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INFLUENCE OF LAST PLANNER® SYSTEM ADOPTION LEVEL ON PROJECT MANAGEMENT AND COMMUNICATION

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ABSTRACT

Construction projects require complex management of people, resources and goals. The Last Planner® System (LPS) provides a systematic framework based on short cycles of work preparation, commitment, and control to allow implementing corrective actions. Successful LPS implementations require the combination of homogeneous mature practices and efficient horizontal collaboration. Nevertheless, partial implementations prevent liking collaboration through mid-term planning, the make-ready process and short-term work-flow stabilization. Therefore, this study aims to assess the relationship and cross-impacts of LPS adoption levels, team collaboration and project performance through an in-depth comparison of two Chilean case-study projects. LPS adoption was measured through a 50 items survey applied to 10 key actors in each project and collaboration was captured through Social Network Analysis (SNA) applied to general interaction, planning, problem-solving, feedback, learning, and leadership surveys answered by all last planners in each project. Also, each project was monitored for at least 18 weeks to capture their Percent Plan Complete (PPC), Reasons for Noncompliance (RNCs) and Schedule Performance Index (SPI). The results, consistent with previous literature, showed that mature LPS adoption significantly aids collaboration and performance.

KEYWORDS

Last Planner® System, collaboration, social network analysis, make-ready planning

INTRODUCTION

Project management requires dealing with high levels of uncertainty and variability, which, in highly interrelated networks of activities carried out by multiple stakeholders, can lead to a schedule deviation tendency (Sarhan & Fox, 2012). Traditionally, construction teams selected a Managing by Results (MBR) approach, using highly detailed initial plans and controlling them systematically using result-oriented systems such as Earned Value Method (EVM) (Kim & Ballard, 2010). Nevertheless, research has

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shown that the use of static plans, lack of stakeholder collaboration, low workforce involvement in planning, and lack of use of process-oriented indicators prevent project teams from taking advantage of continuous planning opportunities to tackle uncertainty and variability (Kim & Ballard, 2010). Thus, the Last Planner® System (LPS) was proposed to systematize planning and control, using short collaborative cycles to identify required work, schedule accordingly, prepare it and stablish execution commitments weekly monitored to determine required corrective actions (Ballard & Tommelein, 2016). Although LPS benefits are well known and widely cited (Daniel et al., 2015), researchers have found that partial implementations can limit its potential (Daniel et al., 2015). Partial adoptions, focused mainly on short-term planning despite lookahead planning and the make-ready process, are common and prevent long-term schedule accomplishment by making management reactive to RNCs rather than proactive (Lagos et al., 2017). Also, a lack of involvement of direct responsibles, called Last Planners (LPs), due to management level exclusive decision-making has been detected as a common shortcomming (Sarhan & Fox, 2012).

Previous research has shown a direct correlation between LPS maturity and performance, both in short-term stabilization and schedule accomplishment (Lagos et al., 2017). The statistically significant correlations found between the PCR, PPC, and SPI reinforce this point (Pérez et al., 2022). On the other hand, transversal studies have shown that mature LPS adoptions and proactive collaboration are mutually beneficial, since efficient communication and horizontal collaboration along the make-ready process is key to ensure short-term stabilization and sustained compliance (Castillo et al., 2018). Also, horizontal case-study research has consistently observed that, as project teams strengthen their LPS adoption, they improve horizontal communication across LPs, allowing them to proactively take continual improvement actions (Retamal et al., 2022). Thus, this study aims at gaining an improved understanding of the effects of LPS maturity on project performance, through a quantitative assessment of the effects of LPS adoption levels on collaboration and proactive management.

