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Health-Check Framework for Assessing Last Planner System Implementation Using Social Network Analysis

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Abstract

Purpose: The Last Planner System® (LPS®)[5] is a lean construction tool aimed at enhancing the reliability of production planning and control. Although effective communication among project stakeholders is recognized as essential for LPS success, limited research has explored the correlation between social network interactions and the level of LPS implementation. This study examines how team member interactions influence LPS effectiveness in the architecture, engineering, construction, and operations (AECO) industry.

Research Method: Utilizing a mixed-methods approach, this research employs Social Network Analysis (SNA) across three case studies to integrate social network characteristics with LPS performance metrics.

Findings: The findings reveal a trend suggestion that a well-connected lookahead planning network may be associated with higher Percent Plan Complete (PPC). Specifically, a positive correlation exists between Graph Density and PPC, while a negative correlation is observed between Average Path Length and PPC. These patterns suggest that robust stakeholder communication may play an important role in enhancing LPS implementation, as stronger communication in lookahead planning appears to be associated with improved project performance by increasing the PPC.

Limitations: The study needs to be replicated on the other projects to increase

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generalizability.

Implications: The proposed framework enables project managers to enhance LPS effectiveness by fostering human-centered collaboration and integrating smart digital technologies. By emphasizing the importance of social interactions in project settings, this research underscores the potential for improved project outcomes through enhanced stakeholder engagement in the AECO industry.

Value for practitioners: This research contributes original insights by proposing a novel health-check framework, which serves as a practical tool for project managers to map current social interactions, identify areas for improvement, and bridge gaps in communication.

Keywords: Last Planner System (LPS), Project Planning and Control, Social Network Analysis (SNA), Stakeholder Communication.

Paper type: Full paper

Introduction

Background and Problem Statement

The Last Planner System® (LPS®) is a collaborative planning and control system used to reduce variations in construction workflow, develop planning foresight, and minimize uncertainty in construction operations (Hamzeh *et al*. 2012). LPS focuses on the collaborative management of the stakeholder network required for project delivery and promotes conversations between trade forepersons and site management (Salem *et al*. 2005). LPS provides numerous benefits to the project processes, which ultimately translate to economic improvements in project time and cost, including smooth workflow, predictable work plans, improved productivity, reduced cost, improved safety, and reduced time of project delivery (Fernandez *et al*. 2013).

Although LPS promises significant advantages over traditional planning and control, researchers have identified certain deficiencies in applying LPS. These deficiencies are primarily related to relationships and interactions among the parties working on a given project, such as unreliable relationships between different project stakeholders (Viana *et al*. 2017), the lack of proper team interactions, and slow information flow (Seppänen *et al*. 2010). According to Hamzeh et al. (2018), and Lahouti and Abdelhamid (2023), the successful application of LPS is contingent on the proper availability of information and inputs. Accordingly, when activities cannot be started due to unavailable prerequisite resources, such as perfect information and complete directives, the work crew will improvise and utilize whatever information is available. This improvisation may lead to rework and the emergence of unexpected situations due to the lack of information.

Moreover, in investing LPS implementation in the lookahead planning stage, Hamzeh and Aridi (2013) noted that failure of constraint identification 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. New tasks are ones that have not been identified in lookahead planning and appear in the week of execution, and ones that were not considered critical before but appear as critical tasks at the execution time (Hamzeh 2009). Rouhana and Hamzeh (2016) showed that some new tasks occur because of a lack of communication and people's behavior. In fact, the decision-making process on projects is influenced by the social interactions and communications between the team members; as such, miscommunication and uncooperative behavior throughout the process might lead to creating more new tasks (Hamzeh and Aridi, 2013). Therefore, problems with team communication on the project lead to a sub-optimized implementation of LPS, causing difficulties in constraint identification and removal, decreased participant involvement in the decision-making process, and project delays (Castillo *et al*. 2018, Ghosh *et al*. 2017, Priven and Sacks 2013, Priven and Sacks 2016).

Accordingly, researchers found that focus on planning behavior is needed to improve project performance (Rouhana and Hamzeh 2016). In this regard, social management and technical dynamics are essential for proper LPS implementation (Liu *et al*. 2020), and Priven and Sacks (2016) confirm that project performance is influenced by teams' interactions. Although a variety of studies have examined social network interactions on projects, Asadian and Leicht (2022) highlight the lack of studies on LPS that investigated participants' interactions to specifically assess the effectiveness of LPS implementation. Therefore, there is a need to study the effect of social interactions and team dynamics on the level of LPS® implementation and overall project success.

Research Objectives

This research aims to address the existing gap in the literature by establishing the correlation between the social interactions of construction team members and the level of LPS implementation. To this end, a health-check framework is proposed to assess current social interactions among team members, identify areas for improvement, and link these factors to LPS implementation. To establish the research need, the authors first conducted a literature review and pilot case study, as published in a previous paper (Eivazi Ziaei *et al*. 2023). Next, various metrics for LPS implementation and social interactions were studied, analyzed, and correlated in three construction projects by conducting two surveys, which focused on LPS implementation level and team interactions. Finally, the authors developed a visual dashboard that offers a more comprehensive view of project performance, integrating metrics and visualizations derived from both LPS and Social Network Analysis (SNA).

This study proposes a health-check framework that maps social interactions and identifies gaps and improvement areas, with the ultimate goal of enhancing project performance. The contributions of this research serve both academic and construction practitioners, who will become more aware of the importance of fostering strong communication networks to improve LPS implementation and overall project performance.

The section is followed by a comprehensive literature review on LPS and social interactions, followed by a detailed methodology, presentation of results, and discussion of implications for practice and research.

Literature Review

Last Planner System (LPS): Definition, Principles, and Processes

The Last Planner System (LPS) is a fundamental application of Lean Construction that enhances production planning and control by minimizing uncertainties and complexities. It achieves this by actively involving subcontractors and frontline specialists in the planning process (Hamzeh et al. 2019, Viana et al. 2017). LPS aims to increase workflow reliability in construction projects, addressing deficiencies associated with traditional planning methods (Ballard and Howell 1997).

LPS is structured around five key planning practices (Hamzeh 2009):

1. Planning in greater detail as the work execution date approaches.
2. Developing the work plan collaboratively with those responsible for executing the tasks.
3. Identifying and removing constraints to ensure work readiness and enhance reliability.
4. Making reliable promises and fostering active negotiation among project parties.
5. Conducting root cause analyses to learn from planning failures.

The LPS comprises five control levels: master scheduling, phase scheduling, lookahead planning, weekly work planning, and daily huddles. Master scheduling identifies key project milestones, while phase scheduling builds on these milestones using pull planning techniques to collaboratively define conditions for success. Lookahead planning breaks down tasks into smaller, manageable components and identifies constraints to prepare them for the upcoming six weeks. The weekly work plan specifies tasks to be completed in a given week, facilitating detailed planning as the work date approaches. Daily huddles support learning and planning by updating commitment statuses (Hamzeh 2009).

