains below steps:

3.4.1. Survey 1: *Identify LPS Success Factors and design questions*:

In order to prepare Survey 1, first the LPS success factors were identified through a literature review, and then the factors were validated by lean experts. Then, some questions were designed to ask team members about each success factor. The questions are also validated by lean experts to ensure they are relevant to the factors. The responders have to rate each question from 1 (low) to 5 (high) in order to understand the level of the LPS implementation. After validation, the survey was ready to be submitted for ethics approval.

3.4.2. Survey 2: *Design the questions and collect team members' information:*

In intending to prepare Survey 2, first, the questions were designed to collect information about the interaction at different LPS management levels. Then, the list of team members has to be collected to design a matrix survey to find who talks with whom regarding the specific subject matter that matters for the LPS management levels.

3.4.2. Survey Approval:

The designed surveys required two approvals. 1) industry approval, and 2) ethics approval.

The industry approval was confirmed after factor identification and question validation by the experts. The ethics application has also been submitted (Pro00119251) to the research ethics office, and after some modifications, the approval was confirmed.

3.4.3. Conduct surveys and Data Collection:

After survey approval, the designed surveys were uploaded into the LimeSurvey platform and were accessible for one month to collect the results (Appendix A).

Besides the surveys, the project manager provided some other required information, like the PPC and constraint log.

3.4.4. Data Analysis:

The next step is analyzing the collected information and finding a suitable method to analyze the social interaction. To address the research objectives, Social Network Analysis method has been chosen since social network analysis is a helpful method for analyzing social interactions among individuals and organizations, which can help us understand the interdependent and transitory systems within a complex system. SNA is a methodical analysis of social networks, and it represents individual actors as nodes within the network and relationships between individuals as ties between the nodes. SNA helps us to identify the nature of the relationships or links between the actors and represents the pattern of nodes both graphically and mathematically (D'Andrea et al., 2010; Easley and Kleinberg, 2010)

Social network theory has been developed in different fields like sociology, anthropology, and biology and has expanded beyond social science. In the construction industry, SNA was mainly used to study the information flow and optimize communication among project parties. Clients, consultants, contractors, and suppliers are observed as nodes, and the link between these nodes shows information exchange, knowledge transfer, and financial and contractual relationships. (Marin, & Wellman 2009; Pryke 2012).

Different network metrics are available to define specific attributes in quantitative terms. Some of the commonly used SNA metrics are used in this research to analyze the team's social structure among five levels of social network analysis: actor level, dyadic level, triadic level, subset level, or network level, according to Arif (2015). The metrics that have been used for this research are:

Network-specific metrics:

Average Degree Centrality: Measures the number of links an individual has with others. A higher number indicates more connections.

Density: This shows how well-connected and cohesive a network is by measuring the number of existing links between individuals and dividing it by the number of all possible links. A higher ratio value indicates a well-connected and interactive network.

Clustering Coefficient: Measures how clustered individuals are. A higher number shows the neighbourhood is well connected and everyone knows each other (not isolated).

Average Path Length: Measures the average number of links individuals require to reach each other. A smaller value is a better reflection of connectivity and faster interactions.

Node-specific metrics:

Betweenness: Measures the fraction of all shortest paths that pass through a given node. A higher number shows the most powerful node to control flow and interactions.

Closeness: measures the total number of links from an individual to others. A higher number shows the least reachable node by others (Varlamis et al. 2010; Arif 2015; Wehbe et al. 2015)

As specified in the research objective, we also need to collect the information to measure the LPS metrics in addition to the LPS survey results and social network metrics. There are several metrics to analyze the LPS implementation in the project, like Percent Planned Completed (PPC), Tasks Anticipated (TA), and Tasks Made Ready (TMR). In addition, measuring some delta based on constraint information will also help to understand the level of LPS implementation in the project (El Samad & Hamzeh, 2017). PPC, constraint log, and variance reason are the most common metrics in the industry to analyze the LPS level, so in this research, these metrics have been used to examine the LPS and planning progress.

3.4.4.1 LPS Analysis:

The LPS implementation level could be calculated based on the LPS survey results. In an effort to achieve that, the average of the rates for each category has to be calculated, and then, based on the result, the LPS maturity level can be calculated. To do so, I have developed a solution to calculate the LPS maturity level. First, a radar graph was designed to show the LPS implementation level, and then the area for the shapes was calculated to have the LPS maturity level.

3.4.4.2. Social Interaction Analysis:

Based on survey 2's result, an interaction graph could be designed and analyzed. The SNA method has been used in this research to analyze team members' interactions. To do so, the interaction networks would have to be designed in Gephi, a network analysis and visualization software, and then the abovementioned metrics could be calculated in the software.

3.4.4.3 Correlation Test:

After analyzing the metrics, a correlation test was done to find the relationship between the SNA metrics and the LPS metrics. The goal of the correlation test is to find the gap among the levels of interaction and understand the importance of communication at different management levels for the project's success.

3.5. Develop a Dashboard

After collecting all the required information, a dashboard was made to give a clear picture of the current project's performance (Appendix A). It contains visualized LPS survey results, actual PPC and constraint logs, social networks, and network metrics.

3.6. Test the Proposed Framework and the Dashboard:

The proposed framework and dashboard have been tested in three projects, and also it has been evaluated by the project management, which will be discussed in Chapter 4, section 4.2.2. Then, after testing the framework, areas for improvement were identified, and a new interaction structure was suggested in order to improve the interaction level and project performance.

Next chapter, we will discuss the detailed steps for each detailed calculation.

CHAPTER 4 – Results and Data Analysis

This chapter shows the details of each step of the framework and then the results of the case studies. Team social interaction and the LPS framework can be applied to all construction projects. The proposed framework contains three stages: data gathering, data analysis, and recommendation. The framework can be easily used as a regular LPS and team interaction tool to have a better performance. This new tool helps to focus more on human behaviour and LPS metrics than on only the metrics as numbers on their own. Low team performance could have other human behaviour reasons that should be studied. Therefore, following this framework helps the team find the weak and the strong networks, to improve the network, and, finally, the LPS performance. Figure 4 presents the proposed framework:

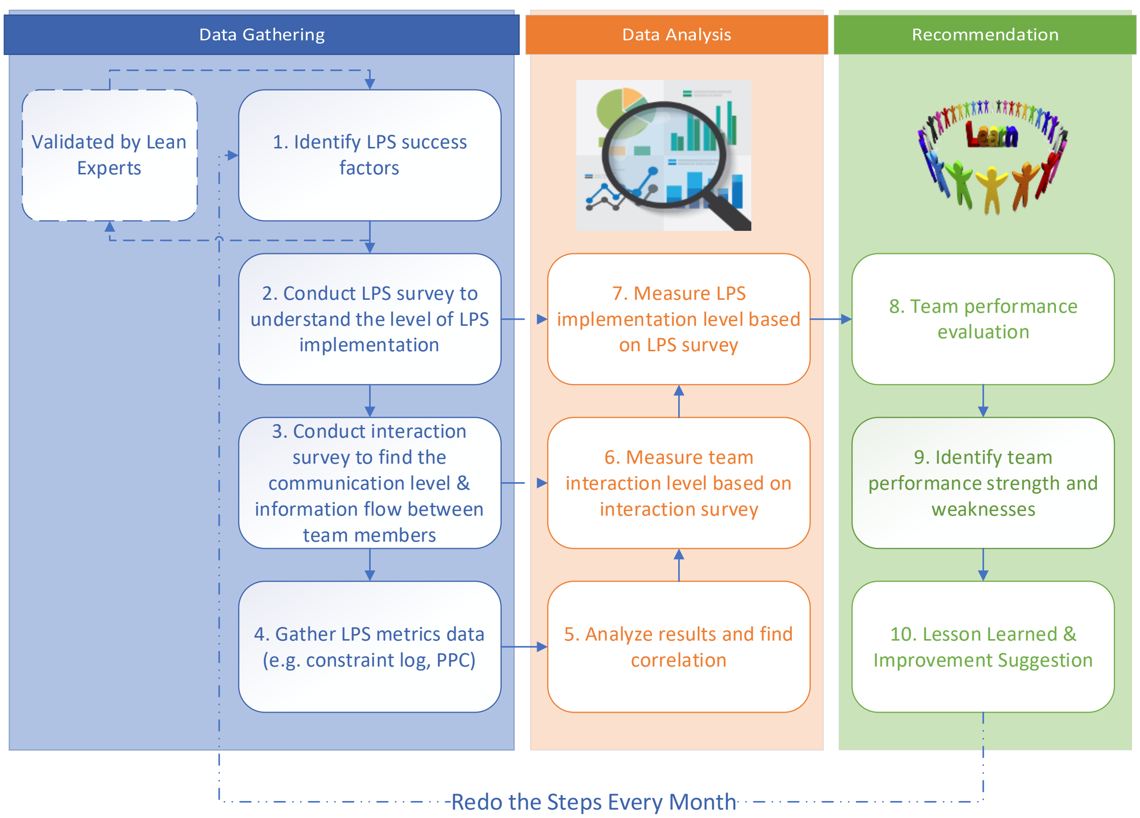

Figure 4. LPS and interaction Framework

4.1 Framework Evaluation and assessment

According to Peffers et al. (2007), a satisfaction survey should assess the framework's utility, quality, and efficiency. The proposed framework has been validated through primary case studies and satisfaction surveys in this study. Following are the survey questions to evaluate the framework:

Question 1: The steps followed in the LPS – Interaction framework is feasible to implement.

Question 2: The steps followed in the LPS – Interaction framework is easy to understand.

Question 3: The suggested steps have the right sequence for implementation.

Question 4: The suggested framework is applicable to other companies.

Figure 5 shows the assessment of the framework which has been done by the project manager.

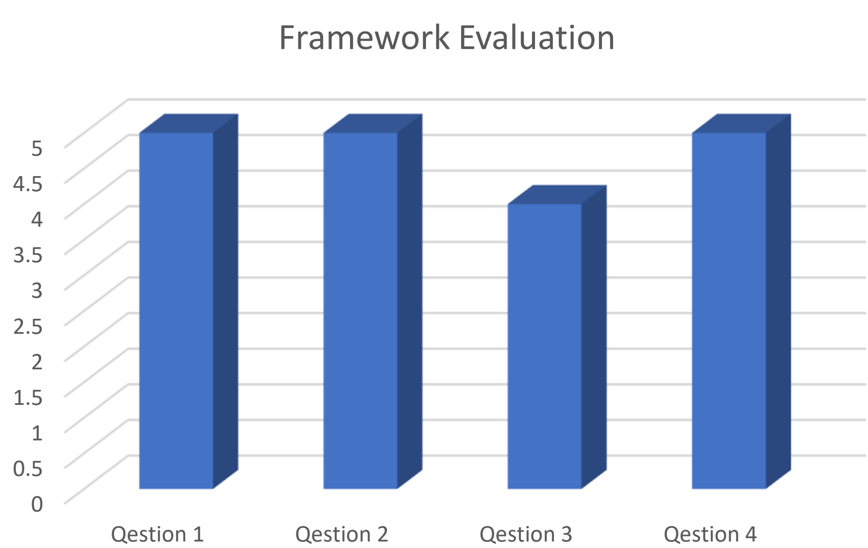

Figure 5. Framework Evaluation

4.2 Case Studies

4.2.1 Pilot Case studies

This section shows the need to study communication and parties' interaction. The case study is a school rehabilitation project in Vancouver, Canada. The project was selected because the lean management system and the last planner system were used for production planning and control. This case study aims to examine lean maturity and behaviour and find the gap to improve the weakness. A survey has examined lean behaviours and the level of lean maturity in the project. The survey questions were designed based on the lean success factors. Each question tries to address one of the factors, and the survey results will explore the lean implementation level. Lean success factors have been identified by literature reviews (Bayhan et al., 2019; Bhattacharjee et al., 2013; Castillo et al., 2018; Hamouda et al., 2014; Hofacker et al., 2008; Kallassy, & Hamzeh, 2021) and lean experts. Table 1 shows the factors and questions which have been finalized by lean experts and project managers and implemented in real projects.

Table 1. Lean Success Factors and Survey Questions

Categories	Survey Questions to Rate Each Factors
Respect for people	"Communication is formalized and communicated when required. "
Teamwork	"The company is flexible in communicating with trades during the execution phase and whenever needed without waiting for RFI."
	"The company trusts the word given by the trade partners and provides an opportunity to the trade partners for decision making."

Communication & Collaboration	"There is a knowledge-sharing culture in the company."
	"The company creates the handover structure and schedule of deliverables."
	"The company cooperates with trades to build trust and commitments
Transparency	"The information on which tasks will be performed during the week is transparent and available to the trades."
Safety	"The company prompts employees about safety in the workplace every day during the daily huddles."
Problem Solving-Learning	"The company is using problem-solving techniques to determine the reasons for variance are identified and discussed during the weekly trades meetings."
Consistency and Standardization	" The company standardizes the best practices and defines certain rules for the trades."
Waste minimization/consciou sness	"Handoff quality is good, and no need to rework."
	"Work activities and tasks are planned in such a way to minimize the DOWNTIME."
Innovation	"There is continuous support from the top management."
Continuous improvement–Quality	" The company continually reports the project status and updates the progress."

	" The company has meetings to discuss lessons learned in the middle of the project."
	"There is an ongoing effort to teach the lean concepts and further specialization."
LPS	"The information on which tasks will be performed during the week is transparent and available to all workers of the construction."
	" The company provides the information regarding what task should be done, when, and by whom.
	" The company keeps a record of the lessons learned on-site for future projects."
	"There is a systematic update of the master plan when it is necessary."
	"Trades are involved in constraint identification and providing solutions."

4.2.1.1 Finding from the Pilot Case Study

Firstly, an ethics application has been submitted to the University of Alberta. After getting the ethics approval (Pro00115874), the survey was conducted on the LimeSurvey platform and was accessible for one month to collect the result. Each respondent can rate the lean success factors between 1 and 5. After getting all the answers, the average of the results was used to check the lean maturity level for the project, which can be seen in Figure 6.