LITERATURE REVIEW

LPS aims at four objectives: First, Ensure close bottom-up coordination between LPs and management level, through collaborative planning and control meetings (Priven & Sacks, 2013). Second, stabilizing the workflow through the lookahead planning and the make-ready process, in which the LPs construct a four to six weeks lookahead plan to search for upcoming execution constraints and plan actions to remove them in advance, to increase the mid-term workable backlog of tasks (WB) (Hamzeh et al., 2008). Third, ensuring compliance by planning on a short-term basis, usually one week, based on commitments considering capacity, readiness and priority (Torre et al., 2021). Finally, it uses a Managing by Means (MBM) approach, where systematic process-oriented control allows teams to implement corrective actions based on compliance and take advantage of planning opportunities presented by the workable backlog (Ballard & Tommelein, 2016).

LPS process-oriented control uses four main sources of information to facilitate proactive management (Alarcón et al., 2014). The make-ready process is captured by the Percent Constraints Removed (PCR), which measures the percent of constraints removed during a short-term period from the number of constraints planned according to the LPs' commitments (Alarcón et al., 2014; Lagos et al., 2017). Short-term compliance is captured by the Percent Plan Complete (PPC), which measures the percent of execution commitments that secured a progress equal or greater than committed out of all short-term commitments made. Each unaccomplished commitment is assigned a Reason for Noncompliance (RNCs), a standardized category used to indicate the source that prevented expected progress. Finally, many implementations use the Schedule Performance Index (SPI), taken from EVM, to compare actual progress against initially planned progress at the end of each short-term period.

Multiple instruments have been proposed to measure LPS adoption, with the Planning Best Practices (PBP) index being a common standard (Viana et al., 2010). PBP studies have consistently found that mid-term scheduling practices, such as constraint identification in the make-ready process are significantly less observed than basic practices such as assessing the PPC and RNCs (Lagos et al., 2017). Nevertheless, since the PBP focuses mainly on detecting the presence of systematic practices, it does not necessarily allow to capture the links between Lean principles, LPS processes and practices to capture how collaboration impacts performance (Priven & Sacks, 2013). On the other hand, Lean maturity assessments such as the Lean Construction Maturity Model (LCMM) focus on the link between principles, processes and practices, however, LCMM captures multiple Lean tools besides LPS (Nesensohn et al., 2015).

Researchers have captured how collaboration at the different LPS processes is exherted either qualitatively through case-study observation, surveys and interviews, or quantitatively through the use of Social Network Analysis (SNA), which captures people interactions as ties between two or more network nodes and uses them to represent communication, affinity, and strength of relationships, among others (Priven & Sacks, 2013). However, SNA networks cannot isolate collaboration in a single process in other to detect how LPS practices influence collaboration (Castillo et al., 2018) , hence, using a LPS maturity instrument focused at linking processes to practices, combining the PBP and LCMM approaches could benefit the interpretation of SNA results. Previous studies have shown that LPS processes adoption positively correlates to SNA strength in planning, knowledge management, learning, and problem-solving, among others (Castillo et al., 2016). Also, similar studies have observed a positive correlation between SNA strength and performance indicators (Herrera, et al. 2018). Hence, this study aims at using SNA to better understand how more mature LPS adoptions can lead to better collaboration practices associated with proactive MBM and higher project performance.

RESEARCH METHODOLOGY

A case study approach was selected since it combines direct observation, quantitative data, and qualitative information, validated with relevant project team members through comparison and analysis, to drive conclusions (Yin, 2014). Two Chilean construction projects, characterized in Table 1, each carried out by a different company, were selected as case studies since they could be followed for a similar period since an early stage of execution, had similar scheduled scopes, belonged to companies with similar LPS experience, were carried out by teams with similar experience that received LPS training by the same consultant team and used equivalent LPS software to support it.

The research was structured in four phases. First, an extensive literature review was used to develop an instrument to evaluate a project management maturity level based on Lean Construction and Last Planner System criteria, which was validated with eight LPS professionals and academic experts and applied in both projects. Second, an online survey comprised of seven questions was applied in both project teams to obtain team communication data, which was processed using the software GEPHI to obtain SNA metrics and sociograms (Castillo et al., 2016). Third, the projects were followed for five months to capture weekly LPS metrics, and statistical analyses were carried out to allow comparison. Finally, quantitative and qualitative comparison between the projects and previous literature findings was used to drive conclusions regarding the effects of LPS adoption on project management and communication.

