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METHODOLOGY TO QUANTITATIVELY ASSESS COLLABORATION IN THE MAKE-READY PROCESS

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ABSTRACT

The Last Planner System (LPS) promotes collaboration to plan, prepare and execute work systematically. Make-Ready Planning (MRP) is a key LPS component, connecting mid- and short-term planning by proactively identifying and removing constraints. However, systematic deficiencies in MRP implementation have been observed, and MRP assessment mechanisms are limited to constraint management indexes and qualitative assessment of practices. Hence, finding easy to apply ways to quantitatively assess MRP collaboration and its impacts on LPS performance is identified as research opportunity. To address this, a Design Science Research approach was used to propose a methodology for evaluating MRP collaboration using Social Network Analysis (SNA) of objective LPS information captured by existing Information Technology (IT) support systems. This approach allows for the creation of a directional social network of interactions between constraint removal (source) and task execution (target) last planners. Assessing the average degree, centrality, heterogeneity, number of connected components and density allows to identify collaboration improvement opportunities as well as understanding the impact of collaboration on LPS performance, as the project progresses.

KEYWORDS

Last Planner System ®, make-ready planning, constraint analysis, collaboration

INTRODUCTION

The Last Planner System (LPS) is a highly effective production planning and control system that is based on the principles of Lean Construction (Ballard & Howell, 2003). It uses a pull framework, in which upcoming work is planned in increasing detail as required for preparation and is only pulled to execution once all potential constraints have been removed (Ballard & Tommelein, 2016). This aims to increase planning reliability through a collaborative effort to stabilize the workflow (Alarcón et al., 2014). LPS takes its name from the concept of last planners, the direct personnel in charge of preparing and executing work on site (Ballard & Howell, 2003). Last planners can be directly or indirectly responsible for task execution,

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through the identification and removal of constraints such as materials, equipment, information, labor, or conditions (Retamal et al., 2020). Instead of relying on a traditional top-down approach, last planners form cohesive horizontal networks in which execution compliance and plan reliability are facilitated by the collaborative assessment and preparation of work, in a process known as Make-Ready Planning (MRP) (Ebbs & and Pasquire, 2018).

MRP is the key link between Lookahead Planning and Short-term Planning (F. R. Hamzeh et al., 2015). The first is the process of identifying, detecting, assessing, and planning upcoming work in a three to six weeks scope, and the second consists of selecting executable work in a scope of one to two weeks, establishing commitments that will be followed throughout, and assessing compliance at the end to determine improvement opportunities (Ebbs & and Pasquire, 2018). The effective transition from Lookahead to Short-term Planning requires a sufficient workflow of executable tasks aligned with the mid-term goals (Hamzeh et al., 2015). Hence, MRP focuses on generating a Workable Backlog (WB) of constraint-free tasks, ready for commitment and execution. A larger WB allows last planners to better align commitments with their capacity, and establish more reliable commitments with flexibility to pull work in Lookahead Planning (Pérez et al., 2022).

MRP relevance is well-documented, and researchers have found a direct relationship between MRP effectiveness and long-term project performance as well as statistically significant positive correlations between the Percent of Constraints Removed (PCR) (Ballard & Tommelein, 2016), the Percent Plan Complete (PPC) and Schedule Performance Index (SPI), indicators that capture the results of the MRP, short-term and long-term planning, respectively. Nevertheless, MRP has been found to be one of the weakest implemented LPS components, significantly lower than aspects such as commitment-based short-term planning and searching for Reasons of Noncompliance (RNCs) (Daniel et al., 2015). Thus, researchers argue that implementing LPS with a short-term focus instead of a systematic mid-term planning and work preparation approach significantly limits its potential benefits (Lagos et al., 2022).