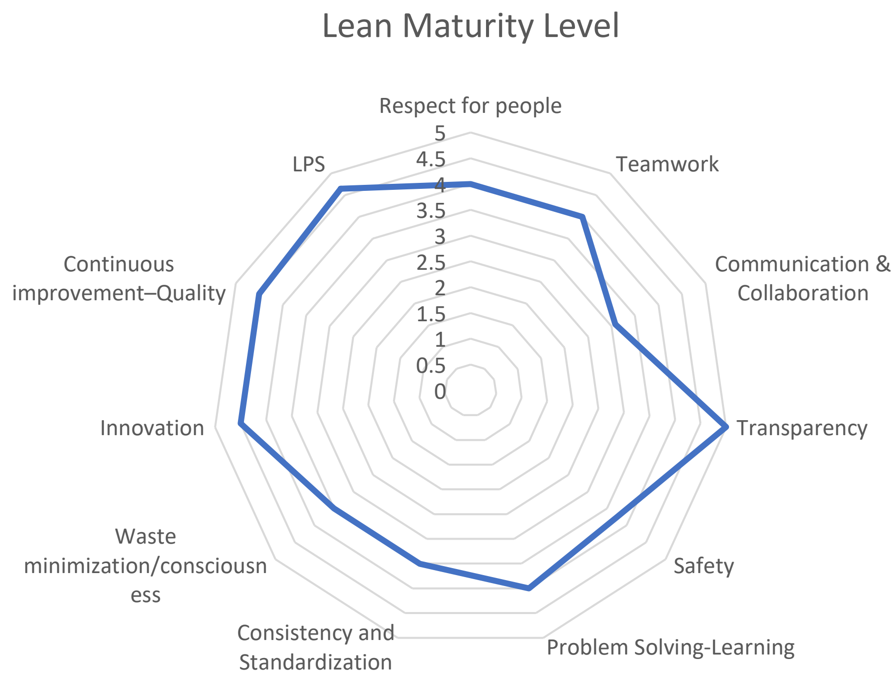

Figure 6. Lean Maturity Level

The company was using daily construction planning software, so besides the LPS results, PPC and constraint log information were also available for study. The average PPC was 65% during the study, which is shown in Figure 7.

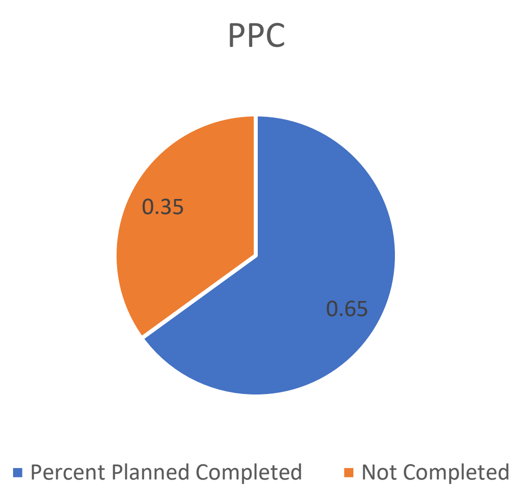

Figure 7. Percent Plan Completed

In addition, the constraint log information shows that 135 constraints had to be removed to do the specific tasks, and among 135 constraints, 25 were removed on time, and 21 were removed ahead of time. In the study period, 40 constraints have not been removed yet, and they were behind in removing 46 constraints. A more detailed result is shown in Figure 8.

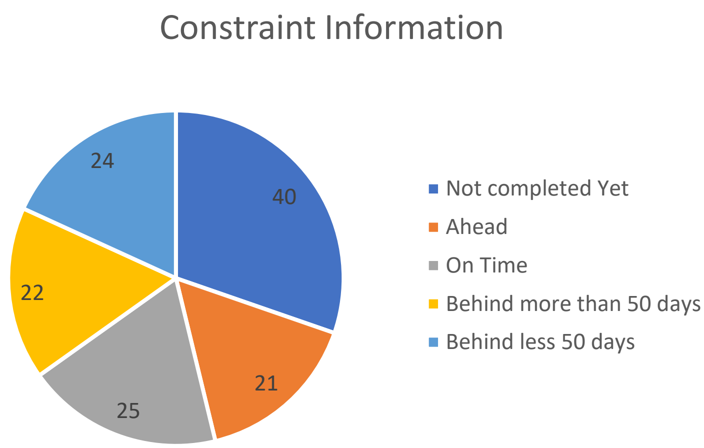

Figure 8. Constraint Log Information

In conclusion, the survey results show that the team was optimistic about how they are doing in LPS; however, the data shows that they are struggling with constraint identification and removal, which can directly affect to implement of the LPS properly, according to (Perez & Ghosh, 2018; Hamzeh et al., 2015; Hamzeh, Zankoul, & Rouhana, 2015; Ballard, 2000). The survey results also show that the level of communication and collaboration is low and needs to be improved. According to Alarcón and Calderón (2003), the communication-transparency factor is one of the main factors that can directly affect the PPC results. The authors also examined that the PPC is higher in projects with a collaborative approach. Therefore, by considering the mixed method approach, which is a combination of survey results and data-driven decision-making, we can find that there could be a relationship between the LPS implementation and the parties' interaction; as a result, there is a need to study the relationship.

4.2.2 Primary Case Studies

The pilot case study shows that there is a need to study and find the relationship between parties' interaction and the LPS, so this section discusses the methodology for using SNA in three different projects under the same organization to examine the implementation of the LPS and participants' communication. To do so, two surveys (Survey 1 and Survey 2) were conducted to understand the level of the LPS implementation and the team's interaction. Survey 1 is the LPS survey, and it contains 18 questions, and each respondent has the option to rate each question from 1(Low) to 5 (high). The questions have been designed to address success factors for different management levels in the LPS. The success factors have been collected through literature reviews (Priven, & Sacks, 2015; Power et al., 2021; Tayeh et al., 2018; Salem et al., 2015) and then finalized by lean experts and project managers to implement in real projects. So, the goal of survey 1 is to understand the level of LPS implementation in the projects and design the LPS maturity level for each project based on the answers.

Survey 2 is the social interaction survey, and it contains 3 questions to understand the level of interaction among the teams. The goal of survey 2 is to understand the network structure among teams and find room to improve the social interaction among the teams to improve the project performance. Firstly, the ethics application for Survey 1 and 2 have been submitted, and after getting approval from the University of Alberta (Pro00119251), the survey was conducted on the Limesurvey platform and was available for two weeks to gather the information. Table 2 shows the LPS management level and survey questions, which have been finalized by lean experts and project managers, to examine the level of the LPS in the projects by focusing on LPS success factors.

Table 2. The LPS Success Factors and Survey Questions (Survey 1)

Categories	Survey Questions to Rate Each Factors
People and partners	“There was an initial and ongoing effort to train the team LPS.”
	"The entire team collaborates to develop the plan."
	"The team has top management support and an open environment to include all trades in the planning process."
Master scheduling	"Master Schedule milestones are used to guide all levels of planning and reviewed frequently by the team."
	"Conditions of Satisfaction and other requirements are identified for each milestone."
Phase scheduling	"Handoffs between trades are identified and optimized."
	“Project constraints are identified during Phase Pull Planning.”
	"The team uses productivity metrics and balances work at Phase Pull."

	"The developed Phase Pull plan is realistic and achievable."
Lookahead planning	“A Project Constraint Log is actively used by the team weekly (at a minimum)."
	"All stakeholders share a common understanding and involvement in the planning process to improve workflow reliability."
	“Drawings, site/area plans, BIM, or other visual aids are used while developing the plan.”
	“A structured agenda is used during the Lookahead & Weekly Work Plan meeting (e.g., DID, SHOULD, CAN, WILL).”
Weekly work plan	“The team measures the Percent Plan Complete (performance) and takes corrective action on Reasons for Variance every week.”
	“Work is planned in the best achievable sequence to close the gap between lookahead and the weekly work plan.”
	"Activities planned include what will be done, where, when, and who will do it.”
Daily huddle	"The team discusses: what was done yesterday, what is being done today, is anything holding up work tomorrow."
	“Weekly Work Plan is used to guide Daily Huddle.”

After getting the LPS implementation level results, survey 2 was conducted to understand the level of communication among team members. The survey contains three questions to understand the frequency of communication in three different phases: lookahead planning, weekly work planning, and PPC. The frequency of communication in lookahead planning and weekly work plan shows how frequently the team members communicate in the specified stage to coordinate with the team member and reach their goals. The third question referred to finding the frequency of communication about PPC. Getting the information for PPC communication will help us to compare the PPC communication result with the actual PPC.

After getting ethics approval from the University of Alberta (Pro00119251), the survey was conducted on the LimeSurvey platform, and it was accessible for two weeks. As shown in Table 3, in this survey, each responder was able to choose the communication level for other team members.

Table 3. Social Network Survey (Survey 2)

Name	How frequently do you communicate about the weekly work planning with this person?					How frequently do you talk about the lookahead planning (constraint identification and/or removal) with this person?					How frequently do you communicate about the tasks that were not completed last week with this person?				
	N/A	>5/week	3-5/week	1-3/week	1/mon.	N/A	>5/week	3-5/week	1-3/week	1/mon.	N/A	>5/week	3-5/week	1-3/week	1/mon.
Person 1															
Person 2															
Person 3 . . .															

These three projects have been chosen for their difference in scale, type, and implementation level of lean management systems and the LPS for production planning and control. Project 1 is a bridge replacement in New Westminster and Surrey, British Columbia, Canada. The project includes the construction of connecting roadways on the north and south sides of the bridge, grade separations on the Highway, and the removal of the existing bridge once the new bridge is complete. The new four-lane cable-stayed bridge over the Fraser River will provide network connections to New Westminster and Surrey, feature a center safety median barrier and wider lanes for both passenger and commercial vehicles and have dedicated walking and cycling lanes.

Project 2 is an international bridge in Windsor, Ontario, Canada. This once-in-a-generation undertaking includes a 2.5-kilometre cable-stayed bridge with six lanes (three Canadian-bound and three U.S.-bound) and two approach bridges. The project includes a 130-acre Canadian Port of Entry and a 148-acre U.S. Port of Entry. The fixed-priced contract is valued at $5.7 billion (nominal value), which includes the design-build (DB) phase and the 30-year operation, maintenance, and rehabilitation (OMR) phase.

Project 3 is an underground station located in Toronto, Canada. The selected project is one of the 19 projects that the company is building. The station will primarily serve local businesses and residents. On-street connections will be provided to TTC buses, and retail spaces will be located at a street level accessible from the secondary entrance. There will be 60 outdoor bicycle parking spaces. Table 4 shows more detailed information about the case studies including different criteria.

Table 4. Case Study Information

Criteria	Project 1	Project 2	Project 3
Project type	Infrastructure (Bridge Replacement)	Infrastructure (Bridge)	Infrastructure (Underground Light Rail Station)
Project Delivery Method	Lump Sum Joint-Venture	Lump Sum Joint-Venture	Lump Sum Joint-Venture
Initial Planned Schedule Duration in Years	5	6	2
Execution Weeks Captured in the Study	28	9	35
Number of Project Team Members	100 (entire team) Construction team (35)	125 Construction team (40)	60 Construction team (25)
Average Years of Team LPS Experience	1	0.25	1
Number of Participants in the LPS survey	8	15	7
Number of Participants in Network Survey	23	19	14

4.2.2.1 Findings from Primary Case Studies

To collect the LPS implementation level for three projects, each respondent has the option to rate each question between one and five. After collecting the required data, the average of the results was used to create the LPS maturity level. Table 5 shows the average for different LPS management levels based on participants' answers. In addition to the project's result, another column has been added to see the ideal condition for LPS maturity. The ideal condition will help us to have a comparison and find the proportional area based on the ideal situation. Figure 9 represents the radar graph for three projects to have a comparison between these cases.

Table 5. The average of results for each level

LPS Management Level	Project 1	Project 2	Project 3	Ideal
People and partners	3.4166	3.9111	4.4761	5
Master scheduling	2.6875	3.3666	4.5	5
Phase scheduling	2.625	3.6833	4.0714	5
Lookahead planning	2.625	3.85	4.1785	5
Weekly work plan	3.5937	3.5	4.3571	5
Daily huddle	4.125	3.2333	4.2857	5

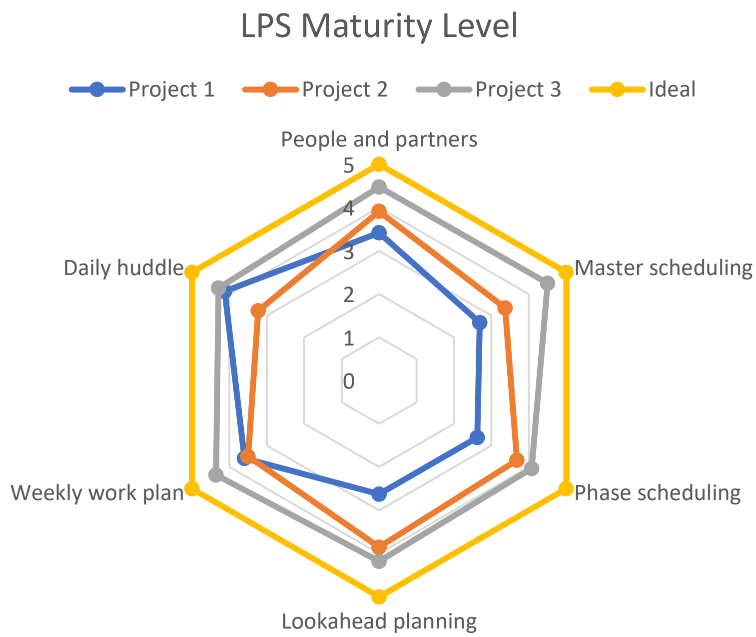

Figure 9. LPS Maturity Level Comparison

Based on the radar graph, I have developed a calculation to estimate the maturity level. Based on Figure 9, the area for each project was also measured to find the proportional maturity level. Figure 9 was created by six points, and since the shape is not a hexagon and there was no other required number to calculate the area, I considered six hexagons for each project and used Table 5's number to calculate the area. After getting the area for six hexagons, the average area was used as the metric to compare.