Table 1. Case study information

Criteria	Project A	Project B
Project type	Industrial construction	High-rise building
Initial planned schedule duration in weeks	51	49
Baseline progress prior to study	4.83%	4.41%
Execution weeks captured in the study	19	18
Baseline progress at the end of the study	52.34%	52.71%
Average number of short-term tasks	16	21
Number of project team members	49	26
Average years of team LPS experience	2.6	2.4

LPS BASED PROJECT MANAGEMENT EVALUATION

The instrument comprised five dimensions (Perez-Apaza et al., 2021; Salvatierra et al., 2015): adoption of a Lean-oriented culture; understanding of the Lean Construction philosophy; implementing known, visible, and auditable standards; following LPS processes; and applying Lean and LPS best management practices. Each dimension was assessed in ten aspects (Diekmann et al., 2003; Nesensohn et al., 2015): (1) value and waste management, (2) standardization, (3) workflow stabilization, (4) systematic planning, (5) process-oriented control, (6) knowledge management, (7) continuous improvement, (8) teamwork, (9) communication and transparency, and (10) Technology adoption to support Lean-based management. Hence, the survey was comprised of 50 questions, each evaluated in a five steps Likert Scale (Nesensohn et al., 2015): 0% – The aspect is not present or observable; 25% – The aspect is present in an unformalized manner; 50% - The aspect is generally formalized but is not known by all parties nor audited systematically; 75% - The aspect is formalized and well known but it is not audited systematically for continuous improvement; 100% – The aspect is highly formalized, well known and continuously audited.

The survey was applied to 10 key members in each team, with a 100% response rate, including at least the project manager, project leader, site engineers, technical officers, LPS facilitators, and supervisor representatives, in addition to two research observers who followed the projects for at least six weeks prior to the survey. Each answered individually and, then the mean, mode, and median of the results were presented in a workshop, where a Delphi validation process was conducted with the responders in each project and the two observers to obtain a single representative evaluation. Also, a Cronbach Alpha Coefficient test was used to assess the instrument's reliability using the 24 responses and yielded a result of 0.851, indicating that the instrument was highly reliable (Lagos et al., 2017). Finally, dimensions and aspects were characterized using the median.

SOCIAL NETWORK ANALYSIS

Interactions from the LP level upwards were captured through a survey applied to all actors involved in the LPS processes; 49 and 26 LPs in projects A and B, respectively.

The researchers held an explanation workshop in each project, give digital and printed instructions with copies of the instrument, made it available online for a two weeks period, and held presential aid instances at the worksite to facilitate response. Actors were made aware that their responses would be anonimized, only used for research purposes and that no individual response would be shared with management or third parties. Finally, management committed means to facilitate that LPs could respond the survey without the presence of third parties, management or collaborators to avoid response bias.

The instrument comprised seven questions used to capture six interaction networks. The first question served as a consistency filter to eliminate the team members with whom the responder did not exhibit frequent interaction (Herrera et al., 2020). Remaining questions captured general interaction, planning, problem-solving, feedback, learning, and leadership, as shown in Table 2. The first question filtered available options for each for the rest, except for leadership, and responders answered based on work-related interactions over the past two months. The results were converted into adjacency matrixes, where each row contained each team member's answers regarding each teammate. Each person represented a node, and each node connection represented a tie (Cisterna et al., 2018). For a valid tie to exist in general interaction, planning and problem solving, the link should be reciprocal, meaning that both teammates indicated a connection with one another (Castillo et al., 2016). A unidirectional link was considered valid in the remaining networks since it indicated that the person received feedback, learned from, or considered another team member to be a natural leader.

