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LPS PERFORMANCE DIAGNOSIS MODEL USING FUZZY INFERENCE SYSTEM

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ABSTRACT

The Last Planner System (LPS) has long been used in construction projects to promote reliable planning and enhance productivity. However, despite various attempts to evaluate LPS implementation efforts, the human aspect of the evaluation attempts has not been given enough attention. This issue may be tackled through Fuzzy Inference Systems (FIS) to capture more information regarding the gradual and intricate changes in scoring systems. Therefore, this paper aims to offer a standardized diagnosis model for LPS performance in construction projects. This model employs an FIS that analyzes the results of an LPS implementation for a more accurate investigation of the implementation. First, a thorough literature review is conducted to select the most prominent factors influencing the LPS implementation process, followed by expert panel questionnaire development and distribution among LPS experts to rank the selected factors. The obtained questionnaire results are then used to develop the FIS. The objective of this paper is hereby twofold: (1) to allow assessing expected LPS benefits through the qualitative assessment of the performance in the four LPS phases, and (2) to facilitate comparing past, current, and future performances throughout the organization's LPS implementation process to ensure continuous improvement.

KEYWORDS

Last Planner® System, fuzzy logic, implementation evaluation, diagnosis model, design science research.

INTRODUCTION

Having sailed into the construction industry with proven perks and inarguable successes, Lean construction tools and techniques have substantiated their efficacy among construction practices during the past decade (Stevens 2014). Lean tools and techniques range from value stream mapping, supply chain management, Just-In-Time delivery, LPS, six sigma, and more (Hanna et al. 2010). Analogous to Liker's renowned "Company X" described in his pioneering book "The Toyota Way" (Liker 2004), countless firms claim to be Lean, proudly flaunting their "Lean" projects for demonstration. However, as various researchers have repeatedly asserted, genuine Lean implementation is being confounded with mere superficial Lean tool applications (Liker 2004).

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Being a widely adopted Lean system, LPS proved wide benefits ranging from 30% increase in productivity, 17% saving in project budget, and 20% decrease in project duration to improvement in overall labour performance (Fuemana et al. 2013). Various studies have addressed investigating LPS implementations across projects, organizations, and countries, such as developing an LPS implementation health check (Power et al. 2021) and quantitative analysis of LPS implementations (Bortolazza et al. 2005; Bortolazza and Formoso 2006). Moreover, a variety of studies presented frameworks for proper LPS implementation, even in virtual environments (Salhab et al. 2021). Amidst the abundance of studies tackling measuring and evaluating LPS implementations, the need for perceiving the factors about LPS implementation as "fuzzy" or of varying degrees of applicability rather than either available or unavailable is deemed necessary. One study by do Amaral et al. (2019) has already developed a Lean score that is calculated using averages based on FIS for Lean implementations in general. However, the body of research on LPS implementation still lacks a diagnosis approach through FIS which is specifically employed in examining the impacts of influencing factors' subjective assessment in construction modelling (Sarihi et al. 2021). There is also a paucity of studies proposing an inclusive model providing a step-by-step approach for diagnosing and systematically improving LPS performance.

Built upon the firm conviction that LPS may be perceived as the gateway to Lean behaviors (Fauchier and Alves 2013), this paper aims to offer a standardized diagnosis model for LPS performance in construction projects, forming the basis for future improvements. This model employs a fuzzy expert system that analyses the results of an LPS implementation for a more accurate investigation of the implementation. First, a thorough literature review is conducted to select the most prominent factors influencing LPS implementation process, followed by expert panel questionnaire development and distribution among LPS experts to rank the selected factors. The obtained questionnaire results are then used to develop the FIS. Using the developed tool, an internal evaluation of the factors allows first determining overall performance of LPS, and second highlighting which factors to address in order to realize better improvements in performance, since different factors affect LPS performance distinctively. The objective of this paper is hereby twofold: (1) to allow assessing expected LPS benefits through the qualitative assessment of the performance in the four LPS phases, and (2) to facilitate comparing past, current, and future performances throughout the organization's LPS implementation process to ensure continuous improvement.

LITERATURE REVIEW

The Last Planner System (LPS) is a production planning and control system directed towards providing foresight for better planning and for stabilizing workflow in construction through attacking uncertainty in operations (Hamzeh et al. 2008). LPS promotes reliable planning, measuring planning system measurement, improving production performance, learning from plan failures, and preparing scheduled tasks (Hamzeh et al. 2008). It comprises four main phases: Master Scheduling, Phase Scheduling, Lookahead Planning, and Weekly Work Planning (WWP) (Ballard and Tommelein 2016). The main steps advocated by LPS comprise planning in more detail when getting closer to perform the work, developing plans with those who will perform the work, identifying and removing constraints ahead of time, making reliable promises for executing the work, and learning from plan failures (Hamzeh et al. 2012). To achieve this study's objectives, previous studies on Lean, specifically LPS, and on FIS are discussed in the following sub-sections.