Here is an example of a calculation for project 1.

The formula for area: $(3\sqrt{3})/2) \times S^2)$

Point 1: 3.416, area 1: $(3\sqrt{3})/2) \times 3.416^2$= 30328)

Point 2: 2.687, area 2: $(3\sqrt{3})/2) \times 2.687^2$= 18.765)

Point 3: 2.625, area 3: $(3\sqrt{3})/2) \times 2.625^2$= 17.902)

Point 4: 2.625, area 4: $(3\sqrt{3})/2) \times 2.625^2$= 17.902)

Point 5: 3.593, area 5: $(3\sqrt{3})/2) \times 3.593^2$= 33.554)

Point 6: 4.125, area 6: $(3\sqrt{3})/2) \times 4.125^2$= 44.207)

Average of the areas for project 1: 27.110

The same calculation steps were used to calculate the area for two other projects. The final answer is shown in Table 6, which contains the average area for each project and the proportional area based on ideal conditions. The results show that the LPS maturity level in project 3 is higher than in the other two projects.

Table 6. LPS maturity level based on area

	Project 1	Project 2	Project 3	Ideal condition
$\boldsymbol{Average\ of\ the\ Areas}$	27.110	33.655	48.356	64.951
$\boldsymbol{\left(\frac{Area}{Ideal\ Area}\right) \times 100}$	41.738	51.816	74.450	100

Existing results for three projects help us find the correlation between different points of LPS maturity Level. To do so, Spearman's ρ was used to find the correlation coefficient between management-level series. According to Evans 2012, when $\rho \geq 0.8$ is very strong and when $0.6 \leq \rho < 0.8$ is strong; therefore, based on the result shown in Table 7, there is a strong correlation between the LPS management level.

Table 7. LPS management level correlation

Management Level Series		Correlation
Phase scheduling	Lookahead planning	0.996
People and partners	Master scheduling	0.991
People and partners	Phase scheduling	0.984
People and partners	Lookahead planning	0.977
Master scheduling	Phase scheduling	0.954
People and partners	Weekly work plan	0.952
Master scheduling	Weekly work plan	0.952
Master scheduling	Lookahead planning	0.948
Phase scheduling	Weekly work plan	0.910
Weekly work plan	Daily huddle	0.907
Lookahead planning	Weekly work plan	0.879
Master scheduling	Daily huddle	0.745
People and partners	Daily huddle	0.737
Phase scheduling	Daily huddle	0.669
Lookahead planning	Daily huddle	0.609

After finding the LPS maturity level for each project, Table 7 was created based on data-driven by the lean management software the organization used to manage the projects. To compare these three projects, the average number of reasons for non-compliance, the average PPC, and the standard deviation of the PPC has been used. The higher average of PPC shows that most of the planned work has been completed as planned, and the lower standard deviation shows that data are clustered around. The average number of reasons for non-compliance has been calculated based on the reasons for variance (e.g., uncleared information, Labor constraint, material constraint, weather), which have been reported weekly.

These three projects were in different phases of the work, and according to Table 8, it seems that the number of reasons for non-compliance is going higher over time. Even though the number of reasons for non-compliance in project 3 is higher than the others, project 3 shows better performance among these three projects because it has a higher number for the average of PPC and a lower number for the standard deviation. After project 3, project 2 is in second place, and project 1 is in last place. Moreover, Figure 10 has been created to show the projects' PPC level. The graph has been created based on the PPC delta, and the more fluctuated graph shows the weakest performance because of being more variable and unstable. The graph also shows project 3 has the best performance because of having the smoothest trend.

Table 8. Project Performance Result

KPI	**Project 1 (28 Weeks)**	**Project 2 (9 Weeks)**	**Project 3 (35 Weeks)**
Avg. of Number of Reasons for non-compliance	3	2.375	4.74
PPC (Mean)	64.19	70.11	72.51
PPC (SD)	33.78	27.33	26.39

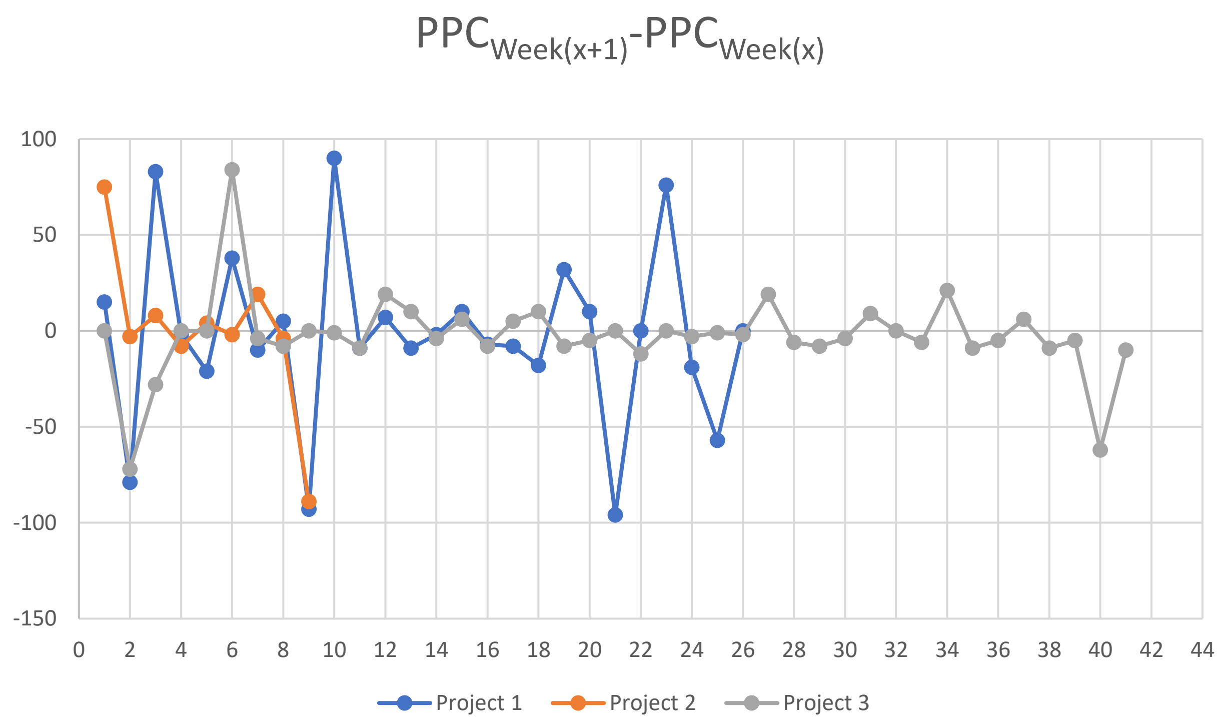

Figure 10. PPC delta

As mentioned previously, interaction and information flow are important factors in project performance, and it is one of the reasons for variance. As we have discussed in the literature review, we are willing to decrease the variance to make a project reliable in construction projects. In this part, the social network analysis method has been used to analyze the team's interaction and have a comparison.

To do so, Gephi, network analysis and visualization software, has been used to analyze the network, create the relationship graph, and measure the network metrics like average degree, graph density, average clustering coefficient, average path length, betweenness, and closeness. These data have been gathered by conducting the SNA survey, and since the survey was designed to get the data for the different planning phases, their network has been created.

4.2.2.2 The Network of Project 1

The interaction networks have been created for different management levels. The graph has been designed based on the team member's role, and Table 9 describes the roles. Figure 11 represents the network structure for the weekly work planning network among the support team, construction team, and subcontractor for project 1. Figure 12 shows the second network, which is the PPC network, and the third one shows the lookahead planning network, according to Figure 13.

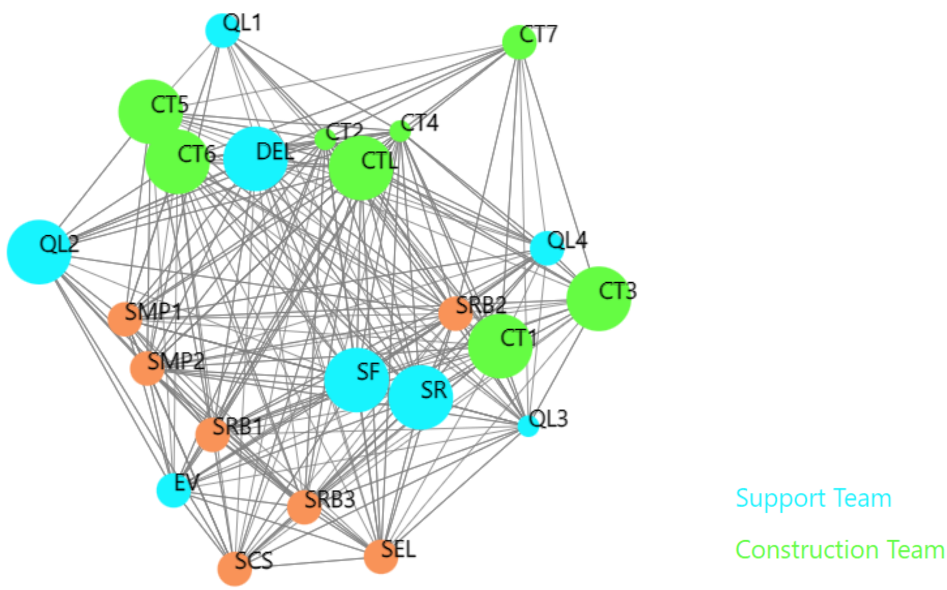

Figure 11. WWP Network (Project 1)

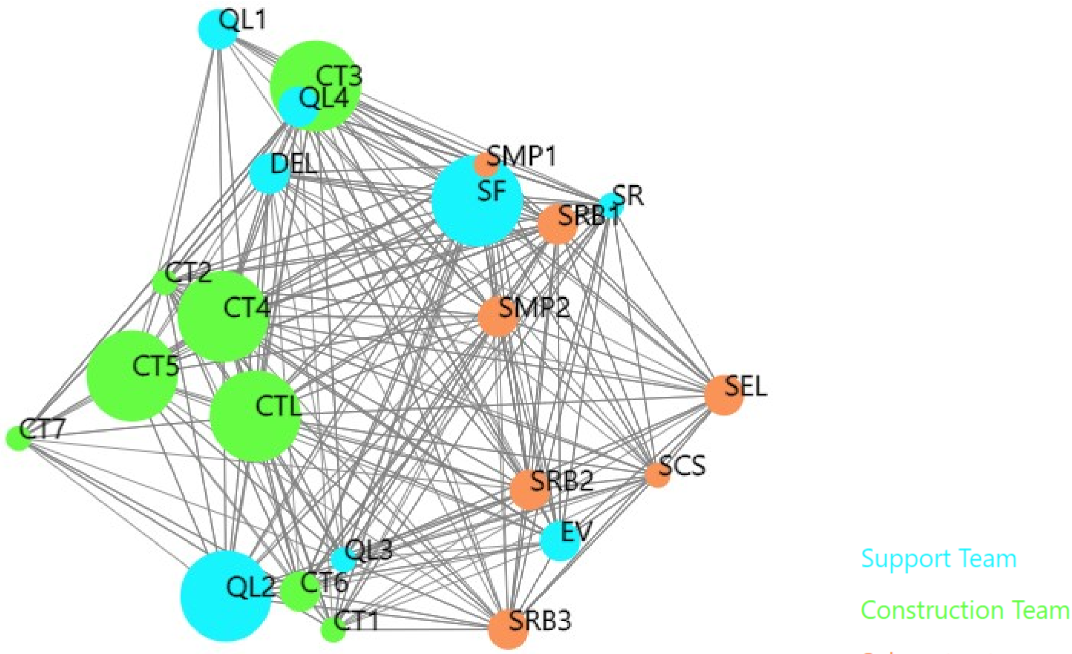

Figure 12. PPC Network (Project 1)

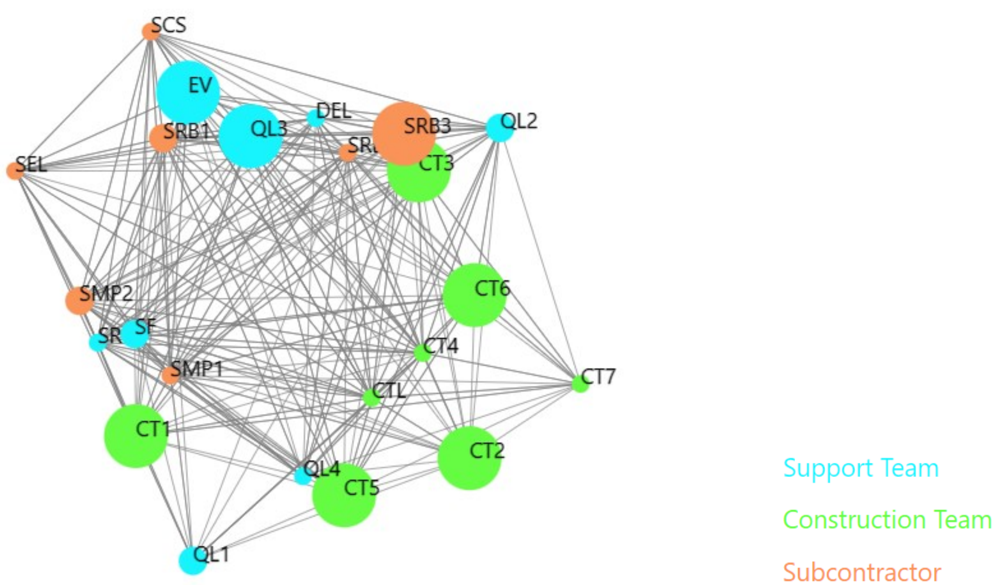

Figure 13. Lookahead Planning Network (Project 1)

Table 9. Description of the Roles of Team Members in Project 1

SMP1	Subcontractor (Marine Piling 1)	CT4	Construction Team Member 4
SMP2	Subcontractor (Marine Piling 2)	CT5	Construction Team Member 5
SRB1	Subcontractor (Rebar 1)	CT6	Construction Team Member 6
SRB2	Subcontractor (Rebar 2)	CT7	Construction Team Member 7
SRB3	Subcontractor (Rebar 3)	EV	Support Department Member (Environmental)
SEL	Subcontractor (Electrical)	QL1	Support Department Member (Quality 1)
SCS	Subcontractor (Concrete supply)	QL2	Support Department Member (Quality 2)
CTL	Construction Team Leader	QL3	Support Department Member (Quality 3)
CT1	Construction Team Member 1	QL4	Support Department Member (Quality 4)
CT2	Construction Team Member 2	SF	Support Department Member (Safety)
CT3	Construction Team Member 3	DEL	Support Department Member (Electrical)
SR	Support Department Member (Survey)		

Table 10 shows the results for each network and the metrics. The metrics show the well-connected network, the network with better connection and faster interactions, the active network, and the neighbourhood connection. Table 11 shows the node metric results for project 1.