The matrixes were processed using the software GEPHI to construct sociograms via the Force-Atlas2 algorithm, which emulates the behavior of electrically charged particles by repulsing nodes based on size and using ties to create attraction (Jacomy et al., 2014). Four indicators were calculated in each network (Abraham et al., 2009): The average Relative Degree of the network measured the number of teammates with whom each member was directly connected, divided by the team size, to assess the percent of direct connections from an average member. The Network Density measured the percent of existing connections over the number of possible connections to assess the strength of communication among the team members. The Clustering Coefficient expressed the probability of two members being part of a completely connected group within the network. Finally, betweenness centrality measured the percent of shortest paths between any two members that passed through a specific member; thus, its average represented network homogeneity.

Table 2. Available questions in social network analysis survey

Dimension	Question	Available Options
Interaction filter	With whom have you interacted at least once during this period in a work-related matter?	List of LPs and management
General interaction	How frequently did you interact with the following teammates?	Once or twice; Approximately once a week; Multiple times during the week; Daily.
Planning interaction	How frequently do you plan collaboratively with the following teammates in a normal week?	Never; Scarcely; Commonly; Every week.
Problem-solving	How frequently have you collaborated in problem solving with the following teammates?	Never; once or twice; approximately once a week; multiple times during the week.

Feedback	What type of feedback have you received from the following teammates during this period?	None; scarce and informal; scarce but formalized; frequent and formalized.
Learning	To what degree has each of the following team members contributed to your learning?	None; little; moderately; highly.
Leadership	If a complex work-related challenge arises, who of the following team members do you think could act as natural leaders to tackle it?	Unlikely; possibly; most probably; certainly.

PROJECT PERFORMANCE MEASUREMENT

Each project was followed weekly and without intervention from the research team from earlier than 5% baseline expected progress until approximately 52% of baseline expected progress. 19 and 18 weeks of information were captured for Project A and B, respectively. In each case, the weekly PPC, RNCs, and SPI were retrieved directly from the LPS support software used by the teams. These indicators were compared among projects using the mean, standard deviation, and coefficient of variation. The average PPC, SPI, number of RNCs, and Percent of Internal RNCs (PIR) were compared among case studies using statistical mean difference analyses. First, a Shapiro-Wilk (SW) test was selected to assess normality since it is well suited for samples under 50 elements. A p-value greater than 0.05 in the SW test would indicate that the sample followed a normal distribution (Pérez et al., 2022). Then, the t-test was used to assess mean differences among normally distributed samples, and the Mann-Whitney's U test (MW) was used to compare metrics where at least one case study did not exhibit a normal distribution (Pérez et al., 2022). The null hypothesis "there is no statistically significant difference at a 95% confidence level" could be rejected if the p-value was equal or lower than 0.05 (Pérez et al., 2022).

RESULTS

LPS ADOPTION RESULTS

Although both projects exhibited at least a 50% or higher adoption in all dimensions and aspects, as presented in figure 1, project B exhibited consistent higher adoption levels. The biggest difference at the dimension level was observed in the adoption of LPS processes, where Project B exhibited formalized, known, and auditable processes in most aspects. In contrast, in Project A, some key processes such as systematic planning and process-oriented control using LPS were not known by all project participants nor audited periodically for continuous improvement. The biggest differences at the aspect level were observed in process-oriented control and technology adoption.