Key metrics, particularly Percent Planned Complete (PPC), have been developed within the LPS framework to assess its effectiveness. PPC measures the reliability of weekly work planning by comparing the number of completed activities against the number promised (El Samad et al. 2017).

Inefficient Social Interactions as a Barrier to LPS Implementation

Despite the advantages of LPS, several barriers hinder its effective application, with implementation challenges persist, especially in communication and stakeholder engagement. Viana et al. (2017) identified unreliable relationships between main contractors and subcontractors as a significant obstacle, noting that formal planning procedures are often not adhered to, especially during lookahead planning. Rouhana and Hamzeh (2016) explored areas where unplanned tasks can emerge—namely, planning, ongoing construction, and uncertainty—emphasizing that improved project performance hinges on a focus on planning behavior. They found that inadequate communication and varied planning behaviors can lead to planning failures, resulting in unplanned tasks. In fact, they observed that increased interaction and communication foster greater transparency and more reliable promises. Moreover, Liu et al. (2020) highlighted challenges arising from the transition from traditional to lean construction cultures. They categorized barriers as socially-driven (e.g., resistance to change and lack of cooperation) and production-driven. Since LPS emphasizes communication, relationships, and commitment among participants, workflow is significantly influenced by social behaviors. Effective implementation of LPS thus necessitates managing both social and technical dynamics (Liu et al. 2020). LPS also aims to enhance value and reduce waste through continuous improvement and collaborative planning (Seppänen et al. 2010). Koskela (2000) illustrated the importance of information flow in lean production processes, while Seppänen et al. (2010) demonstrated that low reliability and high variability in planning often stem from ineffective team interactions and slow information flow. This underscores the necessity to improve information flow to mitigate variability in planning. Alarcón et al. (2005) and Asadian and Leicht (2022) have identified gaps in LPS implementation that can be addressed by improving project coordination and workflow through effective social interactions. They noted a lack of studies focusing on participants' interactions and human factors in demonstrating the effectiveness of LPS. Hence, investigating social interactions and team dynamics within LPS processes is essential for effective implementation.

The Need for Social Network Analysis (SNA) in LPS Applications

Social Network Analysis (SNA) is a quantitative tool applicable in construction research, enabling the representation of organizational relationships as a system of nodes (actors) connected by classified relationships (Loosemore 1998, Pryke 2012). SNA is recognized as a robust approach for modelling information flow and team interactions in construction environments, particularly at the point of installation where critical decisions are made (Moore 2013).

Priven and Sacks (2013) utilized SNA to investigate behavioral patterns between subcontractors and general contractors, discovering that social networks among subcontractors strengthened following LPS implementation. Similarly, Ghosh et al. (2017) found that projects utilizing LPS exhibited higher levels of information exchange, positive relational interactions, and participant involvement in decision-making. Priven and Sacks (2016) demonstrated that LPS enhanced coordination among stakeholders, leading to stronger social networks where LPS was more thoroughly implemented. Additionally, Castillo et al. (2016) identified a positive correlation between LPS implementation and social network strength across planning, knowledge management, learning, and problem-solving domains. Herrera et al. (2018) also confirmed a positive relationship between social network strength and performance indicators.

Given the significant influence of team interactions and planning behaviors on planning reliability (Rouhana and Hamzeh 2016), it is essential to study and measure the communication levels among project participants. The relationships among parties play a crucial role in project performance (Castillo et al. 2018, Priven and Sacks 2016). Pryke (2005) and Nohria and Eccles (1992) highlighted SNA's utility in investigating relationships within construction teams.

Recent studies have shown that strong social networks among project team members significantly influence project performance. However, the specific impact of these interactions on LPS effectiveness remains underexplored. This study seeks to leverage SNA to understand how improved collaboration can foster more mature LPS implementation and enhance project performance by evaluating human behaviors and social interactions during LPS meetings across three phases: weekly planning, lookahead planning, and PPC interactions.

Methodology and Methods

The research implements the design science research (DSR) methodology to propose a health check framework. DSR focuses on creating an artifact to resolve specific problems and demonstrating its effectiveness. In this study, the artifact is an LPS and SNA health check framework, which is designed to enhance project performance by focusing on relationships and metrics.

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 can alter a particular occurrence (Vaishnavi and Kuechler 2007). Alsehaimi et al. (2012) suggest that design science can assist in developing innovative managerial tools and tackling managerial construction problems, making it suitable for construction management research. March and Smith (1995) state that the design science research process involves creating artifacts to address real-world issues and evaluating their performance.

Hevner (2007) identifies three primary DSR cycles:

1. **Relevance Cycle**: Developing an artifact to solve a relevant problem.
2. **Design Cycle**: Iterating design and assessment until a satisfactory product is achieved.
3. **Rigor Cycle**: Using existing knowledge and artifacts to ensure innovation.

Based on these principles, DSR was chosen as the methodology for this research due to its suitability for creating practical, innovative solutions in construction management. The research method consists of three stages, as shown in Figure 1, which are: the need for a framework (problem identification), solution development, test the framework:

Stage A: Problem Identification

Literature Review: An extensive literature review has been conducted using databases such as Scopus, with keywords including ‘Last Planner System’, ‘Lean construction’ and ‘Social Network Analysis’. Studies were selected based on their relevance to LPS implementation. This investigation revealed that, although LPS is widely used, it is still new to many construction professionals, and partial implementation of lean and LPS methods results in these practices falling short of their full potential (Lagos *et al*. 2017, Nesensohn *et al*. 2014, Porwal *et al*. 2010, Pozzi *et al*. 2021). Therefore, there is a need to focus more on proper LPS implementation by studying the impact of team interactions on LPS implementation and project performance to address the existing gap.