Table 10.Network Metrics Results

Network Metrics	**WWP Result**	**PPC/Learning Result**	**Lookahead Result**
Avg. Degree	15.913	15.913	15
Graph Density	0.723	0.723	0.682
Average Clustering Coefficient	0.767	0.766	0.716
Avg. Path Length	1.277	1.277	1.318

Table 11.Node Metrics Results

Node Metrics	WWP Result		PPC/Learning Result		Lookahead Result	
Betweenness	Max	18.26	Max	17.27	Max	24.17
	Min	0	Min	0.05	Min	0.17
Closeness	Max	1	Max	1	Max	1
	Min	0.56	Min	0.57	Min	0.84

As previously mentioned in Chapter 3, each metric defines something about the network and its structure. Based on the concept of each metric, Table 12 has been created to represent the interpretation of the network metrics, and Table 13 shows the interpretation of node metrics results.

Table 12.Network Results

Metrics interpretation	Network
The well-connected and cohesive network	WWP Network
The poorly connected network	Lookahead Planning Network
The network with better connection and faster interactions	Lookahead Planning Network
The network with poorer connection and slower interactions	WWP Network
The active network	WWP Network
The inactive network	Lookahead Planning Network
How well a node’s neighbourhood is connected and know each other	WWP Network
How poorly a node’s neighbourhood is connected	Lookahead Planning Network

Table 13. Node Results

Node Metrics interpretation	Node
The node with a higher connection and more central	Lookahead: Construction team member 1
	PPC: Construction team member 1
	WWP: Construction team member 1
The node with a lower connection and more central	Lookahead: Support team member 1
	PPC: Support team member 1
	WWP: Support team member 1
The most powerful node to control flow and interactions	Lookahead: Construction team member 1
	PPC: Construction team member 1
	WWP: Construction team member 1
The Least powerful node to control flow and interactions	Lookahead: Support team member 1
	PPC: Support team member 1
	WWP: Support team member 1
The most reachable node by others	Lookahead: Support team member 1
	PPC: Support team member 1
	WWP: Support team member 1
The least reachable node by others	Lookahead: Subcontractor 1
	PPC: Construction team member 1
	WWP: Construction team member 1

In summary, the interpretation results show that even though the lookahead planning network is the network with the faster interactions, it is the inactive, poorly connected, and most isolated network. The node results show that even though construction team member #1 is a powerful and highly connected node, it is the least reachable node by the others. Comparing these results show that there is a need to focus on the lookahead planning network and construction team member #1 to have a better connection. One of the suggestions is to focus on construction team member #1 to be more reachable by others to have a more robust lookahead planning network.

4.2.2.3 The Network of Project 2

The interaction networks have been created for different management levels. The graph has been designed based on the team member's role, and Table 14 describes the roles. Figure 14 shows the first network shows the weekly work planning network among trade partners and general contractors for project 2. Figure 15 shows the second network, which is the PPC network, and the third one shows the lookahead planning network, according to Figure 16.

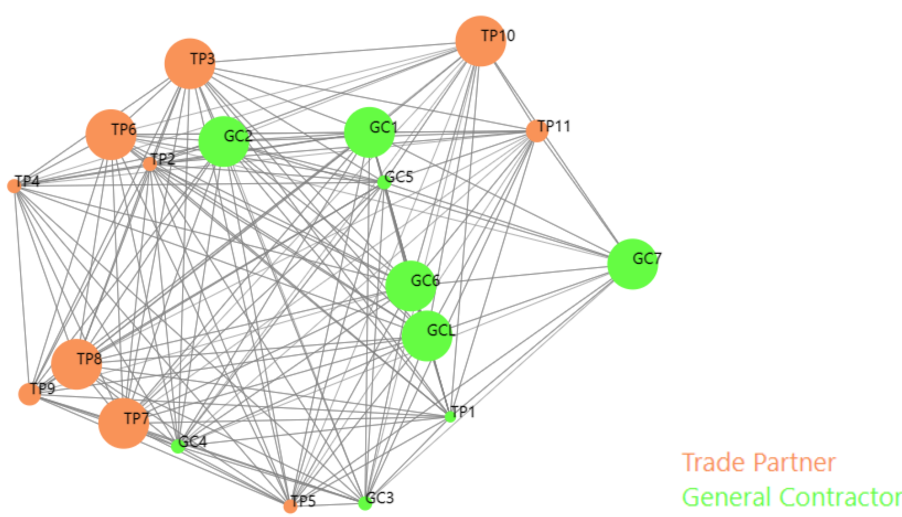

Figure 14. WWP Network (Project 2)

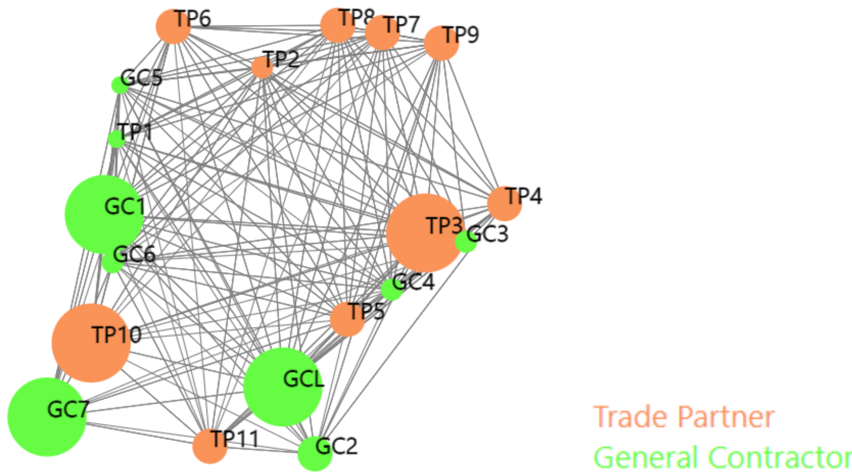

Figure 15. PPC Network (Project 2)

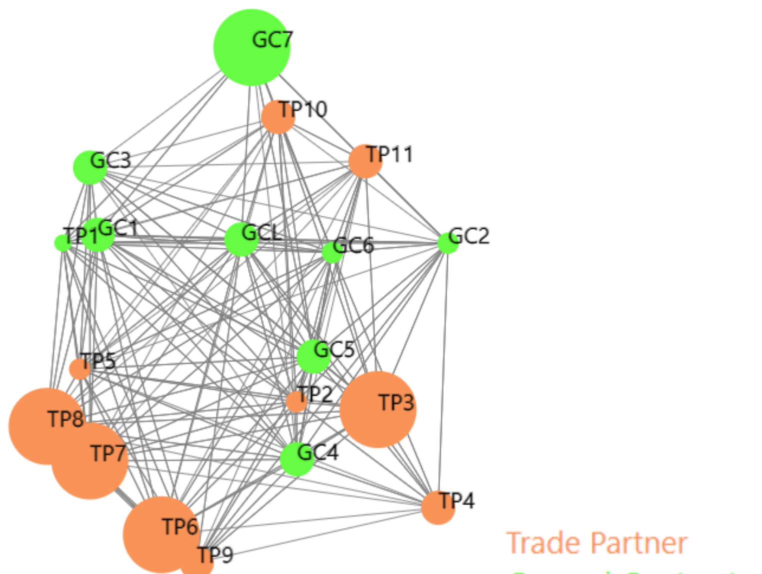

Figure 16. Lookahead Planning Network (Project 2)

Table 14. Description of the Roles of Team Members in Project 2

GCL	General Contractor Leader	TP3	Trade Partner Member 3
GC1	General Contractor Member 1	TP4	Trade Partner Member 4
GC2	General Contractor Member 2	TP5	Trade Partner Member 5
GC3	General Contractor Member 3	TP6	Trade Partner Member 6
GC4	General Contractor Member 4	TP7	Trade Partner Member 7
GC5	General Contractor Member 5	TP8	Trade Partner Member 8
GC6	General Contractor Member 6	TP9	Trade Partner Member 9
GC7	General Contractor Member 7	TP10	Trade Partner Member 10
TP1	Trade Partner Member 1	TP11	Trade Partner Member 11
TP2	Trade Partner Member 2		

Table 15 shows the result for each network and the metrics. The metrics show the well-connected network, the network with better connection and faster interactions, the active network, and the neighbourhood connection. Table 16 shows node metric results for project 2.

Table 15. Network Metrics Results

Metrics	**WWP Result**	**PPC/Learning Result**	**Lookahead Result**
Avg. Degree	15.947	14.737	14.211
Graph Density	0.886	0.819	0.789
Average Clustering Coefficient	0.899	0.831	0.824
Avg. Path Length	1.114	1.181	1.211

Table 16. Node Metrics Results

Node Metrics	WWP Result		PPC/Learning Result		Lookahead Result	
Betweenness	Max	3.78	Max	7.06	Max	9.37
	Min	0.33	Min	0.76	Min	0.21
Closeness	Max	1	Max	1	Max	1
	Min	0.69	Min	0.67	Min	0.64

As mentioned above, each metric defines the network's structure. Based on the concept of each metric, Table 17 has been created to represent the interpretation of the metrics, and Table 18 shows the interpretation of node metrics results.

Table 17. Network Results

Metrics interpretation	Network
The well-connected and cohesive network	WWP Network
The poorly connected network	Lookahead Planning Network
The network with better connection and faster interactions	Lookahead Planning Network
The network with poorer connection and slower interactions	WWP Network
The active network	WWP Network
The inactive network	Lookahead Planning Network
How well a node’s neighbourhood is connected and know each other	WWP Network
How poorly a node’s neighbourhood is connected	Lookahead Planning Network

Table 18. Node Results

Node Metrics interpretation	Node
The node with a higher connection and more central	Lookahead: General contractor member 1
	PPC: General contractor member 1
	WWP: General contractor member 3
The node with a lower connection and more central	Lookahead: General contractor member 2
	PPC: General contractor member 2
	WWP: General contractor member 2
The most powerful node to control flow and interactions	Lookahead: General contractor member 1
	PPC: General contractor member 1
	WWP: General contractor member 1, General contractor member 3, General contractor member 4
The Least powerful node to control flow and interactions	Lookahead: General contractor member 2
	PPC: General contractor member 2
	WWP: Trade Partner member 1
The most reachable node by others	Lookahead: General contractor member 2
	PPC: General contractor member 2
	WWP: General contractor member 2
The least reachable node by others	Lookahead: General contractor member 5
	PPC: General contractor member 1
	WWP: General contractor member 1, General contractor member 3, General contractor member 5

In summary, the interpretation results show that even though the lookahead planning network is the network with the faster interactions, it is the inactive, poorly connected, and most isolated network. In this project also, we can see that general contractor member #1 is the least reachable by others even though it is a powerful and highly connected network. In contrast, the least powerful and poorly connected node is the most reachable node in the network. One of the suggestions to improve this network is to level the nodes and change the pattern. For example, the highly connected and the most powerful node should be the most reachable by another node as well.

4.2.2.4 The Network of Project 3

The interaction networks have been created for different management levels. The graph has been designed based on the team member's role, and Table 19 describes the roles. Figure 17 shows the network structure for the weekly work planning network among the project administrator, deputy director, lean manager superintendent, GC pm/coordinator, project manager, and scheduler for project 3. Figure 18 shows the second network, which is the PPC network, and the third one shows the lookahead planning network, according to Figure 19.