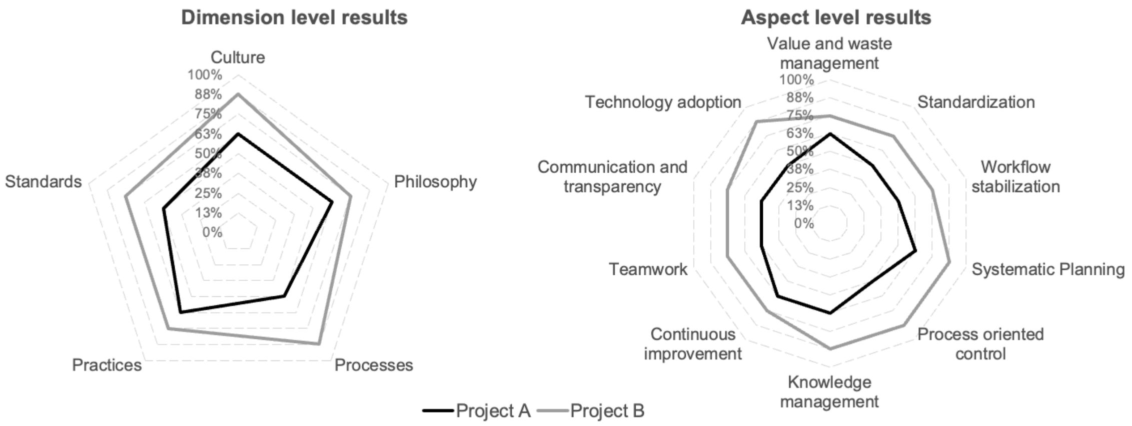

Figure 1. Comparison of LPS project management levels among case studies

SOCIAL NETWORK ANALYSIS RESULTS

As Table 3 shows, both projects exhibited similar patterns regarding the strength of the networks: Interaction and feedback were the strongest in both cases and almost equivalent to one another, planning was the third strongest network in both cases, followed by problem-solving and, finally, learning and leadership were significantly weaker than the general interaction. Also, in most cases, clustering was greater than density, indicating that not all individual interactions were direct. Although project A exhibited lower integration levels in all six networks compared to project B, it presented almost twice as many team members, which affects the results since it is less probable that a larger team has direct connections between all its members (Abraham et al., 2009). Hence, to facilitate the assessment, the results were normalized by dividing each network's metrics by the general interaction results in each project, as presented in Table 4.

Table 3. Social network analysis metrics prior to normalization

	Project A				Project B			
Network	Degree	Density	Clustering	Centrality	Degree	Density	Clustering	Centrality
Interaction	46%	47%	69%	62%	70%	73%	73%	79%
Planning	22%	23%	59%	51%	41%	43%	51%	62%
Problem solving	17%	18%	41%	45%	35%	36%	51%	56%
Feedback	45%	46%	67%	65%	70%	73%	73%	79%
Learning	11%	11%	33%	38%	28%	30%	46%	57%
Leadership	11%	11%	28%	34%	34%	35%	54%	61%

Table 4. Normalized social network analysis metrics

	Project A				Project B			
Network	Degree	Density	Clustering	Centrality	Degree	Density	Clustering	Centrality
Planning	48%	49%	86%	82%	59%	59%	70%	78%
Problem solving	37%	38%	59%	73%	50%	49%	70%	71%
Feedback	98%	98%	97%	105%	100%	100%	100%	100%
Learning	24%	23%	48%	61%	40%	41%	63%	72%
Leadership	24%	23%	41%	55%	49%	48%	74%	77%

As observed in Table 4, despite the normalization, Project B still exhibited higher integration levels regarding planning, problem-solving, learning, and leadership. Only four metrics were higher in Project A after normalization: Planning's clustering coefficient, and the betweenness centrality of planning, problem-solving, and feedback. However, these metrics were lower than Project B without the normalization. As presented in Figure 2, the administration team from Project A occupied the most central part of the planning and leadership networks while also presenting a significantly greater node degree than their teammates. In contrast, Project B presented more homogeneous planning and leadership networks, with on-site engineers occupying the center of the networks. Also, case A's planning network presents a subcontractor team excluded from the center, which was repeated in the rest of the networks.