Improving MRP requires continuously assessing the effectiveness of constraint identification, committing and removal; employment of correct practices and benchmarking its results (Ballard & Tommelein, 2021). The results of MRP can already be captured using LPS indicators such as the PCR, Tasks Made Ready (TMR) and Tasks Anticipated (TA) indicators, while practices can be assessed using multiple implementation guidelines, maturity and adoption surveys (Lagos et al., 2019). However, there is a gap in the systematic assessment of last planners' collaboration to identify, manage, and remove constraints in an effective and efficient manner. Construction management requires multiple stakeholders, from suppliers to engineers and subcontractors to work in coordination under fast changing conditions (Ebbs & and Pasquire, 2018; Lagos et al., 2022). Without MRP collaboration, Last Planners can plan to execute constrained work packages or fail to detect executable packages when committing in short-term. In a high-performing LPS team, silos are replaced with closely tight networks, where Last Planners communicate actively to commit work or request its preparation (Castillo, Alarcón, & Salvatierra, 2018; Ebbs & and Pasquire, 2018)

Social Network Analysis (SNA) has been used as a diagnostic tool to assess collaboration and information flows in Lean Construction and AEC (Herrera & Alarcón, 2022). Its use in research and practice allows discovering unknown patterns of information flow and comparing them against expected interactions, also allowing to surpass preconceived perceptions of team collaboration (Priven & Sacks, 2013). SNA can be applied to multiple networks from general interaction to planning, problem-solving and learning (Alarcon et al., 2013). Also, it provides a wide array of indicators for objective representation of these networks, such as density, centrality, homogeneity, and isolated components, among others (Marin & Wellman, 2011).

SNA has mostly been applied in Lean Construction via perception surveys and required significant information preprocessing through tools to obtain representative graphs and indicators (Castillo, Alarcón, & Salvatierra, 2018). However, the AEC industry has considerably increased its technological adoption during the past decade, especially since the start of the pandemic (Assaad et al., 2022; Elrefaey et al., 2022). This has prompted the adoption of IT support systems for LPS, which can be easily use in combination with data science tools in a single stream, to facilitate the use of SNA applied to existing information being captured periodically by LPS software, instead of relying on surveys.

This research proposes a methodology to evaluate MRP collaboration and its impact on LPS performance, by applying SNA to objective LPS information captured by IT support systems for LPS. Resulting metrics from mapping interactions between constraint removal (source) and task execution (target) last planners (LPs), can complement existing LPS indicators, facilitating the identification of improvement opportunities.

RESEARCH METHODOLOGY

This research aims to propose a methodology to assess last planner collaboration on the make-ready process, based on objective information generated through mid- and short-term planning. The Design Science Research (DSR) methodology was selected as it facilitates the generation of prescriptive knowledge to model and solve complex problems. DSR focuses on designing artifacts, such as methods, models, or tools, that capture the existing understanding of the problem, its requirements, key factors, and their relationships, as well as goodness criteria necessary for potential solutions (Da Rocha et al., 2012). Thus, artifacts, can be iteratively refined by testing their fitness to model and facilitate finding solutions to the intended problem.

The following two questions were formulated to structure the research: “How can MRP collaboration be assessed using existing LPS information?” and “How can MRP collaboration metrics complement existing LPS indicators to assess performance?”, consequently, the research was structured into four stages:

1. **Problem space:** Assessing the existing body of knowledge to model how MRP collaboration and its impacts LPS performance.
2. **Solution space:** How to capture MRP collaboration using existing LPS information.
3. **Artifact design:** Proposing a methodology matching the problem and solution spaces.
4. **Artifact testing:** Validation with empirical information from LPS case studies.