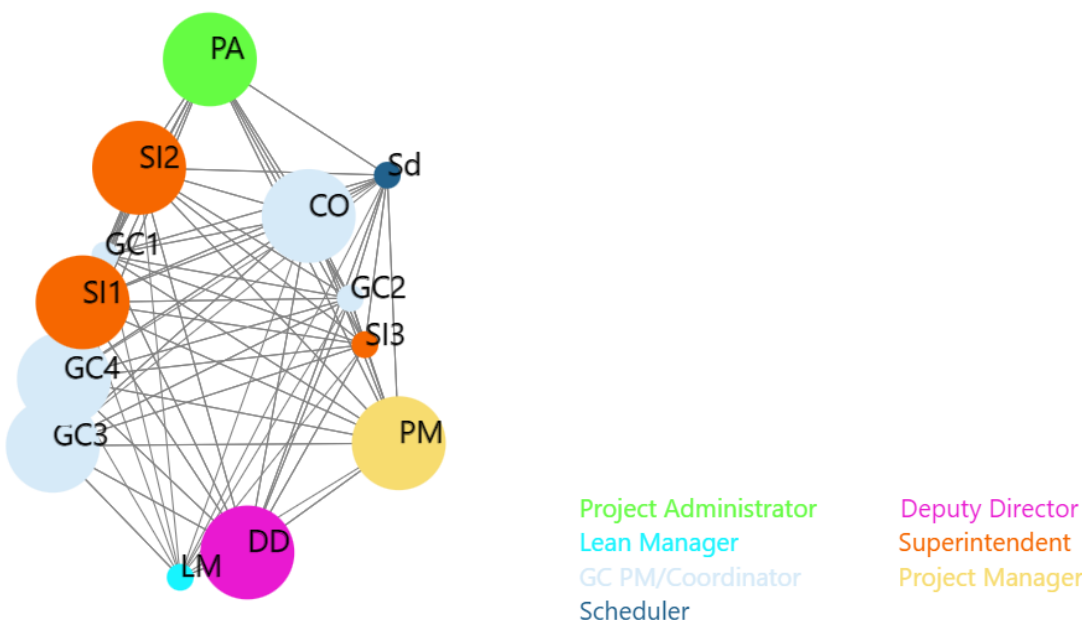

Figure 17. WWP Network (Project 3)

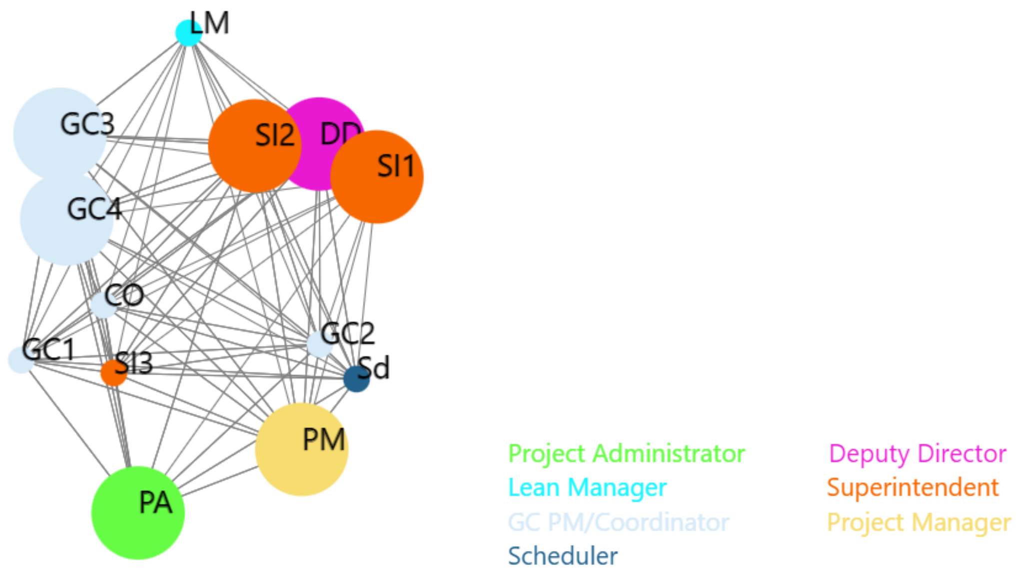

Figure 18. PPC Network (Project 3)

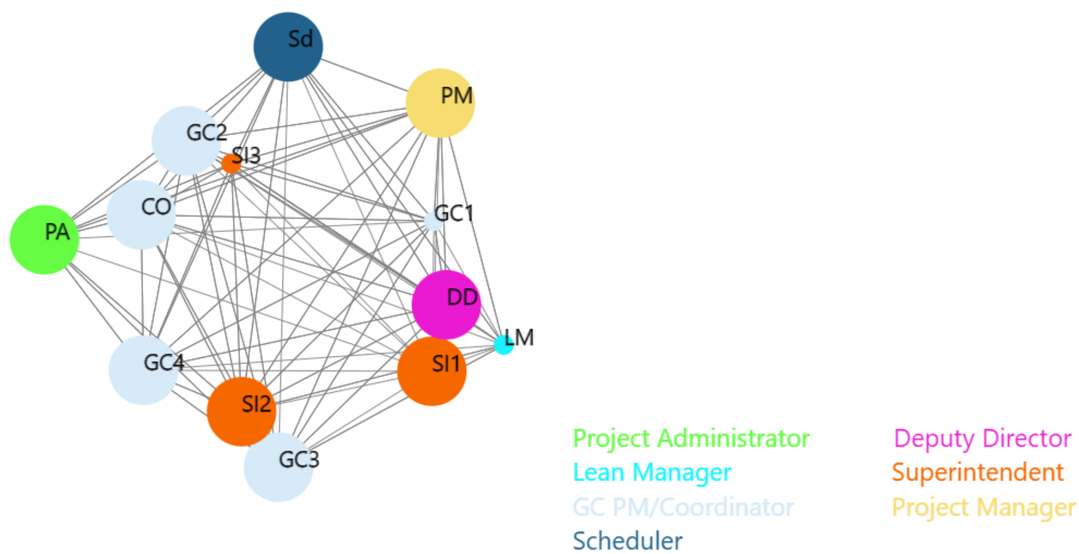

Figure 19. Lookahead Planning Network (Project 3)

Table 19. Description of the Roles of Team Members in Project 3

PA	Project Administrator	PM2	Project Manager 2
DD	Deputy Director	SD	Scheduler
LM	Lean Manager	GC1	GC PM/Coordinator 1
SI1	Superintendent 1	GC2	GC PM/Coordinator 2
SI2	Superintendent 2	GC3	GC PM/Coordinator 3
SI3	Superintendent 3	GC4	GC PM/Coordinator 4
PM1	Project Manager 1	CO	Project Coordinator

Table 20 shows the result for each network and the metrics. The metrics show the well-connected network, the network with better connection and faster interactions, the active network, and the neighbourhood connection. Table 21 shows the node metrics and the results for project 2.

Table 20. Network Metrics Results

Metrics	**WWP Result**	**PPC/Learning Result**	**Lookahead Result**
Avg. Degree	11.714	10.692	10.923
Graph Density	0.901	0.891	0.91
Average Clustering Coefficient	0.905	0.896	0.916
Avg. Path Length	1.099	1.109	1.09

Table 21. Node Metrics Results

Node Metrics	WWP Result	PPC/Learning Result	Lookahead Result
Betweenness	Max 6.27	Max 5.77	Max 2.63
	Min 0.2	Min 0.22	Min 0.2
Closeness	Max 1	Max 1	Max 1
	Min 0.81	Min 0.8	Min 0.86

Since each metric defines something about the network and its structure, Table 22 and Table 23 have been created to represent the metric interpretation based on each metric's concept. Table 22 shows the interpretation of the network metrics results, and Table 23 shows the interpretation of node metrics results.

Table 22. Network Results

Network Metrics interpretation	Network
The well-connected and cohesive network	Lookahead Planning Network
The poorly connected network	PPC Network
The network with better connection and faster interactions	Lookahead Planning Network
The network with poorer connection and slower interactions	PPC Network
The active network	WWP Network
The inactive network	PPC Network
How well a node's neighbourhood is connected and know each other	Lookahead Planning Network
How poorly a node's neighbourhood is connected	PPC Network

Table 23. Node Results

Node Metrics interpretation	Node
The node with a higher connection and more central	Lookahead: Superintendent 2
	PPC: Superintendent 2
	WWP: Project Manager 1
The node with a lower connection and more central	Lookahead: Lean Manager
	PPC: Lean Manager
	WWP: Lean Manager
The most powerful node to control flow and interactions	Lookahead: Superintendent 2, GC PM/Coordinator 1
	PPC: Superintendent 2, GC PM/Coordinator 1
	WWP: GC PM/Coordinator 1
The Least powerful node to control flow and interactions	Lookahead: Lean Manager, Project Administrator, Deputy Director
	PPC: Lean Manager
	WWP: Lean Manager
The most reachable node by others	Lookahead: GC PM/Coordinator 1, Project Administrator, Deputy Director, GC PM/Coordinator 3
	PPC: GC PM/Coordinator 1, GC PM/Coordinator 2
	WWP: GC PM/Coordinator 1, Gc PM/Coordinator 2
The least reachable node by others	Lookahead: Superintendent 2, Scheduler, Project Manager 2
	PPC: Superintendent 2, Lean Manager
	WWP: Lean Manager

To summarize, in this project WWP network appears only as the active network, and the lookahead planning network is the well-connected network with the faster interactions. The node's neighbourhood is also well-connected in the lookahead planning network. In contrast, the PPC network is a poorly connected network with slower interactions. It is also an inactive network with a more isolated neighbourhood. Comparing the node results show that the most powerful and highly connected node is the node with the least reachable node by others. So, focusing on having a balance for the nodes would be beneficial to improve the network result. On the other hand, it seems the lean manager is the node with the lowest connection, the least powerful, and the least reachable node; therefore, focusing on the lean manager to improve the interaction with the team would be more helpful in implementing the better lean management system and LPS correctly.

4.3 Correlation Test

Since one of the research objectives is finding the relationship between LPS performance and social interactions, Spearman's ρ correlation has been used to find the correlation between SNA metrics and PPC. Since there are three different answers for these projects, three different results have been used as three points to calculate the correlation. Figure 20 is an example of a calculation to find the correlation between the SNA metrics and PPC. According to the correlation results, we have found that graph density and average path length are the two metrics that are good in predicting the PPC. This means that if the network is well-connected and has a better reflection of connectivity and faster interactions, it will end up with a higher PPC. More detailed correlation results will be discussed further to show the correlation between SNA metrics and management levels.

Metrics (Lookahead)	Project 1	Project 2	Project 3	PPC Project 1	PPC Project 2	PPC Project 3
Avg. Degree	14.211	14.211	10.923	64.19	70.11	72.51
Graph Density	0.789	0.789	0.91	64.19	70.11	72.51
Average Clustering Coefficient	0.824	0.824	0.916	64.19	70.11	72.51
Avg. Path Length	1.211	1.211	1.09	64.19	70.11	72.51

Figure 20. Correlation Calculation

According to Evans 2012, when $\rho \geq 0.8$ is very strong, and when $0.6 \leq \rho < 0.8$ is strong. The below tables (Table 24, Table 25, Table 26) show the correlation between the SNA metrics, LPS management levels, and PPC. Comparing the results show that there is a correlation between some of the LPS management levels (People and partners, Master scheduling, Phase scheduling, and Lookahead planning) with the SNA metrics.

Table 24 shows that there is a very strong correlation between the weekly work plan and average degree and week correlation between the weekly work plan and other SNA metrics (Graph Density, Average Clustering Coefficient, Avg. Path Length). The other two tables (Table 25 and Table 26) show that there is a very strong correlation between the weekly work plan and SNA metrics. Since the results for Table 25 and Table 26 are very close, we cannot rely on only these results. So, I have considered there is only a correlation between weekly work plans and average degrees based on the results. There are almost similar results between daily huddle and SNA metrics. Because of the abovementioned reason and inconsistency for a positive or negative relationship between daily huddle and other SNA metrics (Graph Density, Average Clustering Coefficient, Avg. Path Length), I have considered there is only a correlation between daily huddle and average degree. Therefore, it seems the SNA metrics have more relation with the longer-term planning networks. Among the longer-term planning, the correlation between the lookahead planning and SNA graph density and average path length is stronger than others.

The tables (Table 24, Table 25, Table 26) show there is a high correlation between SNA metrics and PPC. The network metrics results for the PPC network and lookahead network are close, and the difference between the correlation level is not noticeable. In other words, Table 25 and Table 26 show that there is a strong correlation between the SNA metrics and PPC, and all the numbers are in the same range. However, the WWP network, Table 24, shows that there is a strong correlation between graph density and PPC, and also, there is a strong correlation between the average clustering coefficient and PPC.

Table 24. Weekly Work plan network metrics results and the correlation with actual PPC

WWP Network Metrics	LPS Project Management Level and PPC						
	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.8813	-0.9260	-0.7024	-0.6583	-0.9956	-0.6231	-0.7178
Graph Density	0.8841	0.8302	0.9827	0.9920	0.4792	-0.3006	0.9784
Avg. Clustering Coefficient	0.8660	0.8087	0.9750	0.9866	0.4459	-0.3362	0.9700
Avg. Path Length	-0.8841	-0.8302	-0.9827	-0.9920	-0.4792	0.3006	-0.9784

Table 25. PPC network metrics results and the correlation with actual PPC

PPC Network Metrics	LPS Project Management Level and PPC						
	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.8846	-0.9286	-0.7073	-0.6636	-0.9950	-0.6177	-0.7226

Graph Density	0.8846	0.9286	0.7073	0.6636	0.9950	0.6177	0.7226
Average Clustering Coefficient	0.8846	0.9286	0.7073	0.6636	0.9950	0.6177	0.7226
Avg. Path Length	-0.8846	-0.9286	-0.7073	-0.6636	-0.9950	-0.6177	-0.7226

Table 26. Lookahead network metrics results and the correlation with actual PPC

Lookahead Network Metrics	LPS Success Factors and PPC						
	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.8846	-0.9286	-0.7073	-0.6636	-0.9950	-0.6177	-0.7226
Graph Density	0.8846	0.9286	0.7073	0.6636	0.9950	0.6177	0.7226
Average Clustering Coefficient	0.8846	0.9286	0.7073	0.6636	0.9950	0.6177	0.7226
Avg. Path Length	-0.8846	-0.9286	-0.7073	-0.6636	-0.9950	-0.6177	-0.7226

$\rho - value$ is another statistical metric to show that the null hypothesis is false or true. According to NIST/SEMATHECH (2015), 0.05 or less is considered a high-significance relationship and shows that the null hypothesis is false. The below tables (Table 27, Table 28, Table 29) show the $\rho - value$ for the network metrics and PPC. $\rho - value$ results also show that I can rely on the correlation hypothesis. So, after data analysis, we can see there is a correlation between the LPS management level and SNA metrics.