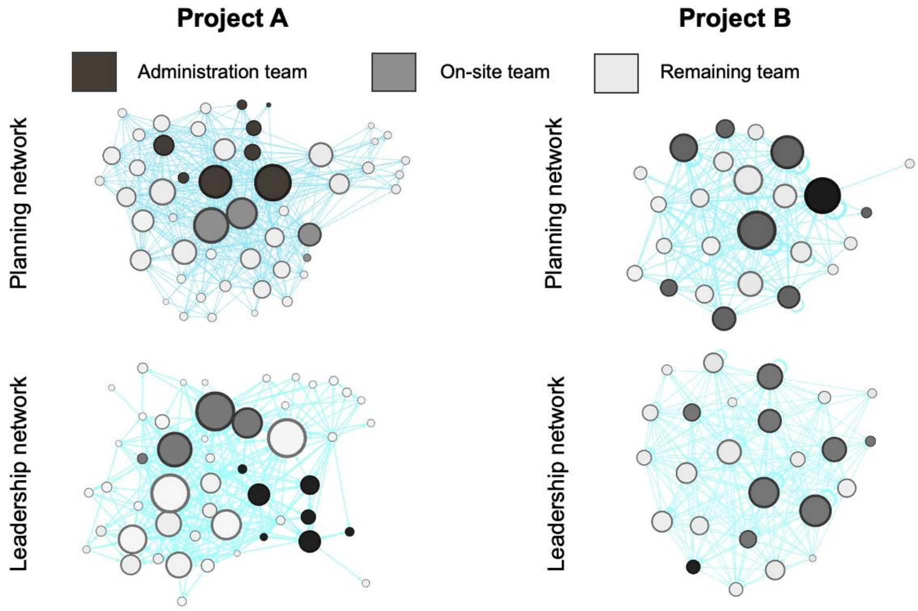

Figure 2. Case studies' planning and leadership network diagrams

PROJECT PERFORMANCE RESULTS

As Table 5 presents, Project A presented a lower SPI average, with a greater coefficient of variation compared to Project B. Project A exhibited an average tendency to decrease its SPI by a weekly rate of -1.73%, obtaining a 72.4% SPI at 52.3% expected progress, while Project B exhibited a slight tendency to increase its SPI by 0.28% weekly, obtaining an SPI of 100.4% at 52.7% expected progress. In contrast, case A presented a greater PPC average with a lower coefficient of variation and a lower number of RNCs. The differences in the SPI, PPC, and number of RNCs were statistically significant at a 95% confidence level. The percent of internal RNCs was similar in both projects and did not exhibit statistically significant differences, despite a significantly greater PIR coefficient of variation in project A. Although both projects presented a similar percent of internal RNCs, the main source of noncompletions in Project A was "overestimation of productivity and achievable progress" (32%), followed by "unforeseen requirements of information or project changes" (19%). In contrast, in Project B, their main RNC sources were "change in priorities" (41%) and "uncontrollable weather conditions" (11%).

Table 5. Project performance results

	Project A			Project B			
KPI	Mean	SD	CV	Mean	SD	CV	p-value

SPI	87.3%	14.8%	16.9%	97.0%	12.3%	12.6%	0.01
PPC	77.3%	14.9%	19.2%	58.3%	15.6%	26.8%	0.00
N° RNCs	3.27	2.14	65.5%	9.50	4.96	52.2%	0.00
PIR	61.7%	16.4%	26.5%	65.5%	3.1%	04.8%	0.07

DISCUSSION

Collaborative assessment with the teams, showed significantly different management approaches, allowing to gain understanding of the differences at adoption, collaboration and performance. First, Project A implemented a more traditional project management approach, closer to MBR, as represented by their LPS adoption levels in processes and standards, in addition to their approach of following the initial plan with minimum changes. In contrast, Project B exhibited a project management system closer to MBM, as shown by their continuous use of LPS control to drive corrective actions, captured in their LPS adoption measurement as significant differences in workflow stabilization and systematic planning, process-oriented control, and knowledge management. Therefore, the approach taken by project A was more reactive, as it focused on securing short-term compliance through corrective actions aimed at removing RNCs (Hamzeh et al., 2008); while Project B was considered systematically proactive since it focused on continuously updating the plan to ensure long-term schedule compliance (Samudio et al., 2012).

Second, Project A focused on following the initial schedule with the least variations possible and corrective actions focused on securing work conditions for tasks in the next period, aiming to improve their next PPC. On the other hand, Project B focused on continuously updating their lookahead to ensure the maximum possible progress each week, through greater attention on the workable backlog of tasks from the lookahead plan to allow flexibility even if that meant dropping certain commitments due to changes in priorities and impacted RNC composition. Although lookahead planning and work preparation metrics as the PCR were not captured in this study, the close collaborative examination of LPS adoption and performance results signaled that collaborating proactively to increase the workable backlog allowed project B to sustain higher long-term compliance, while the short-term focus of project A yielded a higher PPC but did not reflect on the long-term schedule compliance.