LITERATURE REVIEW

BODY OF KNOWLEDGE REGARDING THE PROBLEM SPACE

LPS promotes horizontal collaboration to assess, prepare and commit upcoming work, reliably, through systematic short-term cycles (Priven & Sacks, 2013). According to the supporting body of knowledge, failing to assess upcoming work will limit the team’s capability to identify constraints and plan accordingly, while failing to prepare it through constraint removal will limit their capability to formulate and accomplish reliable execution commitments (Retamal et al., 2020). Previous transversal studies have observed statistically significant correlations between the PCR, PPC and SPI (Lagos et al., 2019). In despite that a full understanding of these relationships would also require connecting them to mid-term assessment and work preparation indicators, such as Tasks Anticipated (TA) and Tasks Made-Ready (TMR), these missing links have been partially covered by constraint management indicators such as the Constraint Identification Time (CIT) and Constraint Removal Efficiency (CRE) (Ballard & Tommelein, 2016; Pérez et al., 2022). CIT measures how far ahead are constraints being identified, compared to the Lookahead scope, while CRE compares the actual time needed to remove them, against the planned time committed when the constraint was identified (Lagos & Alarcón, 2021).

Both the CRE and CIT exhibited empirical correlations with the PCR and PPC (Pérez et al., 2022).

On the other hand, transversal studies using SNA to assess LPS interactions have discovered statistically significant relationships between SNA metrics of collaboration, LPS indicators and project performance measures (Castillo, Alarcón, & Salvatierra, 2018; Retamal et al., 2020). Particularly, stronger collaboration in the exchange of relevant information, as well as planning and problem solving, captured through SNA metrics of density and average degree, showed statistically positive correlations with constraint release and planning effectiveness, measured by the PCR and PPC (Castillo, Alarcón, & Salvatierra, 2018). A subsequent study by the same authors also correlated the network strength metrics with benefits in quality, safety, costs, and productivity (Castillo, Alarcón, & Pellicer, 2018). Furthermore, a case study using a similar methodology to compare two projects of similar characteristics and LPS experience, observed that the project with higher horizontal collaboration in planning and problem solving exhibited significantly better MRP practices and long-term schedule compliance, while the project with a more traditional top-down management approach exhibited work-preparation silos that allowed to obtain high PPCs but prevented them from sustaining high long-term schedule performance due to the lack of flexibility of the WB (Lagos et al., 2022).

These studies support the statement that horizontal collaboration in planning and work preparation is key to support the LPS virtuous cycle of proactive planning, committing and control, which in terms of MRP, corresponds to (1) efficient constraint identification and (2) reliable removal (Ballard & Tommelein, 2016). Horizontal collaboration facilitates that last planners take part in this process (Lagos et al., 2022), while the strength of these interactions, i.e. close collaboration between multiple parties, leads to work preparation reliability (Castillo, Alarcón, & Pellicer, 2018). Also, since the goal of MRP is to facilitate the reliable commitment and execution of upcoming tasks, MRP effectiveness can be assessed by three subsequent factors: Effective work preparation, reliable work commitment and schedule compliance (Ballard & Tommelein, 2016). Therefore, based on these relationships and supporting evidence, the problem space is modeled by a six steps process from lookahead planning to sustained schedule compliance, aided by strong horizontal last planner collaboration, as shown in Figure 1.