Table 27. ρ-value of WWP network metrics, LPS Project Management Level, and PPC

WWP Network Metrics	LPS Project Management Level and PPC						
	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	0.0242	0.0286	0.0237	0.0245	0.0236	0.0226	0.0043
Graph Density	0.0068	0.0308	0.0199	0.0227	0.0069	0.0128	0.0012
Average Clustering Coefficient	0.0074	0.0326	0.0215	0.0243	0.0073	0.0127	0.0012
Avg. Path Length	0.0162	0.0551	0.0423	0.0457	0.0127	0.0131	0.0013

Table 28. ρ-value of PPC network metrics, LPS Project Management Level, and PPC

PPC Network Metrics	LPS Project Management Level and PPC						
	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	0.0283	0.0333	0.0275	0.0285	0.0274	0.0262	0.0041
Graph Density	0.0083	0.0340	0.0243	0.0273	0.0068	0.0104	0.0012
Average Clustering Coefficient	0.0085	0.0345	0.0246	0.0276	0.0070	0.0106	0.0013
Avg. Path Length	0.0136	0.0503	0.0360	0.0392	0.0121	0.0154	0.0013

Table 29. ρ-value of Lookahead network metrics, LPS Project Management Level, and PPC

Lookahead Network Metrics	LPS Success Factors and PPC						
	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	0.0216	0.0266	0.0213	0.0223	0.0209	0.0199	0.0035
Graph Density	0.0075	0.0318	0.0228	0.0259	0.0059	0.0097	0.0012
Average Clustering Coefficient	0.0081	0.0335	0.0240	0.0270	0.0065	0.0102	0.0012
Avg. Path Length	0.0149	0.0535	0.0383	0.0414	0.0135	0.0165	0.0013

4.4 Proposed Dashboard

After validating the proposed framework, a dashboard has been created for each project with the ability to track the current situation. The goal of creating the dashboard is to provide a clear vision of the current project performance by visualizing the collected information. In the proposed dashboard, the team members are able to see the team interaction and current LPS metrics in the project. The dashboard contains social networks, network metrics, actual PPC, Variance reasons, and the LPS survey results. The dashboard has been designed using Power BI, an interactive data visualization software. The dashboard, Figure 21, shows the teams' interaction at each management level, the LPS implementation level in the project, and other LPS metrics like PPC and constraint log, which have been directly collected from the planning software the company was using. The dashboard also has the feature to focus on each node or each team by filtering and seeing all the interaction levels in different LPS management levels, which can be seen in Figure 22 and Figure 23.

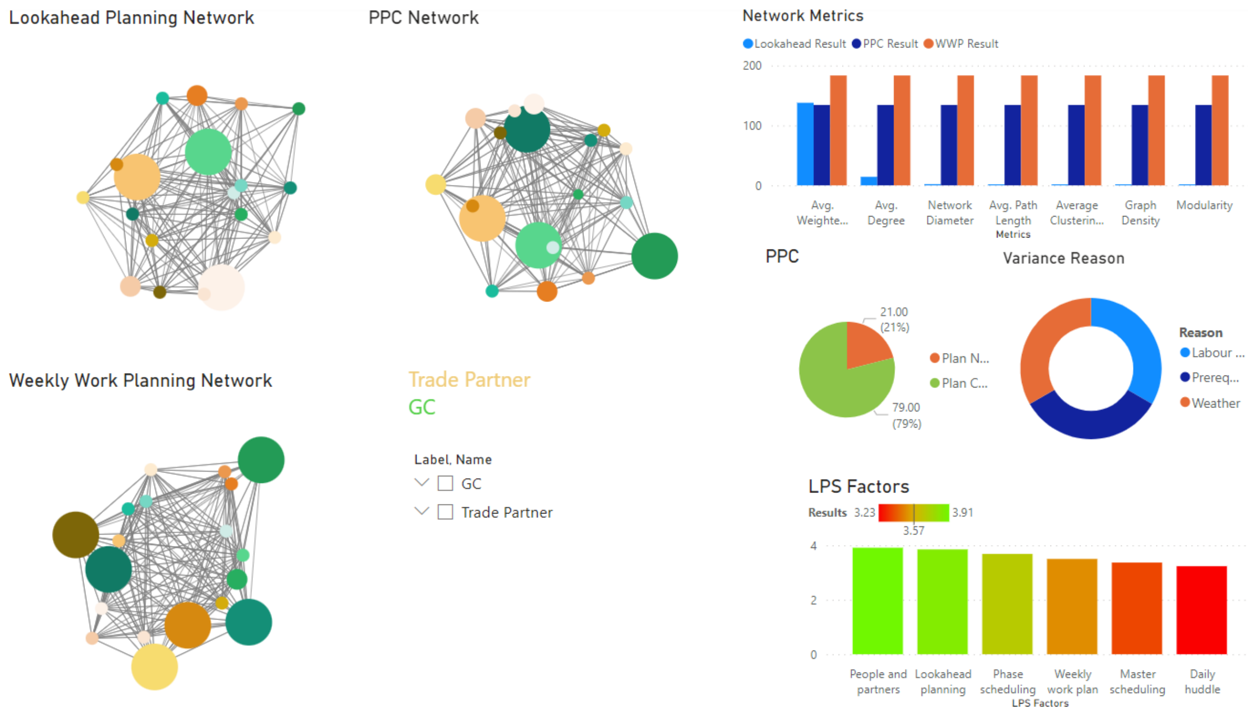

Figure 21. Proposed Dashboard

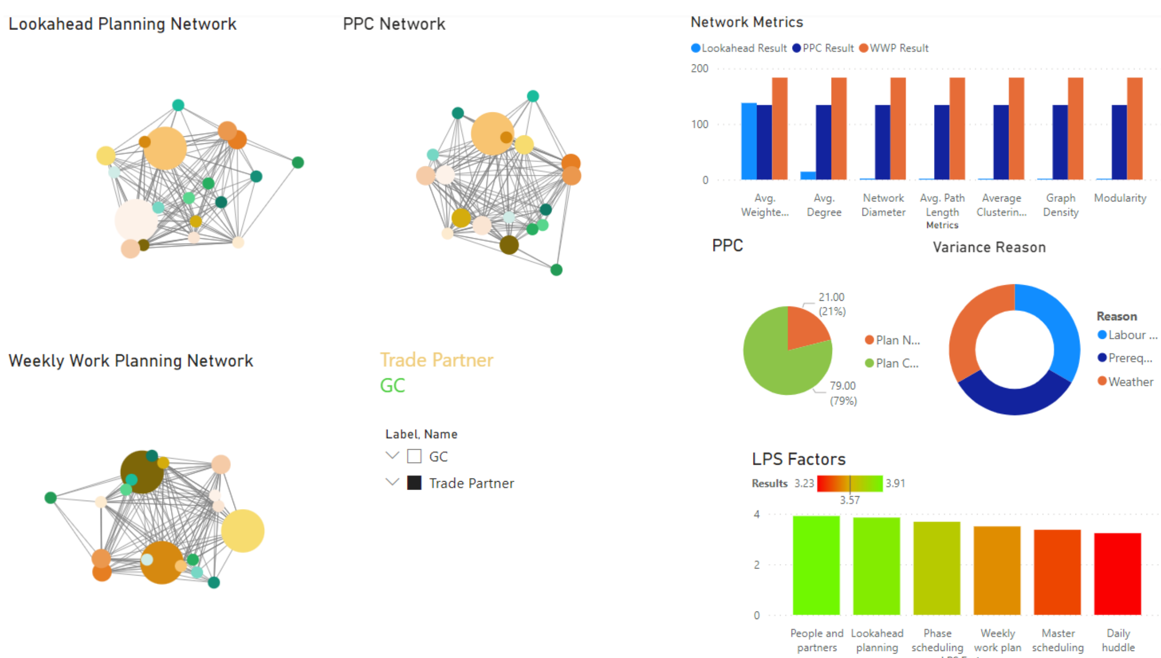

Figure 22. Proposed Dashboard with Team Filtering Feature

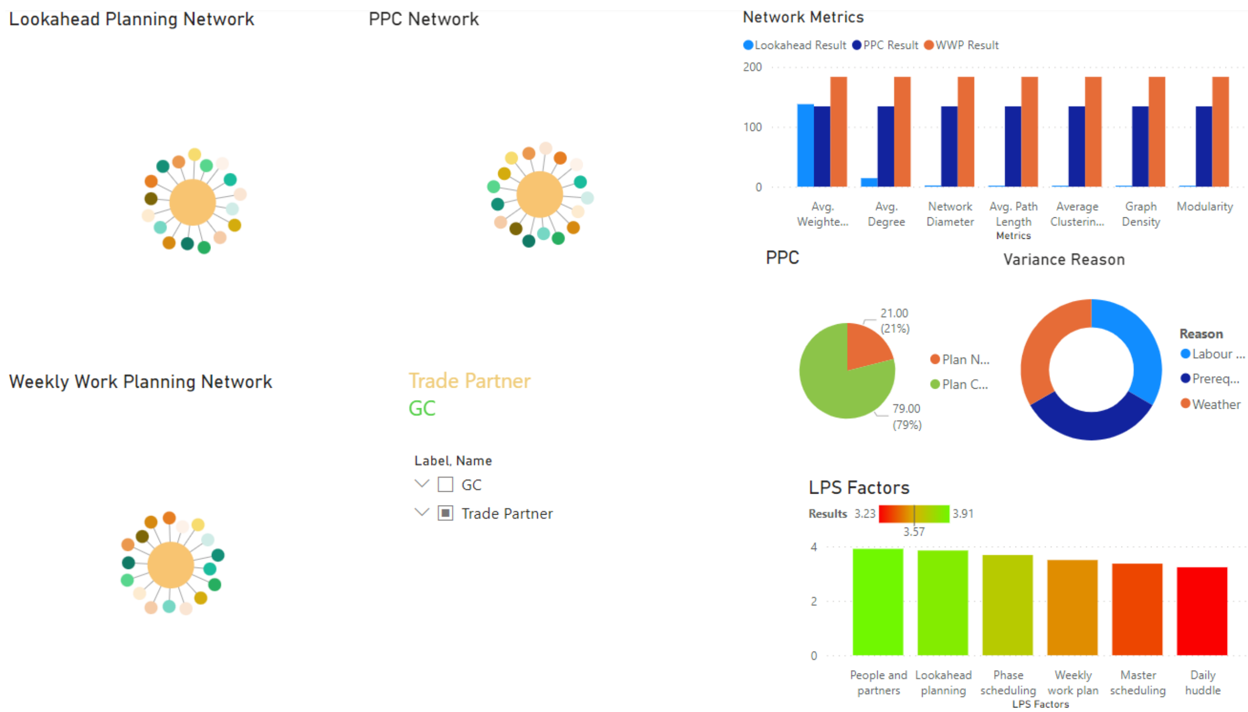

Figure 23. Proposed Dashboard with Node Filtering Feature

4.5 Suggestions for improvement

The PPC improvement makes the planning more reliable, and we also need to focus on human behaviour to be more successful in having a higher PPC. The study shows how much interaction and a healthy network will help us to end up with a higher PPC. According to the research result, there should be some suggestions for future work.

One of the suggestions for project 1 is to focus on LPS implementation and increase the LPS maturity level in the master schedule, phase scheduling, and lookahead planning which are the weakest among the other six management levels. Another suggestion should be working on the lookahead planning to make the interaction stronger and try to maintain the balance for the nodes by keeping the most powerful node as the most reachable node as well. Finally, decreasing the number of reasons for variance. Since the results are almost the same for project 2, the abovementioned improvements are also the improvement suggestion for project 2.

Even though the performance of project 3 is better than the other two projects, we are always looking for improvements in lean construction. So, one of the suggestions could be to focus more on lookahead planning to make it also an active network. Watching out to decrease the number of reasons for variance could be another suggestion for improvement. The third suggestion should be finding a suitable way to keep the balance for the nods (e.g., being more reachable when you are the most powerful node in the network) and involve the lean manager more in the connection.

These three case studies prove a need to focus on human behaviour by strengthening the network structure. As a general improvement suggestion for future work, the construction team should focus more on creating a healthier network during the long-term planning. To have a stronger network, the team should ensure that the nodes with a higher ability to control flow (network hub) and have a higher connection are also available and reachable by other nodes.

The other suggestion could be creating a new structure for the network by giving power to the edge. In this case, each node has the power to act at a specific level. A circular network is an answer to creating the network with this function which can be seen in Figure 24 and Figure 25. In the traditional structure, which is a hierarchy structure, the team member should wait for the response from the network hub. In this case, the hub might be a bottleneck for the network. Therefore, creating a circular network instead of a hierarchy structure will decrease the pressure from the network hub and create a better network with a higher information exchange rate.

A simulation model has been created for project 1 in Gephi to find a better structure. Figure 24 shows the improved network for this project by focusing on creating a circular network. Project 1 contains three groups: the construction team, the support team, and the subcontractor. Examining the current network proved that node 8 is the network hub and bottleneck. So, a circular network is created by considering node eight as the center of the network. Figure 25 shows the role of each node and the detailed structure. As can be seen in Figure 25, three different circles are connected together, and they have the power to act at a specific level, but subcontractors are not connected directly to node eight to reduce the pressure from the network hub.