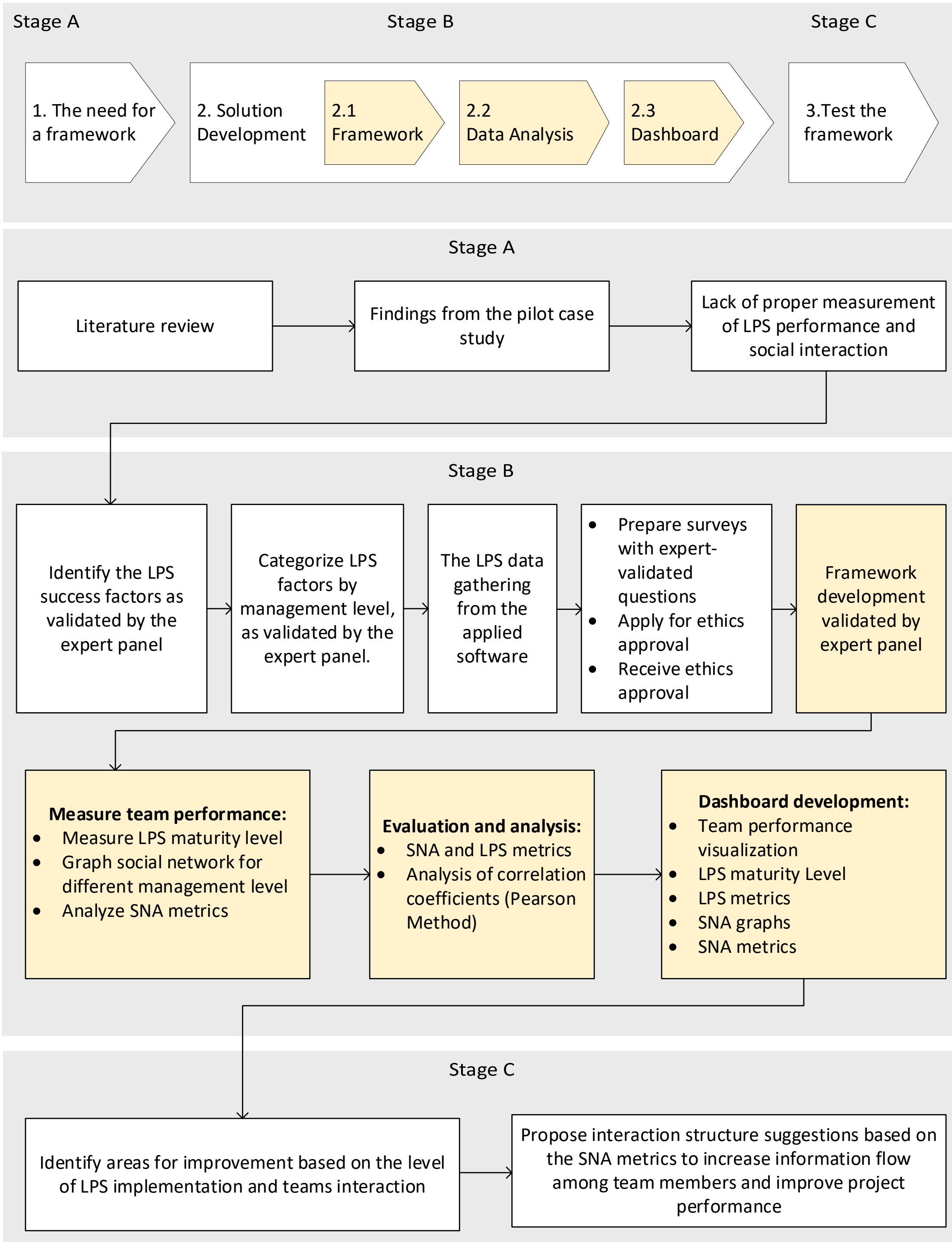


Figure 1. Research Methodology Flowchart

Pilot Case Study: In addition to the literature review, a pilot case study has been conducted to validate the research gap by examining the relationship between lean success factors and lean maturity levels. The study aimed to assess the lean maturity level by analyzing success factors found through the literature review and interviews with lean experts, sourced both from academia and industry, including senior managers and vice presidents. Interviews were conducted with five lean construction experts from both academia and industry, selected based on their experience with LPS implementation. A semi-structured format was used, focusing on questions related to LPS maturity and team communication. This helped assess the relevance of maturity levels in lean practices and provided a basis for further investigation into social interactions within the team, particularly in the Last Planner System. For this purpose, a project was selected, and a lean survey was conducted to analyze the lean maturity level. Respondents answered survey questions representing different lean factors and assigned a rating from 1 (low) to 5 (high). Additional project information, mainly PPC and constraint log data, was gathered from the company's planning software. Although the pilot study findings are referenced to support this research, they are not included in the primary analysis. The results of the pilot were previously published in another paper by the authors (Eivazi Ziaei *et al*. 2023).

Stage B: Solution Development

Stage A established a significant gap in assessing proper LPS implementation and highlighted the need to study social interactions within LPS practices. To address these issues, the authors developed a framework in Stage B that provides a practical solution to apply the methodology uniformly across all construction projects. The framework was introduced as the core artifact of the DSR process, offering a structured and repeatable approach for improving LPS implementation.

The proposed framework, as shown in Figure 2, focuses on obtaining social interaction and LPS metrics and consists of three stages: (1) data gathering, which includes identifying LPS success factors and conducting surveys; (2) data analysis; and (3) recommendations based on progress reviews. Identifying LPS factors is generally a one-time activity, though it can be revisited later if new success factors emerge. To ensure continuous improvement, the data-gathering and analysis cycle—which includes conducting surveys, analyzing results, reviewing progress, and implementing improvement actions—should be repeated regularly, ideally on a monthly basis, to monitor performance and track changes. However, the frequency can be adjusted based on the specific needs and complexity of each project. Generally, following the framework will help the team identify strong and weak networks, areas for network improvement, and LPS performance. The framework can be easily used as a regular LPS and team interaction tool to improve performance.

To address the research need, three large-scale infrastructure projects located in Canada were selected to investigate the correlation between the social interactions and the LPS implementation level on the project. Project 1 is the replacement of a large metropolitan bridge in British Columbia, including roadway improvement, grade separations, and demolition of an existing structure. Project 2 is cross-border transportation infrastructure development between Ontario and the United States, including a multi-lane cable-stayed bridge, extensive port facilities, and long-term operation and maintenance under a Public-Private Partnership

(P3) model. Project 3 is a metropolitan light rail transit system in Ontario, consisting of both underground and surface-level segments, with multiple stations and stops. It is also delivered on a P3 basis and involves complex urban construction and long-term maintenance commitments.