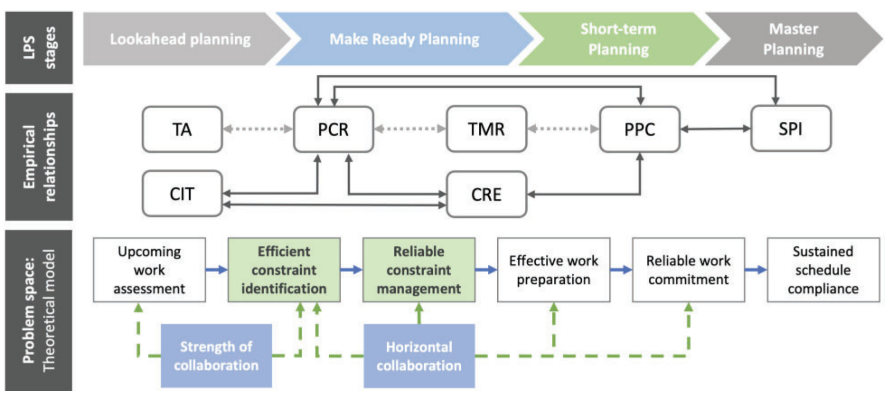

Figure 1: Theoretical Design of the Problem Space

Body of Knowledge Regarding the Solution Space

Social network analysis (SNA) studies the relationships and connections between individuals in a network, allowing to represent them in quantitative metrics as well as graphs (Marin & Wellman, 2011). It allows to study the structure and dynamics of a network, as well as the roles and influence of the different actors within it. SNA has been used in LPS to study the communication and collaboration patterns among the different stakeholders, including project managers, contractors, subcontractors, and the wider project team (Priven & Sacks, 2015). SNA facilitates identifying key roles such as connectors, bottlenecks, influencers, and decision-makers, as well as areas with lacking communication or collaboration (Flores et al., 2014).

Researchers have mainly captured social networks by employing indirect means, consisting in surveys of perceived interactions, applied to all members of the network (Herrera & Alarcón, 2022). These surveys cover general as well as specific interaction such as information exchange, planning and problem solving, learning, leadership, and feedback, among others. The surveys ask each team member a linking question, that can be (1) bidirectional, such as with "whom do you interact for this specific purpose?" Or directional, such as "who provides you key information necessary to carry out your work?" Also, responses can be binary or weighted, usually by a perceived frequency or relevance of the interaction (Alarcon et al., 2013).

Although researchers have used both bidirectional and directional links to capture networks, the later are preferred, since they allow to assess an individual's interactions based on the times it was targeted by other team members (incoming links), instead of by their own perceived interactions (outgoing links), helping to remove respondent bias (Cisterna et al., 2018; Herrera et al., 2020). Also, the way in which the question is formulated and the use of incoming or outgoing links can affect the network's representativeness. For example, if outgoing links are used to map an information exchange network, asking "to who do you provide relevant work information?" would have a higher risk of bias than asking "who provides relevant information for your work?". The use of objective information captured by IT support systems employed in LPS can help remove the risk of biased responses.

Regarding the assessment of MRP collaboration, some of the metrics used to quantify and describe the structure and dynamics of a network include the (Arif, 2015):

Density: Represents the strength of the network, as the number of existing connections over the total possible connections between its nodes. Hence, the higher the density, the higher the number of direct connections between the network's individuals.

Clustering coefficient: This measures the degree to which an individual's connections are connected to one another. It is often used as a measure of the cohesion of the network since it provides a representation of how likely is an individual to reach all others through its connections.

Closeness: Distance of an individual to all remaining nodes of the network. Equates to the number of interactions required to reach the remaining individuals. Therefore, is a measure of easiness of communication or the spread of information.

Path length: Average distance between any two individuals in a network. It is often used as a measure of the efficiency of information or resource flow through the network.

Degree: Relevance of an individual in a network via the number of connections (links) it possesses. It can be measured by the outgoing, incoming, or bidirectional links, using weighted or binary connections.

Betweenness: This measures the extent to which an individual is a "bridge" between other individuals in a network. It is often used as a measure of an individual's potential control or influence over the flow of information or collaboration within the network.

Eigenvector centrality: This measures the importance of a node in a network based on the importance of its neighbours. It is often used as a measure of how likely a node is to be reached by a random individual through its connections in the network.

Since the focus is placed in the assessment of network collaboration during MRP, individual metrics should be transformed to represent the cohesion, efficiency, and efficacy of the make-ready planning network, and not of a specific individual. Common practice is averaging individual metrics to represent the network, for example, using the average degree and average clustering coefficient as measures of cohesion. On the other hand, the following LPS metrics were selected to represent the short-term cycle's components (Hamzeh et al., 2019):

Percent Constraints Removed (PCR): Represents the constraint management reliability, measuring the number of constraints effectively removed during a short-term period, over the number of constraints planned to be removed during that cycle.