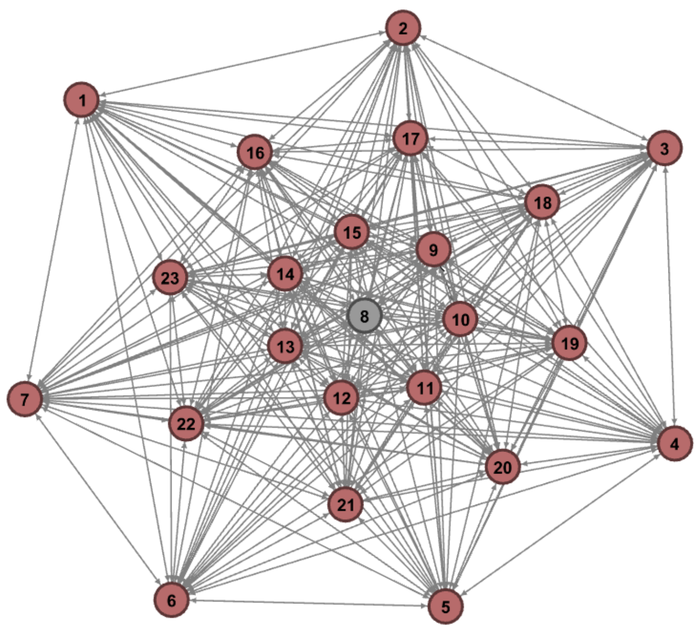

Figure 24. Suggested Network Structure

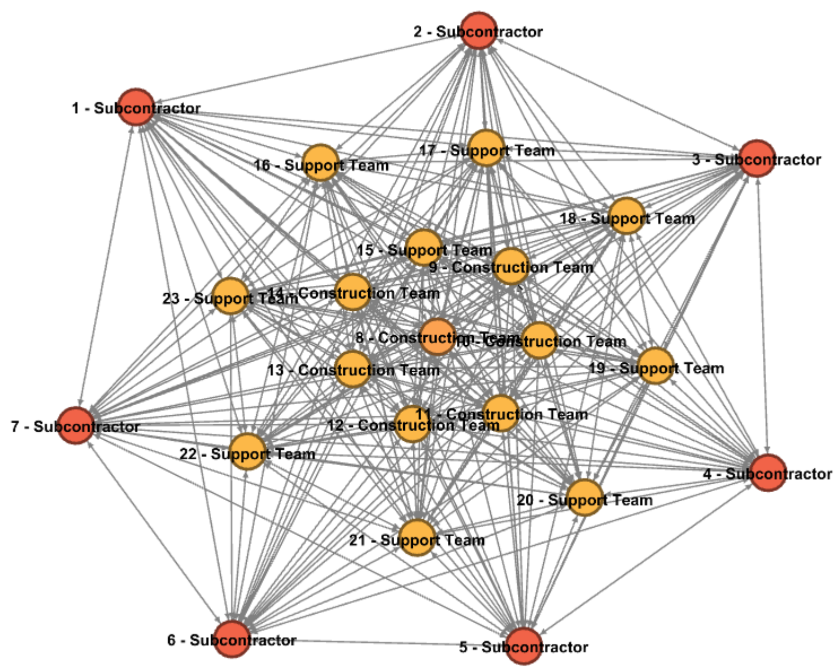

Figure 25. Information on Suggested Network

Table 30 shows the result for the suggested network. The result proves that the graph density and Average path length are better, so the lookahead planning will be better according to the correlation test.

Table 30. SNA Metrics for Suggested Network

Graph Density	0.947
Avg. Path Length	1.053

Focusing on team alignment and integration and three specific social dynamic variables (trust, goal setting, and power distance), which have been stated by González et al. (2015), will help us achieve the suggested stage from the current stage. By improving the team interaction to accomplish the proposed stage, we expect to see better performance and a higher PPC.

CHAPTER 5 – Conclusions

Lean project management is part of modern project management because it focuses on increasing quality and value and decreasing waste. LPS is one of the essential applications of the lean construction concept, which helps control planning. Even though the LPS is widely used worldwide, it is still new to many construction professionals, and partial implementation of lean and the LPS will decrease its potential. Implementing the LPS not only improves production control but also helps build relationships among construction teams and strengthen social networks; accomplishing an effective LPS requires effective communication to collaborate and exchange information.

After the literature review, the pilot case study was done to find the need for this research. The results of the pilot case study indicate that the communication level is not very strong. In addition, the PPC result shows that the project is not working well in the LPS implementation. According to these results, the need to study team interaction and the LPS implementation was found.

Creating effective communication requires understanding the room for improvement; therefore, studying the interaction among team members will help us find the gaps. SNA is a suitable method to study social interaction. Some metrics in SNA help us analyze the social network and find a correlation with LPS metrics like PPC. Hence, a framework has been created to analyze the LPS implementation level and teams' interaction.

The proposed framework shows that two surveys must be conducted to gather LPS and network data. After collecting the LPS and network data, the LPS maturity level has to be calculated for the project, and the interaction network needs to be structured. Finally, data will be analyzed to see the project's performance. Three primary case studies have been selected to validate the proposed framework and find the relationship between the team's interaction and the LPS implementation level.

After analyzing the LPS survey results and the PPC results, I have found that the LPS maturity level and PPC in project 3 are higher than those in the other two projects, and the average number of reasons for variance in project 3 is more than the other two projects. In addition, the network results show that lookahead planning is well-connected with faster interaction, a node's neighbourhood is not isolated, and they know each other very well. The active network in this project is the WWP network.

The PPC in project 2 is less than the third project and better than the first project; moreover, the average number of reasons for variance in project 1 is more than in project 2. The network results for project 2 and project 1 are almost similar. The look-ahead planning is a poorly connected, inactive, and more isolated network. The lookahead planning network only appeared as the network with the faster interaction. WWP is a well-connected, active, and networked community with a strong neighbourhood.

In conclusion, having a well-connected network with faster interactions and a more connected neighbourhood leads to higher PPC, like in project 3. Hamzeh 2009 also stated that weak lookahead planning would end up with less PPC. Even though the average number of reasons for variance in project 3 is higher than in projects 2 and 1, having strong lookahead planning leads to higher PPC. Besides, other research examined that focusing on complete LPS implementation like weekly work plan, lookahead planning and learning process will end up with a higher PPC (Alarcón et al., 2005). So, according to the research results and previous research, we can conclude that to have better performance and high PPC, we need to focus on having strong weekly work planning, lookahead planning, and learning process.

In contrast, the PPC is lower in projects 2 and 1 because the lookahead planning is not strong enough. But what is the reason for having less PPC in project 1 compared to project 2 with almost similar interaction pattern? In this case, comparing the results shows that the number of reasons for variance in project 1 is greater than that in project 2; as a result, the PPC is more dependent on the number of reasons for variance because of poor lookahead planning.

After finding a relationship between having a better lookahead planning network and higher PPC, it is time to find which SNA metrics help us in decision-making. As discussed in Chapter 4 - Correlation test, the results prove a strong correlation between the SNA metrics and the longer-term planning process (people and partners, master scheduling, phase scheduling, and lookahead planning). Among the SNA metrics, graph density and average path length are two metrics that have a stronger relationship and less $\rho - value$ with the LPS management level. Among the LPS management level, the lookahead planning strongly correlates with the mentioned SNA metrics (graph density and average path length). So, this could be the other metric in the planning process that should be considered to make the planning process more reliable.

In summary, having a strong relationship during long-term planning will help us improve plan reliability according to correlation results and case study results. Because the strong relationship will help to control the information flow and interaction faster, and as a result, the PPC will be higher. Comparing the SNA metrics, LPS management level, and PPC correlation proves that graph density and average path length have a stronger relationship, and both could be other planning metrics that help us predict the PPC, so they should be considered in the planning process as well.

5.2 Research Contribution

5.2.1 Academic Contribution

The main academic contributions of this research are as follows:

- Contribute to the body of knowledge related to SNA and LPS management systems by focusing on the role of team interaction in project performance.
- Provide a methodology for assessing the team's performance and mapping the team's relationship, which helps find the strongest and the weakest networks and the node with the highest impact in the network.
- The correlation coefficient test is used to find the relationship between the current and common LPS metric, PPC, and the SNA metrics. The results demonstrated a high relationship between the PPC and SNA metrics (especially graph density and average path length).
- The correlation coefficient test determines the relationship between the LPS management level and SNA metrics. The results demonstrated that there is a strong relationship between the longer-term planning process and SNA metrics (especially graph density and average path length).

- $\rho - value$ test to prove that the hypothesis is valid, and the null hypothesis is false.
- Introducing new metrics as project performance metrics to improve the plan's reliability.

5.2.2 Industrial Contribution

- Improvement suggestions for the current practice by introducing the new performance metrics
- Develop a dashboard that shows the current performance and team interaction network.

5.3 Research Limitations and Recommendations for Future Research

The following limitations were encountered in the research, and recommendations are suggested for future work:

- Conducting the social interaction and LPS surveys regularly: Since the study of human behaviour is time-dependent, the LPS survey and SNA survey should be done regularly to study more about the social network structure.
- Finding the relationship between the social network structure and the project phase: After conducting the survey regularly, there should be a chance to study the relationship between team interaction and the project stage. I assume that if the team members do not know each other and have not had any chance to work on previous projects, the network structure will be weak in the project's first stage.
- Behaviour simulation: the team members' interactions can be simulated in NetLogo, which is an agent-based modelling simulation software. In this case, we are able to model a critical situation and find out the result based on the current network structure. Then, a new network pattern can be suggested based on the simulation results.
- Automating the dashboard: Data collection was one of the main challenges in this research.

Creating a more robust dashboard needs to have strong data which will be updated every month. Existing the required data every month will help us to have an updated dashboard, and in this case, we only need to conduct the survey every month, collect the PPC and constraint information and refresh the dashboard to monitor the current situation. In this research, Power BI data visualization software has been used to create the dashboard, and after conducting the surveys on the LimeSurvey platform, the data format has been updated to be matched to create the social network. Then, the LPS metrics and survey results are imported, and the dashboard is created. The dashboard can be automated and updated after conducting the surveys. To implement this suggestion, the survey should be created in an Excel sheet and then created in the dashboard in Google Looker Studio. Hence, the dashboard can be easily refreshed when the survey data is updated in Google Sheets.

- Case Study: In this research, we only considered the team interaction by considering the number of team members, the frequency of the interaction and information exchange, and lean and LPS metrics. But, we have not studied the project's nature and complexity. Future research should focus on team interaction by considering the above-mentioned factors.

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Appendix A

LPS Assessment (Forest Hill)

Welcome to the survey.

This survey contains 18 questions, and it should take around 10 minutes to complete.

The purpose of the survey is to assess the current implementation practices of the Last Planner System.

The responses are anonymous and data will be kept confidential.

Completion and submission of the survey mean your consent to participate.

Next

Project Role and Responsibility

Please choose your role from dropdown list.

Choose one of the following answers

Please choose...

Next

Project Role and Responsibility

Please choose your role from dropdown list.

Choose one of the following answers

Please choose...

Please choose...
GC PM / Coordinator
Trade Partner PM
GC Superintendent
Foreman/ General Foreman
Other:

Next

LPS Assessment

On a scale of 1 (Low) to 5 (High), how would you rate for the below statements?

	1	2	3	4	5
"There was an initial and ongoing effort to train the team LPS"					
"The entire team collaborates to develop the plan."					
"The team has top management support and an open environment to include all trades in the planning process."					
"Master Schedule milestones are used to guide all levels of planning and reviewed frequently by the team."					
"Conditions of Satisfaction and other requirements are identified for each milestone."					
" Hand-offs between trades are identified and optimized."					

Next

LPS Assessment

On a scale of 1 (Low) to 5 (High), how would you rate for the below statements?

	1	2	3	4	5
"Project constraints are identified during Phase Pull Planning"	○	○	○	○	○
"The team uses productivity metrics and balances work at Phase Pull."	○	○	○	○	○
"The developed Phase Pull plan is realistic and achievable."	○	○	○	○	○
"A Project Constraint Log is actively used by team weekly (at a minimum)."	○	○	○	○	○
"All stakeholders share a common understanding and involvement in the planning process to improve workflow reliability."	○	○	○	○	○
"Drawings, site/area plans, BIM, or other visual aids are used while developing the plan."	○	○	○	○	○

Next

LPS Assessment

On a scale of 1 (Low) to 5 (High), how would you rate for the below statements?

	1	2	3	4	5
"A structured agenda is used durring the Lookahead & Weekly Work Plan meeting (e.g. DID, SHOULD, CAN, WILL)."	○	○	○	○	○
"The team measures the Percent Plan Complete (performance), and takes corrective action on Resons for Variance every week."	○	○	○	○	○
"Work is planned in the best achievable sequence to close the gap between lookahead and the weekly work plan."	○	○	○	○	○
"Activities planned include: what will be done, where, when, and who will do it."	○	○	○	○	○
"The team discusses: what was done yesterday, what is being done today, is anything holding up work tomorrow."	○	○	○	○	○
"Weekly Work Plan is used to guide Daily Huddle."	○	○	○	○	○

Submit

Factor	Project 1	Project 2	Project 3	Ideal
People and partners	3.416666667	3.911111111	4.47619	5
Master scheduling	2.6875	3.366666667	4.5	5
Phase scheduling	2.625	3.683333333	4.071429	5
Lookahead planning	2.625	3.85	4.178571	5
Weekly work plan	3.59375	3.5	4.357143	5
Daily huddle	4.125	3.233333333	4.285714	5

Figure A-2. LPS maturity Results

Section 2 : Network Analysis (Project 2)

Welcome to the survey.

This survey contains 4 questions and it should take 5-7 minutes to complete.

The purpose of the survey is to understand the team member's interactions and find the relationship between social interactions and Last Planner System.

The responses are anonymous and data will be kept confidential.

Completion and submission of the survey mean your consent to participate.

Next

Network Analysis (Frequency)

Please specify the frequency of the communication about LPS and constraint removal with each person. (If not applicable, please select N/A).