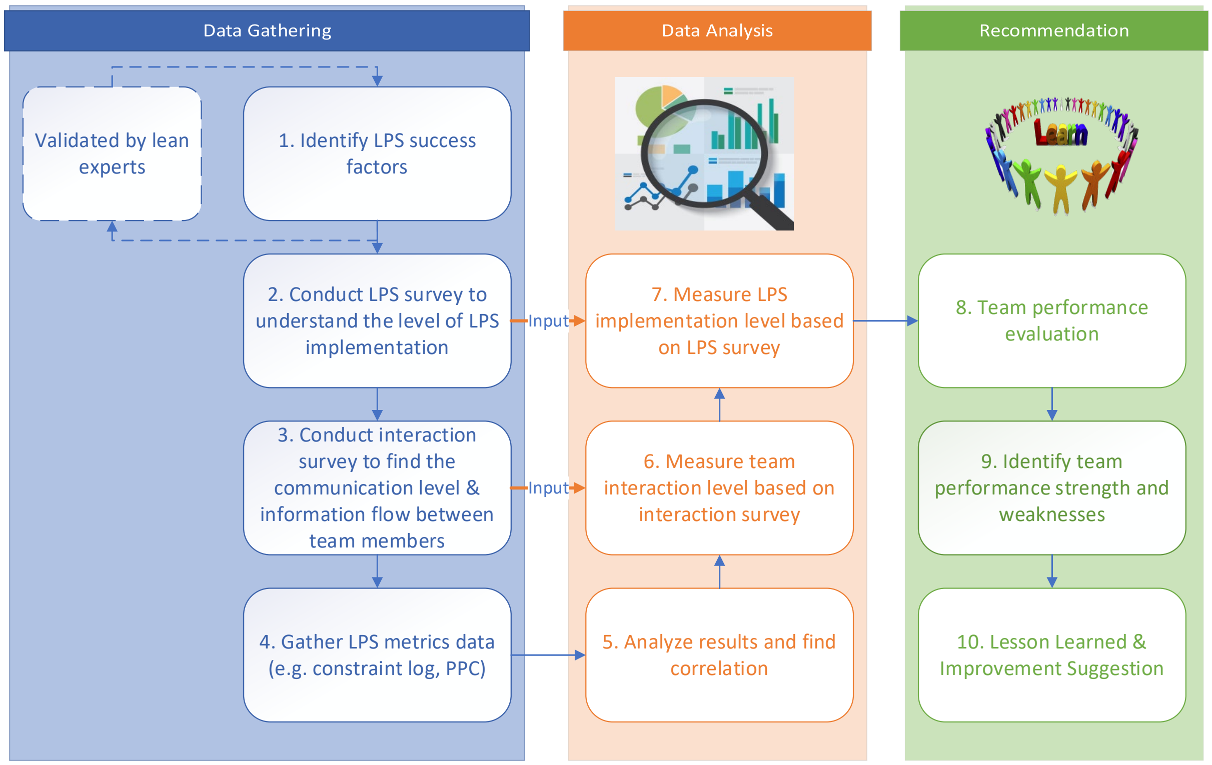


Figure 2. Application Framework

The three projects were selected due to their varying levels of LPS implementation and their diversity in scope, delivery models, and planning environments, providing a comprehensive basis for analyzing communication patterns within planning teams. Two different types of surveys were conducted: Survey 1, designed to evaluate the level of LPS implementation, and Survey 2, developed to assess communication within teams. Details of the survey design, structure, and implementation will be discussed in the subsequent section.

Stage C: Test the Solution

Survey 1: Investigate LPS Implementation Level

For survey 1, LPS success factors were identified through a literature review (Power *et al*. 2021, Priven and Sacks 2015, Salem *et al*. 2005, Tayeh *et al*. 2018) and semi-structured interviews and were validated with five LPS experts from both academia and industry, including continuous improvement managers and a vice president of continuous improvement with extensive expertise in Lean and the Last Planner System, to ensure their relevance and accuracy. Eighteen questions were designed to understand the implementation level of success factors across different management levels and categories which are: people and partners, master scheduling, phase scheduling, lookahead planning, weekly work plan, and daily huddle, as shown in Table 1. Next, team members are asked to rate the factors, in terms of levels of implementation, from 1 (low) to 5 (high). To calculate the LPS implementation level, the average rates for each category (factor) are calculated. These are plotted on a radar graph and the area of the resulting shapes is used to represent the overall LPS implementation level. As for LPS metrics, PPC, constraint log, and reasons for variance are used.

Table 1. LPS Success Factors and Relevant Survey Questions

Categories	Survey Questions to Rate Each Factor
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 and 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.”

Survey 2: Investigate Team Interactions

Survey 2 was designed to investigate the communication networks among project team members, focusing on the level and frequency of interactions at different LPS management levels: lookahead planning, weekly work planning, and PPC. The survey questions were also reviewed and refined based on input from the same panel of experts, ensuring clarity and alignment with the management levels. The participants, who were planners and key individuals involved in the planning process, were asked 3 questions regarding the frequency of communication about (a) lookahead planning (constraint identification and/or removal), (b) weekly work planning, and (c) tasks that were not completed the previous week with their corresponding team members. Then, the participants were asked to respond to the survey by choosing the frequency of communication about (a), (b), and (c), ranging from more than 5 times per week to once per month. The same survey process was applied consistently across the three projects to visualize their communication networks for lookahead planning, weekly work planning, and PPC.

To better understand the structure and dynamics of these communication networks, SNA was applied. To do so, an interaction graph was created in Gephi, a network analysis and visualization software, using the results from Survey 2. Next, the software was used to calculate SNA metrics and analyze the communication networks on the project, providing quantitative insights into how team members interact and how information flows within the project teams. Different network metrics are available to define specific attributes in quantitative terms. In this research, some commonly used SNA metrics were selected to analyze the team's social structure across five levels of social network analysis: actor level, dyadic level, triadic level, subset level, and network level. These metrics, as described by Arif (2015), Varlamis et al. (2010), and Wehbe et al. (2015), are outlined below in two sections: the first covers network-specific metrics, and the second covers node-specific metrics.

Network-specific metrics

These comprise four (4) metrics, being (1) *Average Degree Centrality*, which measures the number of links an individual has with others; a higher number indicates more connections, (2) *Density*, which 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, (3) *Clustering Coefficient*, which measures how clustered individuals are; a higher number shows that the neighborhood is well connected, and everyone knows each other, and (4) *Average Path Length*, which 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

These comprise two (2) metrics, being *(1) Betweenness*, which measures the fraction of all shortest paths that pass through a given node; a higher number shows the most powerful node that controls flow and interactions, and (2) *Closeness*, which measures the total number of links from an individual to others; a higher number shows the least reachable node by others.

After gathering the results from both surveys, the data were analyzed using quantitative methods to better understand the link between LPS implementation and team communication. Survey 1 results helped determine the level of LPS implementation, while Survey 2 provided valuable insights into how often and effectively teams communicated across different management levels. This combined analysis helped show how communication impacts the success of LPS within the projects.

Correlation Test

Alongside the survey results, additional project information, including Percent Plan Complete (PPC) and constraint logs, was obtained from the project managers. These data were then used in further analysis, where a correlation test was conducted to study the relationship between the SNA metrics and the LPS metrics. The goal of this correlation test was to understand the importance of communication at different management levels for the project's success.

Dashboard Development

After collecting all the required information, a visual dashboard is created to present a clear picture of the current project’s performance. It presents LPS survey results, actual PPC and constraint logs, social networks, and network metrics.

Stage C: Recommendations for Improvement

Based on the obtained results, areas for improvement are identified, and a new interaction structure is suggested to improve the interaction level and project performance.

Results

Survey 1 Results

After obtaining all responses, the average of the results was used to calculate the LPS implementation level for each project. Figure 3 shows the LPS implementation level for all three projects. As per the results, Project 3 has the highest LPS implementation level, as indicated by the greatest area occupied by this project in the radar graph. In fact, Project 3 ranked highest in terms of the level of satisfaction of the different identified LPS success factors falling under: People and partners, master scheduling, phase scheduling, lookahead planning, weekly work plan, and daily huddle.

Survey 2 Results

Based on Survey 2 results, interaction networks were created in Gephi software to visualize communication patterns at different LPS management levels. In this study, the focus was limited to three levels: lookahead planning (LA), weekly work planning (WWP), and Percent Plan Complete (PPC). To illustrate the approach, Figure 4 presents the communication networks for Project 1. The assigned planning team for this project, categorized by team member roles in different colours, completed the survey, reporting their communication patterns for all three planning activities. Using their responses, three separate networks were created:

- **LA network:** who communicates with whom about lookahead planning,
- **WWP network:** who communicates with whom about weekly work planning,
- **PPC network:** who communicates with whom about PPC.