Percent Plan Complete (PPC): Represents the short-term planning reliability, measuring the number of short-term task execution commitments accomplished over the number of commitments made.

Schedule Performance Index (SPI): Represents the accomplishment of the master plan at the end of each period, by comparing the accumulated progress against the expected progress according to the initial plan, i.e., the Baseline.

SOLUTION ARTIFACT

To support LPS, IT systems require to capture and monitor commitments on a short-term basis. Therefore, they must contain four sources of information: (1) Tasks, which conform the master plan, (2) Constraints, which are linked to tasks, (3) Last Planners, who identify, plan, commit and manage tasks and constraints, and (4) terms, which contain the constraints and tasks committed in every period and their compliance. As last planners manage their short-term cycles, they will take tasks from the master-plan, pull them to the lookahead plan, assess them in search of constraints to be committed and once these are removed, the tasks are committed and executed accordingly. This process is captured periodically as terms.

The solution artifact represented in Figure 2 was developed with these four sources of information in consideration, to represent the transition from Lookahead Planning to short-term and master planning outcomes, via make-ready planning. The existing LPS indicators PCR, PPC and SPI are used to represent compliance and variability of performance in make-ready, short-term and master planning, respectively. In addition, a PWC indicates the Percent of Work Complete (PWC) indicator, explained in detail in the following sections. Finally, the relationship between constraint identification, reliable removal, the strength and horizontalness of collaboration is expanded using a set of SNA metrics taken from the existing body of knowledge and the aforementioned LPS indicators.

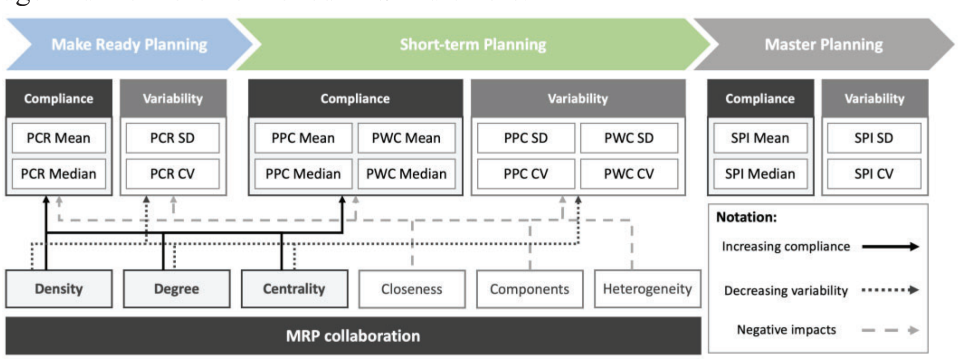

Figure 2: Solution artifact design

MRP NETWORK

Since MRP focuses on committing constraint removal to prepare the work, the MRP collaboration network can be mapped using the relationships between constraint Last Planners, the tasks' constraints, and the tasks' Last Planners. The MRP represents directional relationships, where the Last Planners committing the constraint removal, or Indirect Last Planners (ILP) prepare the work of the Last Planners that subsequently commit the execution of the task being prepared, i.e., the Direct Last Planners (DLP). Hence, MRP forms directional networks linking an ILP to a DLP. The indirect last planner acts as a source node, who removes constraints for the direct last planner, i.e., the target node. An ILP who prepares more work for a given DLP would have a higher relevance, giving way to a directional weighted network.

These interactions were obtained from the empirical data captured in the terms, by listing the last planners in a symmetrical two-dimensional matrix, with one dimension representing their role as DLPs and the second as ILPs. Each interaction is represented by the number of constraints which an ILP commits to remove for a DLP and the number of tasks that the DLP has committed. The ratio between the number of ILP's constraints over the DLP's tasks serves as a weighting factor. The connectivity of an individual node is given by the strength of the MRP collaboration, hence, its captured by the sum of incoming weights to a node, indicating that more constraints are being removed to prepare its tasks. Since the main characteristics of interest of the network are its strength and horizontalness the following indicators were calculated from the matrix:

Degree: Strength metric obtained as the arithmetic mean of all individuals' degrees, where each degree corresponds to the sum of incoming weight.