LEAN PERFORMANCE EVALUATION

Various studies have attempted to assess or evaluate Lean performance generally and LPS performance specifically in construction projects. One study recently addressed specious Lean implementations across construction firms by developing a Lean Culture Index that measures its Lean culture and its readiness to apply Lean (Kallassy and Hamzeh 2021). Their study found that among the surveyed construction companies, there was still room for improvement in some areas, including enhanced training and better human focus. Another study presented an analysis of the implementation of Lean Construction and an evaluation of the potentialities that three different previously developed calculation methods provided in the diagnosis process (do Amaral et al. 2019). It was found that all three methods used to estimate the level of implementation fulfilled their purpose. Similarly, Li et al. (2017) evaluated the extent of implementation of Lean Construction and explored the influencing factors of Lean Construction. They found that different firms have different implementation extents of Lean Construction. The key determinants of Lean Construction implementation are organizational structure, knowledge of Lean Construction, organizational culture, and market factors.

Zooming into the LPS, a guideline and implementation health check for LPS was proposed to evaluate the applications of all LPS functions through case study design and data collection (Power et al. 2021). They concluded that an implementation assessment tool must be utilized to sustain consistent LPS implementation across different projects. Another study conducted a quantitative analysis of the implementation of LPS (Bortolazza et al. 2005; Bortolazza and Formoso 2006). Their results indicated a major problem in most projects: the lack of effective implementation of look-ahead planning of the LPS. A study by Soares et al. (2002) has also proposed an "Implementation Efficacy Indicator", where a set of fourteen practices are subjectively evaluated in terms of full or partial implementation. Each practice is given a weight of either 1.0 (practice is largely used), 0.5 (practice is partially used), or 0.0 (practice is not implemented). From another perspective, other studies such as Pérez et al. (2022) aimed to determine the relationships between project performance and some LPS components by establishing twenty-three metrics to evaluate six components. They found statistically significant correlations between the six components and statistically significant differences between high and low performance through six of the metrics.

FUZZY INFERENCE SYSTEMS (FIS)

It has been argued that the human thought process holds in a degree of fuzziness translated through logic with fuzzy truths, fuzzy connectiveness, and fuzzy rules of inference instead of the two or multi-valued logic (Silva 2014). Fuzzy logic originates from the need to elude the rigidity of conventional Boolean logic that evaluates any statement as true or false, allowing a degree of truthfulness when measuring the extent to which an object is comprised in a fuzzy set (Cherkassky 1998). FIS is an important aspect of fuzzy logic, and it is simply defined as a system that performs non-linear crisp mapping described using fuzzy rules that encode common-sense or expert knowledge pertaining to the problem at hand (Cherkassky 1998). Fuzzy logic applications have gone beyond representing subjective concepts, partial truth statements, and uncertain meanings into modelling complex systems in a direct and plain linguistic way (Kulkarni, 2001).

Resorting to using fuzzy logic can be attributed to its ability to handle the input data's uncertainty and turn qualitative variables into quantitative ones (Abreu and Calado 2017).

Lately, rapid growth in various fuzzy logic applications has been seen in different industries, including construction. For instance, aiming to maximize the buffers' reliability to match the real degree of variation, Farag et al. (2010) presented a study integrating LPS with a buffering assessment model based on fuzzy logic. Results show a 14% increase in the master schedule's level of reliability and optimizing the buffer sizes, leading to a decrease in overall time wasted in buffers. Moreover, acknowledging the need for continuous assessment of management performance, Li et al. (2020) developed an analytic network process-fuzzy comprehensive evaluation model to help construction enterprises evaluate and improve their management performance of Lean construction. The results are reflected in evaluating factors such as Lean quality management, Lean safety management, Lean time, and cost management, etc. Likewise, the concern of evaluating an organization's Lean thinking environment is addressed by Abreu and Calado (2017) through fuzzy logic reasoning. The authors suggested a methodology that aims to provide the organization manager with information required for continuous improvement by identifying the organization's existing constraints. The method's advantage is that it can be adjusted to be used by any organization regardless of its size, nature, strategy, etc.

RESEARCH METHODOLOGY

Design Science Research (DSR) is commonly used as a research methodology for studies that tackle real-world problems by introducing a novel artifact (Hevner et al. 2017). In this study, the addressed problem is the improper, unsustainable, or ingenuine LPS implementation across construction projects. An LPS performance diagnosis tool is developed in order to tackle this issue. The tool is part of an inclusive LPS diagnosis tool employment model that is developed to ensure a proper and sustainable LPS implementation. This study is started with a thorough literature review to select the most prominent factors influencing the LPS implementation process. Once the factors are selected, an expert panel questionnaire is developed and distributed among LPS experts to rank the selected factors. The obtained questionnaire results are then used to develop the FIS using MATLAB.