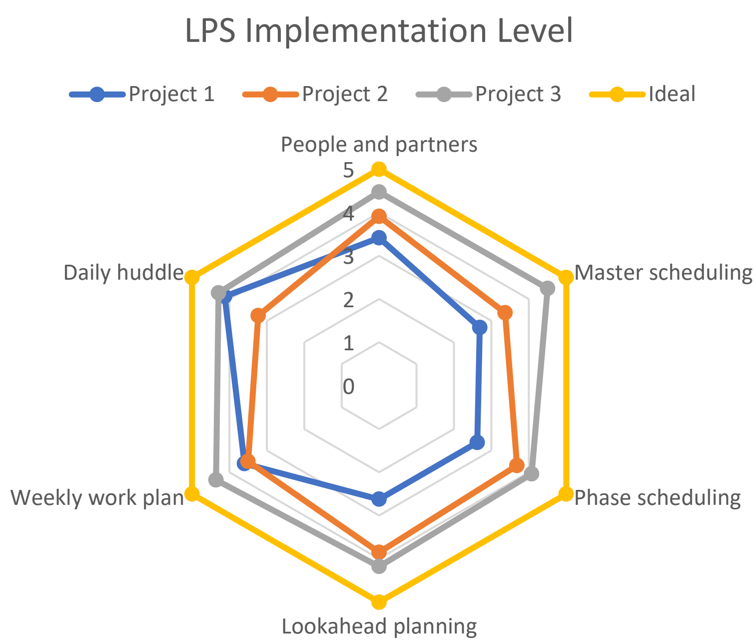
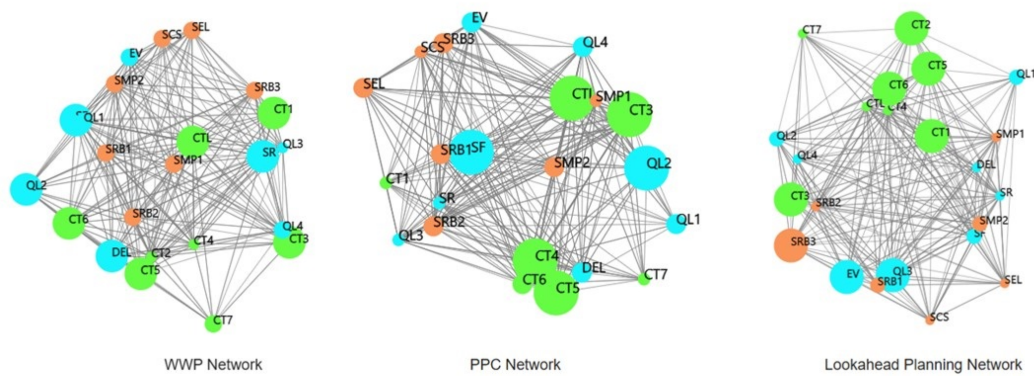


Figure 3. LPS Implementation Level Comparison

Because the same group of participants in Project 1 provided input for all three topics, the LA, WWP, and PPC networks for this project are directly comparable within that project. The networks highlight how communication patterns shift depending on whether the focus is on LA, WWP, or PPC. The same process was applied in the other projects, with each project's own assigned planning team. This produced three networks per project, each representing communication patterns specific to that team. Since the method was applied consistently, the results not only allow comparisons within a project (across LA, WWP, and PPC), but also enable comparisons between projects, showing how communication structures differ from one planning group to another.

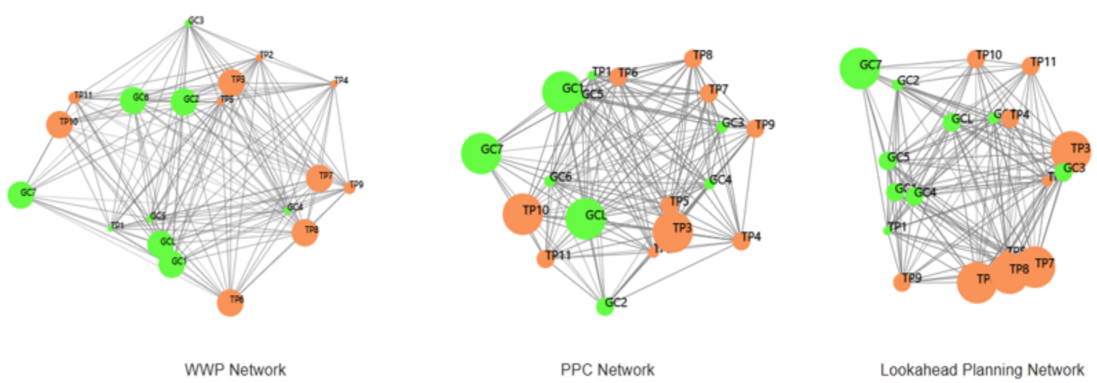
Figure 4 further details of what these nodes and edges reveal about the structure of communication. In each network, the nodes represent individual team members, and the size of the nodes corresponds to degree centrality, or how many direct communication links someone has in that given planning context. The color of nodes has been used to differentiate individuals or roles. Edges (the lines) between nodes are reported communication links, and the width of each edge is a function of how frequently these interactions occurred.

In other words, larger nodes indicate individuals who communicate with more people, and thicker edges represent a greater frequency of communication. When a node is large and connected by many thick edges, it is an indication that the individual is a core participant in the communication process and might be a bottleneck or key connector in the planning activity. These visualizations allow project managers to identify key communicators, constraints, potential bottlenecks, and under-engaged roles, offering actionable insights to improve collaboration and planning effectiveness. Figures 5 and 6 follow the same structure and visualization logic, representing the LA, WWP, and PPC communication networks for Projects 2 and 3, respectively.