Density: Strength metric obtained as the number of directed links observed, divided by the total potential links between individuals, where a density of 1 indicates that every individual prepares work for each of the remaining nodes.

Connected components: Inverse strength metric representing the number of disconnected sub-groups in the network. The presence of two or more components indicates that one or more individuals are disconnected from the remaining group.

Heterogeneity: Inverse homogeneity metric representing the coefficient of variation of the mean degree, calculated as the standard deviation over mean. A higher coefficient of variation indicates disparity among individuals.

Closeness: Calculated as the arithmetic mean of the closeness centrality, which represents the average distance from anode to all other nodes, i.e., the average number of interactions required to reach any individual.

Centrality: Obtained as the arithmetic mean of the nodes' Eigenvector Centrality. Eigenvector centrality compares the degree of the nodes directly accessible by an individual, against the degrees of the network, where greater centrality indicates that an individual is closely connected to relevant ones.

LPS Metrics

In addition to obtaining the PCR and PPC as the percent of accomplished commitments in each term, for constraint removal and task execution, respectively, the authors also calculated the actual progress, SPI and Percent Work Complete (PWC) for each term. The SPI compares actual accumulated progress and expected progress; therefore, a baseline progress was calculated using the planned task dates at the start of the masterplan. Each task was assigned a weight equivalent to its planned execution days over the total planned execution days from all tasks in the initial plan. Each task would provide progress according to its weight distributed linearly across its execution days. The progress added by all tasks being executed was summed for each term, and the accumulated progress at the end of each term was calculated to obtain the Baseline expected progress (BL). The progress of each task was calculated at the end of each term, multiplied by the task's weight, and summed to obtain the actual accumulated progress (AP) at the end of each term. Then, the SPI divided the AP by the BL in each term.

The PWC represents the ratio between the percent of work completed in each period and the percent of work committed, using the progress, commitment, and weight of the tasks in each term. The numerator of the PWC corresponds to the weighted sum of the relative progress achieved by the tasks of a term, and the denominator, to the weighted sum of the relative progress committed for these tasks. Hence, as Equation 1 shows, the relative progress of a task is the difference between the progress achieved at the end of the current term, minus the progress achieved at the end of the previous. On the other hand, the relative commitment corresponds to the commitment in the current term, minus the progress achieved in the previous. The relative progress of each task participating in the term is multiplied by its weight and summed to obtain the relative progress of the term, and the same is done to obtain the relative commitment for that term. Then, their division represents the ratio between the actual progress gained in a term, and the progress expected by the commitments made.

$$PWC_{term\ j} = \frac{\sum_{task\ i}^{N} \left\{ \left(Progress_{i,j} - Progress_{i,j-1} \right) \cdot Weight_i \right\}}{\sum_{task\ i}^{N} \left\{ \left(Commitment_{i,j} - Progress_{i,j-1} \right) \cdot Weight_i \right\}}$$

The PCR, PPC, PWC and SPI of each term are aggregated for each project, using their descriptive statistics of mean, median, standard deviation (SD), and coefficient of variation (CV). The mean and median are used as measures of performance compliance, and the standard deviation and coefficient of variation, used to represent variability across terms.

RESULTS AND DISCUSSION

ARTIFACT TESTING METHODOLOGY

The proposed methodology was tested using empirical information from 68 projects that employed the same IT support system for LPS. All had implemented LPS for at least 8 weeks prior to the data collection and were followed for at least 10 weeks, capturing, in average 50% of their execution scope. Table 1 presents the sample's descriptive statistics. The solution artifact was validated by (1) its fitness to capture relevant relationships between indicators, as well as (2) the usefulness of MRP indicators to discover impacts in LPS metrics.