Third, Project A focused most management responsibilities on their administration team, as their network sociograms and metrics represented, while Project B, which shared these responsibilities with on-site engineers, supervisors, and LPs, achieved more dense and homogeneous networks, measured by degree, density, clustering, and centrality. This was also captured by the differences in teamwork and communication observed in the LPS adoption assessment. For example, Project A concentrated lookahead planning decisions at the administration level and then asked LPs to validate the plan and establish constraint removal and execution commitments. At the same time, Project B opted to ask LPs to update the lookahead plan and then validated the plan against the current state of the WB with the administration team to develop the short-term plan collaboratively. Researchers have signaled that enclosing planning, control, and decision-making mainly on high-level leadership leads to less LP participation, preventing them from proposing alternative opportunities based on the workable backlog (Mcconaughy & Shirkey, 2013). The SNA results and performance metrics are consistent with that assumption and show that while project B was able to proactively collaborate on the make-ready process to increase flexibility and protect long-term schedule accomplishment, project A was comparably more limited to reacting on RNCs to improve short-term compliance.

Fourth, even though both projects implemented LPS as their main management approach and had equivalent support systems, they significantly differed on their use of information. Project A focused mostly on following their long term plan with minimum changes, controlling short-term compliance tightly and using historical RNC information on a week to week basis to select appropriate corrective actions aimed at sustaining a high PPC.Thus, their main use of the support software and captured information was to control compliance and act accordingly. On the other hand, Project B focused mostly on securing the workable backlog, thus, using the software to assess alternative scheduling opportunities aimed at securing flexibility through collaborative planning and using theprocess-oriented information to implement lookahead planning actions and improve their make-ready process. These differences were also reflected when asking the teams "what is the main use given to the software's information on a daily basis?" where Project A answered "Tracing RNCs to detect corrective actions needed and capacity improvement opportunities aimed for the next short-term period" and Project B answered "Assessing the current state of constraints and the workable backlog to update the lookahead plan". Suppose these answers are combined with the networks' differences, it can be inferred that Project B was able to collaborate with more time to detect improvement opportunities proactively instead of reacting to RNCs based mostly on the administration team's decision-making process (Samudio et al., 2012).

CONCLUSIONS

This study assessed the relationship between LPS adoption level, team collaboration, and project performance by comparing six social networks and LPS indicators in two Chilean projects, against their LPS adoption levels, to drive conclusions using a case study approach. Both teams exhibited different approaches and results despite having similar previous LPS knowledge, experience using LPS as their main project management system, and using an equivalent LPS support system. Project A implemented an approach closer to MBR, which reflected in less connected networks, most management responsibilities enclosed in the administration team, and a lower LPS adoption level, especially in LPS processes and standards. In contrast, Project B exhibited a management approach closer to MBM with a significantly higher presence of key LPS aspects such as workflow stabilization, systematic planning, process-oriented control, teamwork, and communication, which granted higher LPs' involvement captured in the networks.

Two relevant management approach differences were identified: First, case A focused on short-term planning and opted to follow the initial plan without major changes. In contrast, project B opted to update the plan using the workable backlog systematically. Second, Project A used LPS information provided by IT support mainly to assess RNCs and implement reactive actions accordingly. In contrast, case B used it mainly to manage the workable backlog in lookahead planning proactively. The performance results showed that case A obtained a significantly greater PPC and significantly lower SPI. Hence, it was inferred that the partial LPS adoption of Project A, its short-term based reactive approach, and high-level management enclosure prevented it from achieving the LPS benefits exhibited by Project B. Therefore, even though this research did not capture make-ready process metrics, it allowed to emphasize the relevance of lookahead planning, workable backlog management, and continuous planning in close collaboration with the Last Planners to improve project performance and outcome.

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