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

Figure 4. Networks' Structure for Project 1



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

Figure 5. Networks' Structure for Project 2

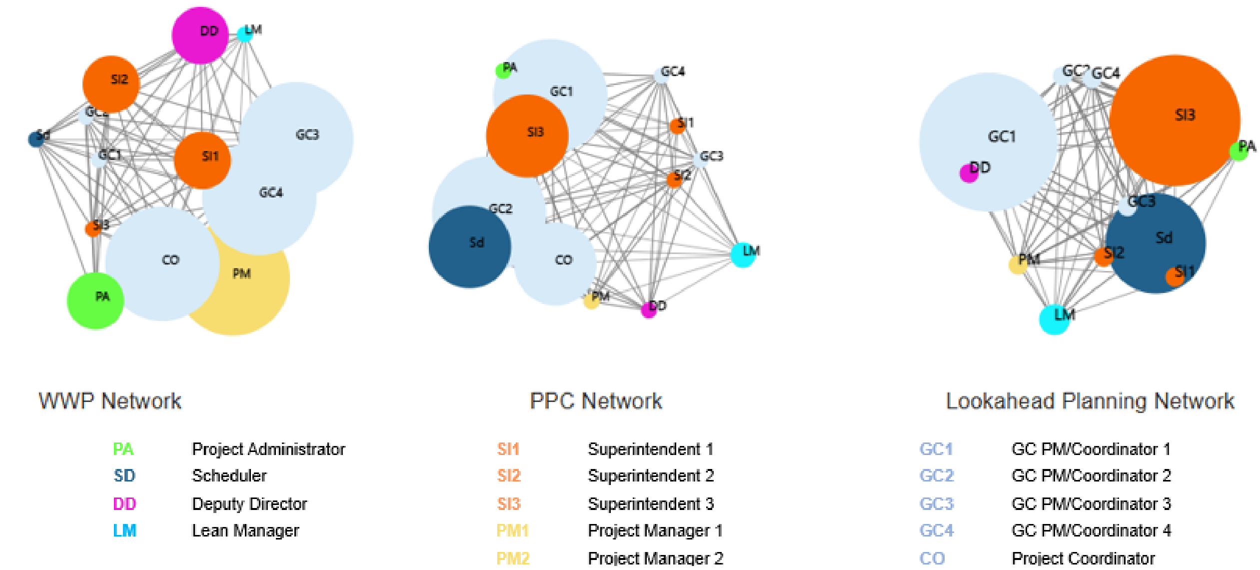


Figure 6. Networks' Structure for Project 3

Table 2 presents key network metrics such as Average Degree, Graph Density, Average Clustering Coefficient, Average Path Length, Betweenness, and Closeness for each project. These metrics help compare the connectivity and efficiency of communication networks across the case studies.

The table is organized to show the performance of three different types of networks, with sections dedicated to each project. Additionally, the columns corresponding to WWP (Weekly Work Planning), PPC/Learning, and Lookahead results are linked to the distinct networks displayed in Figure 4, Figure 5, and Figure 6. This structure allows for a clear visualization of how each network performed in relation to these key metrics. The values in Table 2 were generated automatically by Gephi software after entering the network data.

Each metric gives valuable information about the network structure, helping us understand their connectivity, efficiency, and centrality. For Project 1, the Lookahead Planning Network was identified as a poorly connected network, with a lower Average Degree (15) and lower Graph Density (0.682) compared to the WWP and PPC Learning results. Despite this, the lookahead planning network has the best connection and faster interactions, as indicated by its slightly higher Average Path Length (1.318). The greater the variation in Betweenness (Max 24.17, Min 0.17) the less active the lookahead planning network is. On the other hand, the node metrics showed that construction team member 1 is a node with higher connections and more central positioning due to having a high closeness (Max 1, Min 0.84). This member was also the most powerful node in controlling flow and interactions due to high Betweenness, but was the least reachable by others because of lower Closeness. Thus, even though the lookahead planning network is the network with the fastest interactions, it is less active, poorly connected, and the most isolated network. Further, while construction team member 1 is a powerful and highly connected node, it is the least reachable node by the others. Therefore, there is a need to focus on improving the lookahead planning network and improving connections to construction team member 1 by making construction team member 1 more reachable to others.

Table 2. Metrics Results

Project 1	**WWP Result**	**PPC/Learning Result**	**Lookahead Result**
Avg. Degree	15.913	15.913	15
Graph Density	0.723	0.723	0.682
Avg. Clustering Coefficient	0.767	0.766	0.716
Avg. Path Length	1.277	1.277	1.318
Betweenness	Max 18.26, Min 0	Max 17.27, Min 0.05	Max 24.17, Min 0.17
Closeness	Max 1, Min 0.56	Max 1, Min 0.57	Max 1, Min 0.84
Project 2	**WWP Result**	**PPC/Learning Result**	**Lookahead Result**
Avg. Degree	15.947	14.737	14.211
Graph Density	0.886	0.819	0.789
Avg. Clustering Coefficient	0.899	0.831	0.824
Avg. Path Length	1.114	1.181	1.211
Betweenness	Max 3.78, Min 0.33	Max 7.06, Min 0.76	Max 9.37, Min 0.21
Closeness	Max 1, Min 0.69	Max 1, Min 0.67	Max 1, Min 0.64
Project 3	**WWP Result**	**PPC/Learning Result**	**Lookahead Result**
Avg. Degree	11.714	10.692	10.923
Graph Density	0.901	0.891	0.91
Avg. Clustering Coefficient	0.905	0.896	0.916
Avg. Path Length	1.099	1.109	1.09
Betweenness	Max 6.27, Min 0.2	Max 5.77, Min 0.22	Max 2.63, Min 0.2
Closeness	Max 1, Min 0.81	Max 1, Min 0.8	Max 1, Min 0.86

Similar to Project 1, the Lookahead Planning Network in Project 2 also showed poor connectivity with a lower Average Degree (14.211) and Graph Density (0.789) and yet better interactions as indicated by the slightly higher Average Path Length (1.211). The network was also less active (Betweenness Max 9.37, Min 0.21) with poorly connected neighborhoods (Clustering Coefficient 0.824), similar to Project 1. The node metrics proved that general contractor member 1 was a node with a higher connection and more centrality, but was the least reachable node by others. Accordingly, despite the lookahead planning network being the network with the fastest interactions, it is less active, poorly connected, and the most isolated network. Furthermore, general contractor member 1 is the least reachable by others even though it is a powerful and highly connected node. In contrast, the least powerful and poorly connected node is the most reachable node in the network. To improve this network, the nodes must be levelled, since the highly connected and the most powerful node should be the most reachable by other nodes.

For Project 3, the Lookahead Planning Network is well-connected and cohesive (Average Degree 10.923, Graph Density 0.91, Clustering Coefficient 0.916) with efficient interactions (Path Length 1.09). This network has better connections, faster interactions, and well-connected neighborhoods. Yet, the PPC Network is a poorly connected network, with a lower Average Degree (10.692) and Graph Density (0.891). The WWP Network was active, reflected by a higher Betweenness (Max 6.27, Min 0.2), in contrast to the less active PPC Network. Node metrics showed that the Lean Manager was a node with lower connections but more central positioning, and also the least powerful node to control flow and interactions. For Project 3, focusing on having balanced nodes is necessary to improve the network result. On the other hand, it appears that the lean manager is the node with the fewest connections, exhibiting the least influence and accessibility. Therefore, efforts should be concentrated on improving the lean manager's interactions with the team, which could greatly facilitate the effective implementation of a superior lean management system and the correct deployment of LPS.

Correlation Test

To establish the link between LPS performance and social interactions, Spearman's ρ correlation has been utilized to ascertain the correlation between SNA metrics and PPC. According to Evans 2012, when $\rho \geq 0.8$, correlation is very strong, and when $0.6 \leq \rho < 0.8$, correlation is strong. Since there are three different results for the three projects, these results have been used as three points to calculate the correlation; however, these findings should be interpreted with caution, as they are based on a limited sample size. Table 3 depicts the correlation between SNA metrics, LPS management levels, and PPC. The results summarize the level of correlation between certain LPS management levels (namely people and partners, master scheduling, phase scheduling, and lookahead planning) and the SNA metrics; nevertheless, these correlations should be interpreted with caution, as they do not imply causation but rather indicate patterns within the available data.