Table 1: Sample's Descriptive Statistics

Statistic	Tasks	Duration (days)	Captured scope	Terms	Constraints	Constraints per task	DLPs	ILPs
Mean	1104	494	50%	32,5	148	0,3	12,7	10,9
Median	585	494	41%	25,0	86	0,2	11,0	9,5
SD	1146	255	29%	20,3	172	0,4	8,7	5,5

The fitness was assessed with statistical correlation analyses, using the Spearman Correlation test with the raw variables and the Pearson Correlation test with the normalized variables. Normalization was performed using the standard conversion and outliers with absolute $z > 3.0$ were removed. A correlation was deemed statistically significant if the resulting p-value was lower than 0.05 and categorized as weak with $R \geq 0.3$, moderate if $R \geq 0.5$ and strong if $R \geq 0.75$.

The usefulness was assessed using statistical mean difference analyses. Each the median of each MRP metric was used to divide the universe into two samples. Then, the samples were compared in each LPS variable. The normality of both samples was assessed, and the t-test was used to compare normal distributing samples, while the Mann Whitney's U test was used if any sample was not parametric. Both tests required a $p\text{-value} < 0.05$ to detect a statistically significant difference and the process was repeated using the 6 MRP metrics to assess differences in the 12 LPS indicators.

VALIDATION RESULTS

Figure 3 maps the relationships found between the SNA and LPS metrics. As observed, MRP collaboration is directly correlated to master plan and MRP performance metrics. Also, its impact is visible through the existing correlations between the complementary LPS metrics. Out of the 58 significant correlations found, 47 were weak, 6 were moderate and 5 strong, nevertheless, all correlations presented a statistical p-value<0.05. It must also be noted that the moderate and strong correlations were found only between PPC and PWC indicators. Table 2 presents the differences in LPS indicators (Tested KPIs) detected when splitting the sample using each the SNA indicators (Sampling KPIs). Each sampling KPI was used to divide projects into groups above and below the median, and then, the groups were tested to find statistically significant differences in their LPS indicators. The table shows the 17 statistically significant differences (23.6%) found, covering all LPS indicators, except the PWC Mean and the SPI.

Table 2: Statistically Significant Mean Differences

Sampling KPI	Tested KPI	Top group	Bottom group	Difference	p-value
Density	PCR Mean	66.1%	74.9%	-11.7%	0.037
Density	PCR Median	65.7%	78.9%	-16.8%	0.020
Degree	PPC Median	69.0%	77.1%	-10.5%	0.046
Centrality	PPC Mean	67.8%	74.9%	-9.4%	0.039
Centrality	PPC Median	68.7%	77.4%	-11.2%	0.032
Centrality	PPC STD	19.4%	16.4%	18.4%	0.028
Centrality	PPC CV	31.0%	22.9%	35.0%	0.004
Centrality	PCR Mean	64.8%	76.2%	-15.0%	0.006
Centrality	PCR Median	65.0%	79.6%	-18.4%	0.012
Centrality	PCR STD	25.8%	21.3%	21.0%	0.020
Centrality	PCR CV	42.6%	30.3%	40.6%	0.007
Centrality	PWC Median	82.8%	90.0%	-8.1%	0.044
Centrality	PWC STD	27.6%	21.2%	30.1%	0.014
Centrality	PWC CV	36.8%	25.3%	45.4%	0.003
Closeness	PCR Mean	65.6%	76.0%	-13.6%	0.013
Closeness	PCR Median	64.8%	80.7%	-19.7%	0.005
Components	PCR STD	27.0%	22.6%	19.2%	0.038