TOOL DEVELOPMENT AND IMPLEMENTATION

FACTORS AND QUESTIONS SELECTION

In order to estimate the level of genuine and sustainable performance of the LPS, a survey consisting of 20 questions that tackle tangible and intangible factors is developed. These factors are directly related to the LPS through its different phases (Hamzeh et al. 2009), vital cultural aspects, and quantifiable metrics. Such an umbrella of areas covered through the factors allows the evaluation of a deep and authentic LPS implementation that may be sustained by considering long-term aspects that are repeatedly stated as vital for Lean cultures generally. The survey questions are divided into four main categories: Phase/Pull Planning, Lookahead Planning, Weekly Work Planning (WWP), and Post-WWP. Some of the questions address core LPS practices, including the process of identifying and removing constraints, preparing a realistic and achievable pull plan, measuring PPC, … etc. Other questions, however, address the aforementioned intangible factors that are essential for ensuring a proper Lean culture for a sustainable LPS implementation. They include collaboration during the process of removing constraints and making tasks ready, performing root cause analysis for missed commitments, deciding on preventive actions for proactive planning, incorporating lessons learned into future planning, etc. Table 1 shows the different questions divided into four different phases.

Table 1 – Survey Topics and Questions

Topic	Question
Phase/Pull Planning	How meaningful is the handoff process among supervisors? How effective is the process of identifying each task's prerequisites, successive tasks, and requirements? How effective is the process of identifying the "global" constraints that impact the whole process? How realistic/achievable is the pull plan that was developed? How would you describe the load in the developed plan compared to the crew's capacity (crewing process)?
Lookahead Planning	How effective is the process of identifying constraints and screening constrained tasks during lookahead planning? How effective is the process of removing constraints and making tasks ready during lookahead planning? How collaborative is the process of removing constraints and making tasks ready during lookahead planning? How sufficient is the time available between identifying and removing the majority of the identified constraints? How efficient is the process of releasing hold points within the teams?
Weekly Work Planning (WWP)	How efficient is the process of measuring PPC (PPC is recorded weekly and accurately)? How efficient is the process of identifying deviations from the plan? How efficient is the process of taking immediate corrective actions based on the deviations? How efficient is the process of performing root cause analysis (asking why a task was not done until u get to the root cause) for missed commitments? How efficient was the process of deciding on preventive actions i.e. actions to avoid future planning failures? How many tasks are newly added to the WWP and are not previously planned in the lookahead phase?
Post-WWP	How efficient is the "continuous improvement/variance" feedback process? How efficient is the process of communicating and learning from the performance of the previous week among team/organization members? How efficient is the process of incorporating lessons learned in the past into future planning? How many tasks that are newly added to the WWP & are not previously planned in the lookahead phase have you executed?

DATA PROCESSING THROUGH FUZZY LOGIC

The two main players in this process are decision-makers and experts. The decision makers rank the importance of each sub-factor with respect to each main factor (LPS phase). The experts evaluate each sub-factor, i.e. assess its implementation in the project. The data processing methodology entails six main steps shown in Figure 1.

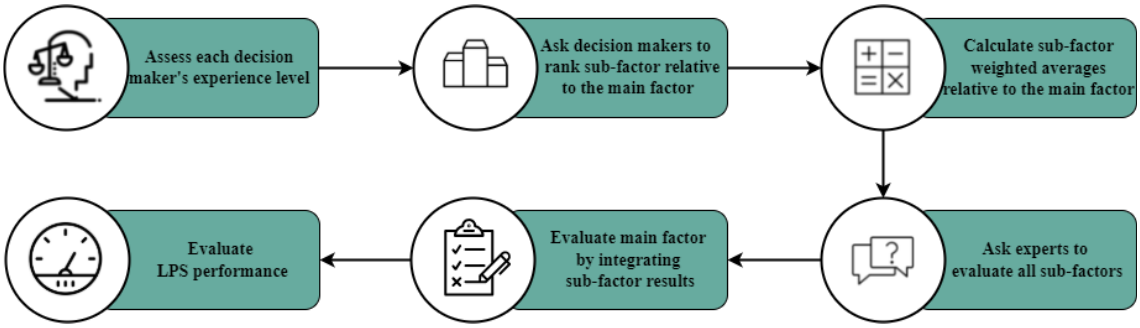
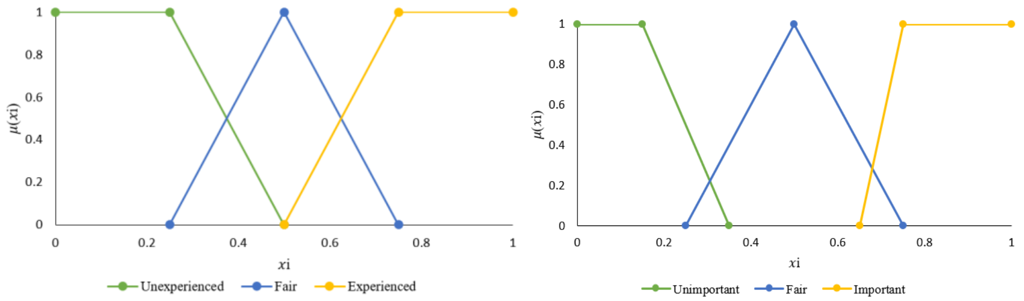