*

	How frequently do you communicate about the weekly work planning with this person?	How frequently do you communicate about the tasks that were not completed last week with this person?	How frequently do you talk about the lookahead planning (constraint identification and/or removal) with this person?
Person 1	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month
Person 2	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month
Person 3	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month
Person 4	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month	○ --N/A ○ 5>= times per week ○ 3-5 times per week ○ Between 1-3 times per week ○ Between 1-3 times per month

Figure A-3. SNA Survey on LimeSurvey Platform

Source	Target	Weight
Sub_C (Marine Piling)	Sub_C (Marine Piling)	40
Sub_C (Marine Piling)	Sub_C(Rebar)	18
Sub_C (Marine Piling)	Sub_C (Rebar)	32
Sub_C (Marine Piling)	Sub_C(Rebar)	9
Sub_C (Marine Piling)	Sub_C (Electrical)	16
Sub_C (Marine Piling)	Sub_C (Concrete supply)	25
Sub_C (Marine Piling)	Construction Team	33
Sub_C (Marine Piling)	Construction Team	32
Sub_C (Marine Piling)	Construction Team	17
Sub_C (Marine Piling)	Construction Team	68
Sub_C (Marine Piling)	Construction Team	60
Sub_C (Marine Piling)	Construction Team	68
Sub_C (Marine Piling)	Construction Team	25
Sub_C (Marine Piling)	Construction Team	16
Sub_C (Marine Piling)	Support (Environmental)	40
Sub_C (Marine Piling)	Support_D(Quality)	24
Sub_C (Marine Piling)	Support_D(Quality)	68
Sub_C (Marine Piling)	Support_D(Quality)	36
Sub_C (Marine Piling)	Support_D(Quality)	48
Sub_C (Marine Piling)	Support_D(Safety)	40
Sub_C (Marine Piling)	Support_D(Electrical)	32
Sub_C (Marine Piling)	Support_D(Survey)	33
Sub_C (Marine Piling)	Sub_C (Marine Piling)	32
Sub_C (Marine Piling)	Sub_C(Rebar)	32
Sub_C (Marine Piling)	Sub_C (Rebar)	40
Sub_C (Marine Piling)	Sub_C(Rebar)	24
Sub_C (Marine Piling)	Sub_C (Electrical)	32
Sub_C (Marine Piling)	Sub_C (Concrete supply)	32
Sub_C (Marine Piling)	Construction Team	17
Sub_C (Marine Piling)	Construction Team	16
Sub_C (Marine Piling)	Construction Team	9
Sub_C (Marine Piling)	Construction Team	24
Sub_C (Marine Piling)	Construction Team	32
Sub_C (Marine Piling)	Construction Team	3
Sub_C (Marine Piling)	Construction Team	1

Figure A-4. Sample of SNA results for Project 1

Source	Target	Weight
1	2	40
1	3	40
1	4	68
1	5	68
1	6	40
1	7	48
1	8	40
1	9	17
1	10	32
1	11	32
1	12	17
1	13	17
1	14	17
1	15	32
1	16	32
1	17	32
1	18	32
1	19	32
1	20	17
1	21	17
1	22	17
1	23	17
2	1	32
2	3	32
2	4	24
2	5	32
2	6	24
2	7	17
2	8	17
2	9	24
2	10	17
2	11	17
2	12	1
2	13	1
2	14	16

Figure A-5. Sample of SNA Results for Project 2

Source	Target	Weight
1	5	8
1	6	8
1	7	8
1	8	8
1	9	16
1	10	16
1	11	8
1	12	8
1	13	8
1	14	8
2	5	8
2	6	8
2	7	8
2	8	8
2	9	8
2	10	8
2	11	8
2	12	8
2	13	8
2	14	8
3	2	16
3	5	8
3	6	8
3	7	8
3	8	8
3	9	8
3	10	8
3	11	8
3	12	16
3	13	8
3	14	8
5	1	8
5	2	8
5	3	8
5	6	8

Figure A-6. Sample of SNA Results for Project 3

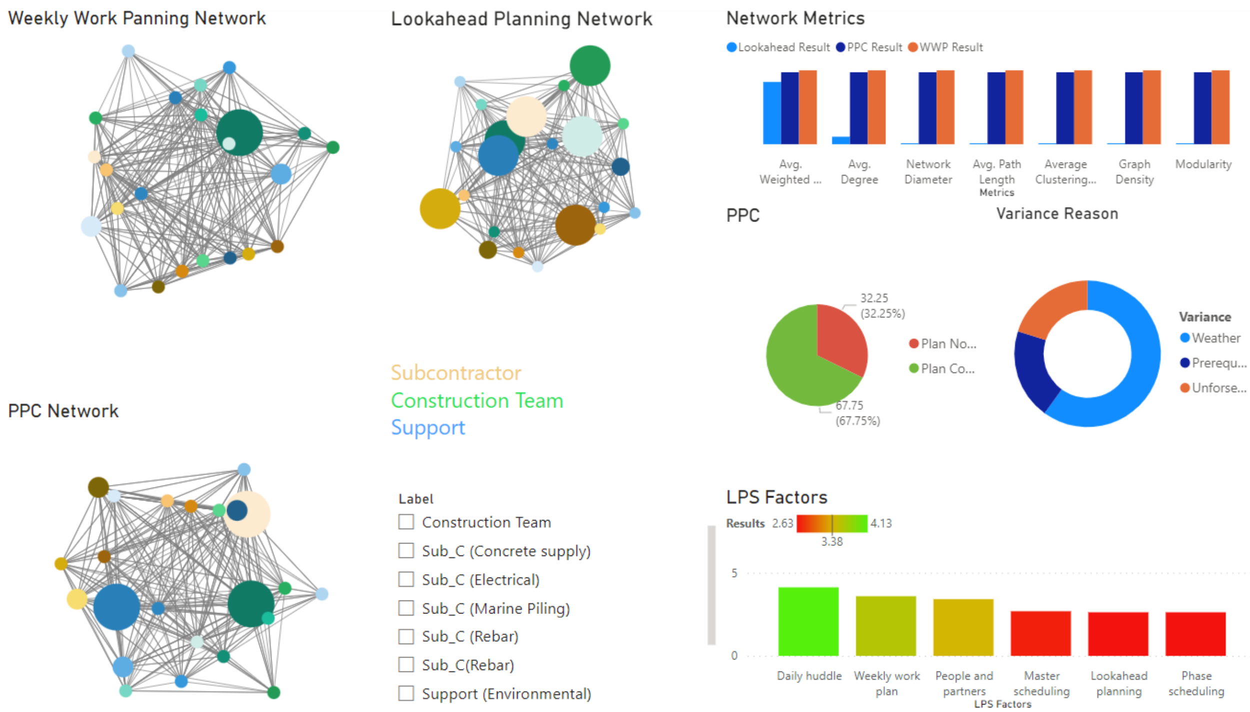

Figure A-8. Project 1

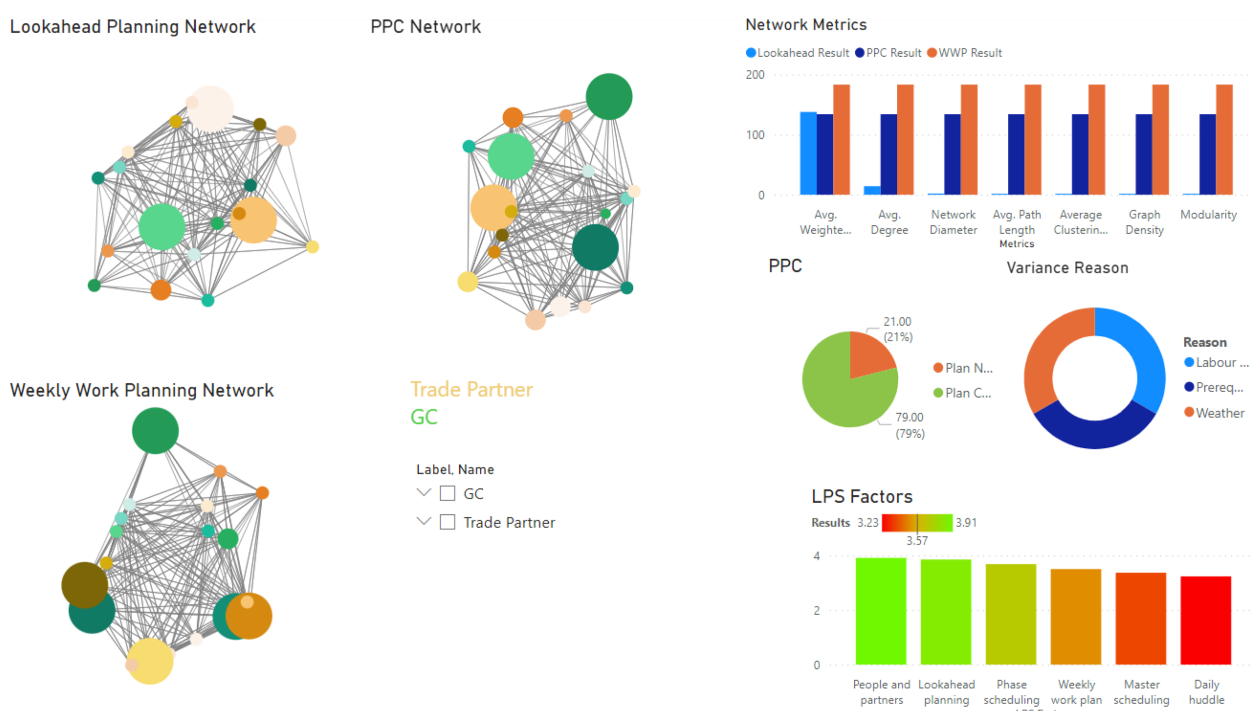

Figure A-7. Project 2

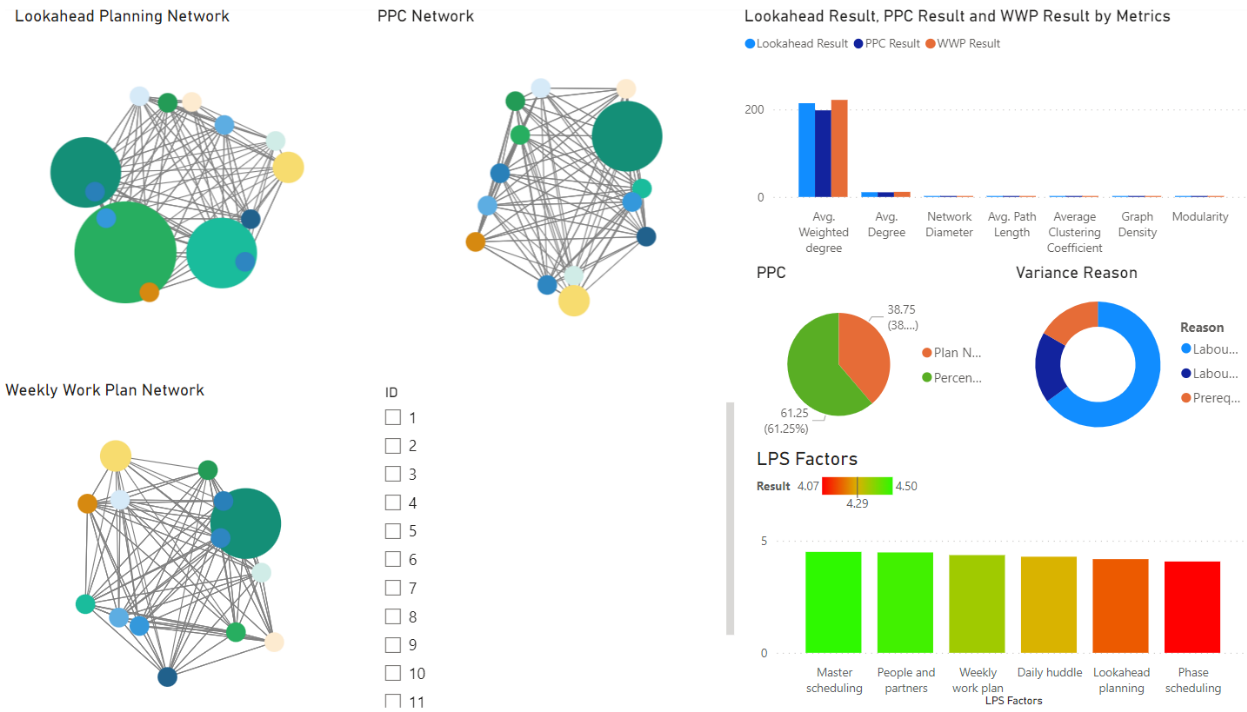

Figure A-9. Project 3

(WWK)	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.881337066	-0.92607937	-0.702430037	-0.658360912	-0.995689384	-0.623181794	-0.717802643
Graph Density	0.884195781	0.830256639	0.982724412	0.992074851	0.479227051	-0.300611723	0.978449318
Average Clustering Coefficient	0.866025404	0.8087337	0.975078865	0.986654957	0.445920012	-0.336225283	0.97000248
Avg. Path Length	-0.884195781	-0.830256639	-0.982724412	-0.992074851	-0.479227051	0.300611723	-0.978449318

(PPC)	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.884615385	-0.928692013	-0.70738372	-0.663601659	-0.99501734	-0.617704644	-0.722647658
Graph Density	0.884615385	0.928692013	0.70738372	0.663601659	0.99501734	0.617704644	0.722647658
Average Clustering Coefficient	0.884615385	0.928692013	0.70738372	0.663601659	0.99501734	0.617704644	0.722647658
Avg. Path Length	-0.884615385	-0.928692013	-0.70738372	-0.663601659	-0.99501734	-0.617704644	-0.722647658

(Lookahead)	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.884615385	-0.928692013	-0.70738372	-0.663601659	-0.99501734	-0.617704644	-0.722647658
Graph Density	0.884615385	0.928692013	0.70738372	0.663601659	0.99501734	0.617704644	0.722647658
Average Clustering Coefficient	0.884615385	0.928692013	0.70738372	0.663601659	0.99501734	0.617704644	0.722647658
Avg. Path Length	-0.884615385	-0.928692013	-0.70738372	-0.663601659	-0.99501734	-0.617704644	-0.722647658

Figure A-10. Correlation test

(WWK)	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	0.024292739	0.028686126	0.023754652	0.024584437	0.023629654	0.022648626	0.004388
Graph Density	0.006815291	0.030874675	0.019970018	0.022712876	0.006919114	0.012864752	0.001257
Average Clustering Coefficient	0.007499401	0.03264663	0.021553958	0.02435695	0.007315799	0.012769388	0.00127
Avg. Path Length	0.016234536	0.055103275	0.042365398	0.045786989	0.012781309	0.013158892	0.001389

(PPC)	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	0.028309032	0.03336986	0.027521656	0.028563528	0.027426391	0.026258534	0.004106
Graph Density	0.008395293	0.034025803	0.024305823	0.02732988	0.00685881	0.01045015	0.001297
Average Clustering Coefficient	0.008566099	0.03453735	0.024660071	0.027689392	0.007031741	0.010604296	0.0013
Avg. Path Length	0.013618848	0.050386601	0.036054858	0.039269358	0.012103972	0.015453843	0.001347

(Lookahead)	People and partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	0.021680869	0.026656947	0.021374053	0.022323118	0.020919416	0.019931245	0.003585
Graph Density	0.007533267	0.031821975	0.022860231	0.025921872	0.005942637	0.009779806	0.001285
Average Clustering Coefficient	0.008124494	0.033523582	0.024007953	0.027073943	0.006550929	0.010282971	0.001293
Avg. Path Length	0.014991367	0.053570984	0.038342034	0.041455688	0.013583085	0.016598767	0.00136

Figure A-11. P value test