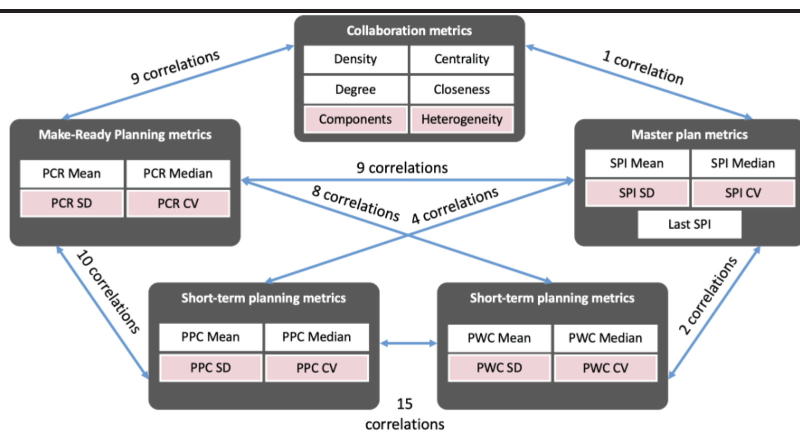

Figure 3: Correlations found Between MRP Collaboration and LPS Components

DISCUSSION

First, the results indicate that the methodology can detect relevant relationships between the 18 combined LPS and MRP indicators, as well as discovering potential impacts of MRP collaboration on LPS performance; thus, the artifact is deemed valid and provides answers to both research questions. Although most correlations found were weak, it must be noted that these were tested in a relatively small universe of case studies (68) and that the case studies presented significant variance regarding the number of tasks, constraints, DLPs, ILPs and, particularly, the number of terms registered, with half of the sample capturing between 15% and 41% of their scope. Nevertheless, the observed connectivity across all five LPS components, including the MRP collaboration poses a relevant opportunity for research that can lead to the discovery of key insights. This opportunity is also supported by the significant differences observed in LPS metrics obtained through the statistical sample comparisons.

On the other hand, it must be noted that all 17 statistically significant differences showed lower LPS indicators in the upper half of the MRP samples. These translate a potentially negative relationship between MRP collaboration indicators and LPS metrics, which must not be mistaken as a negative effect. For example, a greater number of components indicates a weakly connected network, thus, the decrease in compliance and increased variability observed are consistent with expectations. The same applies to the Closeness indicator, as a greater number indicates the necessity to go through more interactions to reach an average node. On the contrary, the network strength metrics degree and density showed relationships opposite to the expected. Authors assumed that higher density and degree would correlate to higher LPS indicators of compliance and lower variability, which was not the case. Two possible causes were inferred and should be addressed with subsequent research: The first, is that larger networks tend to be less connected. Thus, teams with less Last Planner involvement would reflect in higher network strength metrics, explaining the negative relation found between density, degree and the LPS indicators. The second is that, since the networks are weighted on the constraints to tasks ratio, a stronger network can indicate more constraints, leading to a more complex MRP process and difficulty to accomplish commitments. Finally, given that the results signal the need to further research the topic, the authors propose the continuation of this study, employing a larger sample with empirical schedule outcome indicators.

CONCLUSSIONS

This article proposed a methodology to quantitatively assess collaboration in the Make-Ready Planning process and its impacts on LPS performance, to help tackle the systematic deficiencies in MRP implementation, signalled as a gap by researchers. The authors used the DSR approach to match the current understanding of the problem with existing opportunities and designed an artifact capable of leveraging existing LPS information captured by IT support. The solution artifact employs six SNA indicators to assess MRP collaboration and complements with 12 LPS indicators to assess impacts on performance. Although the results showed mostly weak correlations between the LPS and SNA metrics used to capture MRP collaboration, the statistical differences analyses showed that when dividing projects using the SNA metrics, differences from 10% and up to 40% were found in their LPS metrics. These results allowed to validate the fitness of the methodology to identify key relationships among LPS components, captured in multiple indicators, as well as finding evidence of the impacts of MRP collaboration on LPS performance. Finally, the author acknowledge that the research should be expanded using a larger project sample with empirical schedule outcome indicators to assess its potential contributions to the state of art and practice in modelling and explaining LPS impacts on performance and the key role of MRP collaboration.

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