In the WWP network, the LPS metrics demonstrate a very strong correlation with the average degree, and a weaker correlation with other SNA metrics such as graph density, average clustering coefficient, and average path length. Further, in the PPC network and lookahead network, there is a very strong correlation between the LPS metrics and SNA metrics. Since the results for PPC network and lookahead network are very close, we cannot rely on only these results, especially since only three points were used to obtain these results and two out of the three are close. Therefore, we have considered that there is only a correlation between the LPS metrics in the WWP and average degree.

On the other hand, we have obtained similar results between daily huddle and SNA metrics in the PPC network and lookahead network. Because of the abovementioned reason and inconsistency of a positive or negative relationship between daily huddle and other SNA metrics (graph density, average clustering coefficient, average path length), we have considered there is only a correlation between daily huddle and average degree. This leads us to suggest that SNA metrics are more related to long-term planning networks. Among the longer-term planning, the correlation between the LPS metrics in the lookahead planning network and SNA graph density and average path length is stronger than others.

Table 3. Weekly Work Plan Network Metrics Results and the Correlation with Actual PPC

WWP Network Metrics	LPS Project Management Level and PPC						
	People & partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.881	-0.926	-0.702	-0.658	-0.996	-0.623	-0.718
Graph Density	0.884	0.830	0.983	0.992	0.479	-0.301	0.978
Avg. Clustering Coefficient	0.866	0.809	0.975	0.987	0.446	-0.336	0.970
Avg. Path Length	-0.884	-0.830	-0.983	-0.992	-0.479	0.301	-0.978
PPC Network Metrics	**LPS Project Management Level and PPC**						
	People & partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.885	-0.929	-0.707	-0.664	-0.995	-0.618	-0.723
Graph Density	0.885	0.929	0.707	0.664	0.995	0.618	0.723
Avg. Clustering Coefficient	0.885	0.929	0.707	0.664	0.995	0.618	0.723
Avg. Path Length	-0.885	-0.929	-0.707	-0.664	-0.995	-0.618	-0.723
LA Network Metrics	**LPS Success Factors and PPC**						
	People& partners	Master scheduling	Phase scheduling	Lookahead planning	Weekly work plan	Daily huddle	PPC
Avg. Degree	-0.885	-0.929	-0.707	-0.664	-0.995	-0.618	-0.723
Graph Density	0.885	0.929	0.707	0.664	0.995	0.618	0.723
Avg. Clustering Coefficient	0.885	0.929	0.707	0.664	0.995	0.618	0.723
Avg. Path Length	-0.885	-0.929	-0.707	-0.664	-0.995	-0.618	-0.723

In summary, the analysis suggests that graph density and average path length may serve as indicators for PPC patterns. A strong positive correlation between graph density and PPC suggests that more interconnected networks may be associated with higher PPC, indicating that smoother, more frequent communication among team members could enhance project performance. Conversely, the negative correlation between average path length and PPC suggests that shorter communication paths, or fewer steps between team members, may be linked to better project outcomes. In addition, comparing the results shows that the project with a stronger lookahead planning network appears to have higher PPC, which aligns with previous research by Hamzeh (2009), suggesting that weak lookahead planning is associated with lower PPC. The observed trends highlight a need to focus on strengthening communication during lookahead planning, as this may be associated with improved project performance. This suggests the potential importance of reducing communication barriers and streamlining interactions within teams. Ultimately, improving social network dynamics among team members appears to be associated with enhanced LPS effectiveness, as suggested by the higher PPC scores across the analyzed projects.

Proposed Dashboard

Following the validation of the proposed framework by interviewing an expert panel, a dashboard was created for each project, equipped with the capability to monitor the current status. The intent behind the dashboard's creation is to provide a clear vision of the current project performance by visualizing the collected information. In the proposed dashboard, team members can observe the team interaction metrics and current LPS metrics in the project. The dashboard comprises social networks, network metrics, the actual PPC, variance reasons, and the results of the LPS survey. It has been designed using Power BI, a software specializing in interactive data visualization. The dashboard, as illustrated in Figure 7, exhibits the teams' interactions at each management level, the LPS implementation level in the project, and other LPS metrics, such as PPC and constraint log, which have been directly collected from the planning software the company was using. The dashboard also offers a feature to concentrate on each node or team by applying filters and viewing all interaction levels across various LPS management levels.

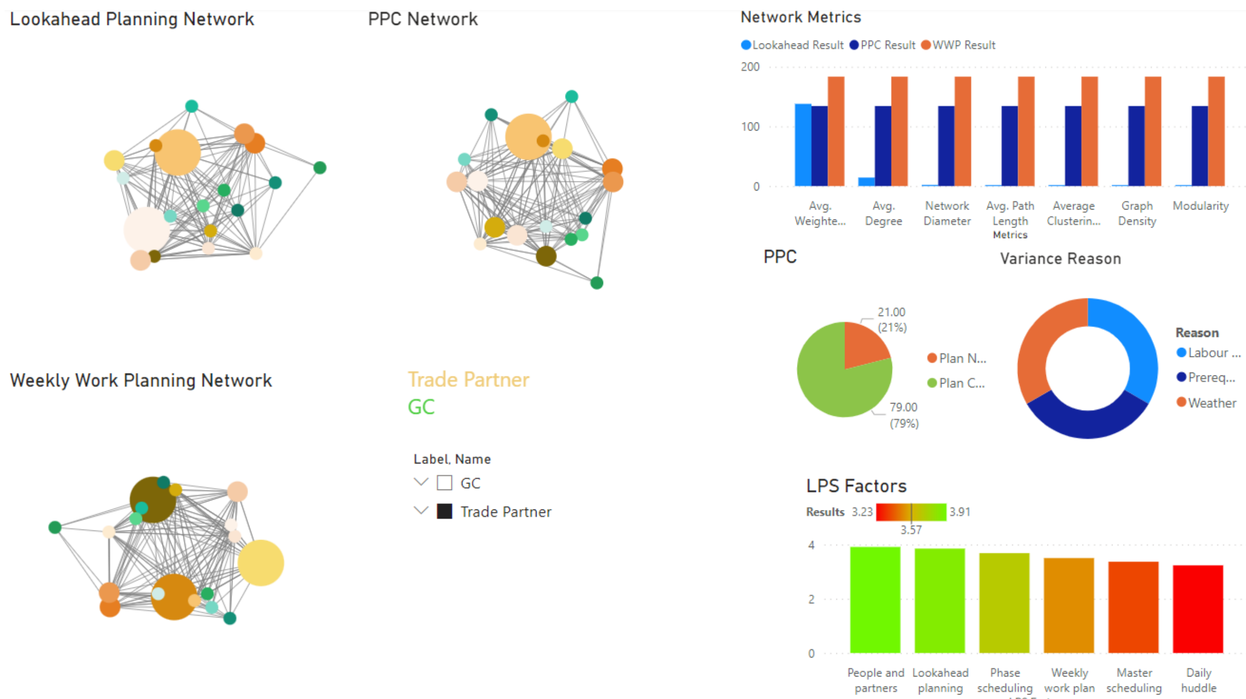


Figure 7. Proposed Dashboard

Recommendation for the Studied Projects

Improvements in PPC enhance the reliability of planning. As per the correlation results, this necessitates an increased focus on human behavior to further drive PPC, reasons for variance, and planning reliability rates. Recent studies highlight how interactive, robust networks contribute to higher performance levels. In light of these findings, the following recommendations are suggested for the projects analyzed:

- **Project 1**: The primary recommendation is to focus on LPS implementation and elevating its implementation level within the master schedule, phase scheduling, and lookahead planning, which are currently identified as weak links in the overall management system. Strengthening lookahead planning, enhancing interactivity, and maintaining a balanced network by designating the most influential node as the most accessible are also suggested.
- **Project 2:** Similar improvements are applicable, given the comparable results observed.
- **Project 3:** Recommendations include further concentration on lookahead planning to activate the network and diligent attention to reducing variance causes. The third suggestion is finding a suitable way to keep the nodes balanced (e.g., being more reachable when you are the most powerful node in the network) and involving the lean manager more in the connection.

Limitations and Future Work

Limitations

This study has several limitations. First, the nature and complexity of the projects were not analyzed, even though these factors may influence team interactions and LPS implementation outcomes. Second, this research examined team interaction considering factors such as team size, interaction frequency, and information exchange alongside Lean and LPS metrics, whereas other variables such as organizational culture, trust, power dynamics, technology adoption, and resource availability were not taken into consideration. Finally, the research was based on three case studies, which may limit the generalizability of findings across different project types and scales.

Future Work

These three case studies provide substantial evidence of the need to focus on human behavior by strengthening the network structure and interactions. As a general improvement suggestion for future work, the construction team should focus more on creating a healthier network during 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. Another suggestion is 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 8.

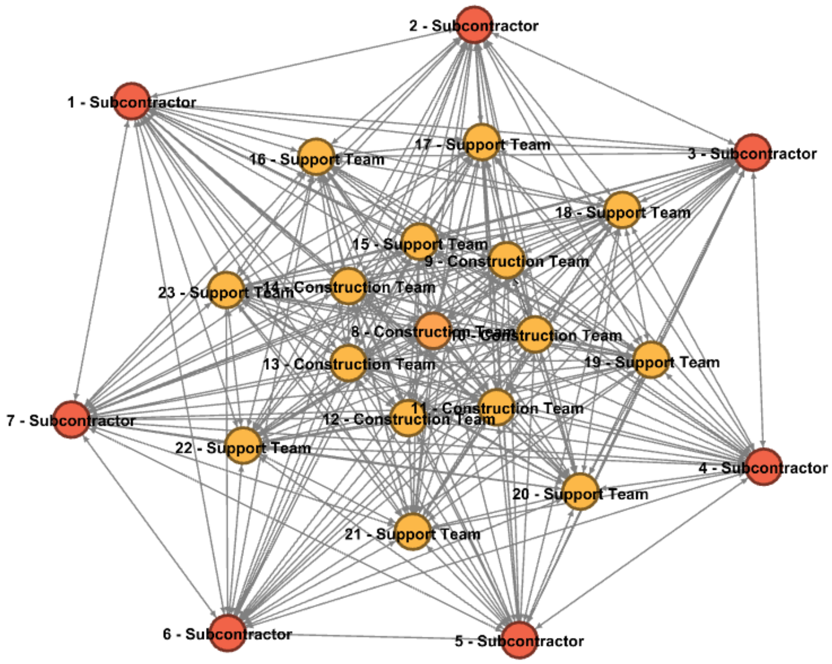


Figure 8. Ideal Network

As a further proposition to improve the structure of project networks, a circular network is recommended to provide more support to the network hub, and create a better network with a higher information exchange rate, contrary to a hierarchical structure where team members await responses from the network hub, potentially creating a bottleneck. Accordingly, the authors experimented with a simulation model for Project 1 in Gephi to propose a better structure (Figure 8). Based on the proposed network structure, the graph density and average path length, respectively measured at 0.947 and 1.053, indicating an improvement. Thus, given the correlation test results, lookahead planning is expected to be enhanced. 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 interactions to accomplish the proposed stage, we expect to see better performance and a higher PPC.

In addition to these propositions, future research should:

- Conduct LPS and SNA surveys regularly to re-evaluate social network structures.
- Explore the long-term effects of enhanced social interactions on project outcomes
- Investigate the application of the proposed health-check framework across diverse project contexts.
- Examine team interactions considering additional contextual factors such as project nature, complexity, and organizational culture.
- Expand simulation studies to validate improvements in graph density and average path length and their correlation with lookahead planning and PPC.

Conclusion

This research introduces a framework to investigate the relationship between project team interactions and LPS implementation levels. Using SNA, the study findings suggest that a well-connected team with efficient communication practices can be more likely to achieve higher PPC scores. In fact, a significant correlation was established between Density and PPC, and a negative correlation between Average Path Length and PPC; however, these findings do not imply causation. Instead, they suggest that both the structure and efficiency of team interactions may influence LPS success. Overall, the results suggest that stronger communication networks, may be associated with an increase in PPC and improved project performance. This aligns with Hamzeh's (2009) assertion that weak lookahead planning results in lower PPC, as well as other researchers' conclusions that focusing on complete LPS implementation (weekly work planning, lookahead planning and the learning process) will result in a higher PPC (Alarcón *et al*. 2005). Therefore, the research suggests that, to achieve better performance and a high PPC, attention must be given to lookahead planning, strong weekly work planning, and planning improvements.

This research fills a gap in the literature and contributes to the body of knowledge on the subject by establishing a link between social networks and LPS implementation. The major research contribution is a health-check framework that is a practical tool for project managers to assess current social interactions, identify areas for improvement, and create a more collaborative environment to improve project outcomes. To that effect, enhancing team communication characteristics not only improves LPS implementation but also contributes to overall project success, fostering a culture of collaboration and continuous improvement within the construction industry. Furthermore, the proposed network restructuring strategies, such as adopting circular networks and empowering nodes at the edge, offer innovative approaches to reduce bottlenecks and enhance information flow. Preliminary simulation results using Gephi suggest that these structures may lead to improvements in graph density and average path length, which could be associated with better lookahead planning and higher PPC.

Overall, these findings provide an initial understanding of how team communication networks relate to project planning practices. By encouraging regular evaluation of team interactions and planning practices, organizations may achieve better outcomes in future construction projects. This proactive approach supports continuous improvement, strengthens collaboration, and builds resilience within project teams. As the industry increases its adoption of lean principles and digital tools, such practices will be essential for sustaining success and delivering superior results.

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