Figure 1 – Fuzzy Logic Data Processing Steps

As a first step, each decision-maker is assessed by linguistic terms (Unexperienced, Fair, or Experienced). Once the labels of the decision-makers ($\widetilde{w}_i$) are identified, decision-makers provide their judgment on the importance (Least Important, Less Important, Average Importance, More Important, or Most Important) of each sub-factor ($\tilde{r}_{ij}$) relative to the main factor, where $\tilde{r}_{ij}$ is the fuzzy linguistic assessment of factor j by decision-maker *i*. Figure 2(a) presents the membership function of linguistic terms for decision-makers' experience level and Figure 2(b) depicts the membership functions for factors rating. In both fuzzy sets, the x-axis (experience level for the first set and importance level for the second set) is a rating from 0-1. The evaluation can also be done using predefined qualitative expressions instead of the 0 to 1 scale. To develop the membership function of decision-makers' experience level, the range of experience is standardized (by dividing it by 40) to fit into a rate between 0-1, and membership grades are identified using the modified horizontal method.



(a) (b)

Figure 2 – Plots representing the membership function of (a) the linguistic terms for decision makers' experience level and (b) factors importance rating

When the linguistic assessment is completed, the weighted average for the importance of each factor is calculated (Dong and Wong 1987). A fuzzy number is calculated using fuzzy arithmetic that defines the overall evaluation for each factor of the assessment process. Equation 1 is used for the evaluation of the factors.

$$I_j = \frac{\sum_1^n \widetilde{w}_i \times \tilde{r}_{ij}}{\sum_1^n \widetilde{w}_i} \quad where\ j = 1,2,\dots,m \qquad \text{Equation 1}$$

Once the weighted average of each factor is calculated based on the experience level of the decision-maker and the provided ratings for the factors, the fuzzy memberships are converted to crisp values by using the center of area defuzzification method (Patel and Mohan 2002). The center of area is calculated using Equation 2. This number shows the importance of each subfactor in the evaluation of its main factor.

$$CA = \frac{\sum_{i=1}^n \mu(x_i).x_i}{\sum_{i=1}^n \mu(x_i)} \qquad \text{Equation 2}$$

An FIS is then used to evaluate LPS performance. Last planners, referred to here as the experts, are asked to fill out the survey by evaluating all sub-factors as ratings from 1 to 10. As it is a rule-based approach, a set of rules must be defined for the model. The formula used for the number of fuzzy rules is the number of membership functions raised to the power of input variables. To simplify the process and to avoid having many rule definitions in the model, rule blocks are used. In this method, instead of using all the sub-factors to predict the performance, the sub-factors are only used to identify their effect on the main factor. For example, the Lookahead phase factor is evaluated by integrating all 5 questions related to this phase. For example, if there are 10 input variables with 3 different membership functions, the number of rules needed would be 3^{10}. However, if the 10 input variables are clustered into two rule blocks, the number of rules needed would be 3^5 for each rule block and 3^2 for aggregating the clusters. This method helps reduce the number of rules considerably. The rule blocking process is shown in Figure 3.

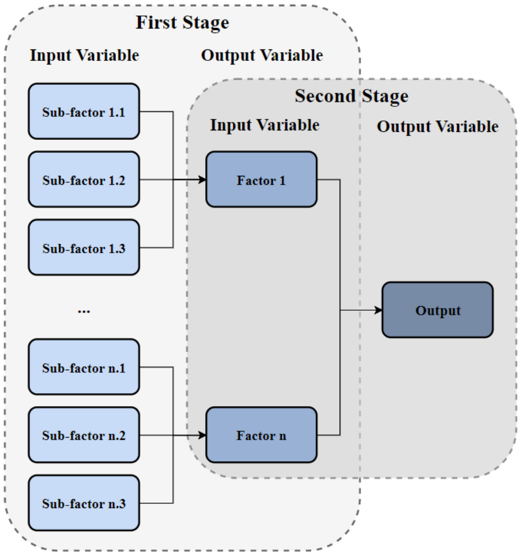
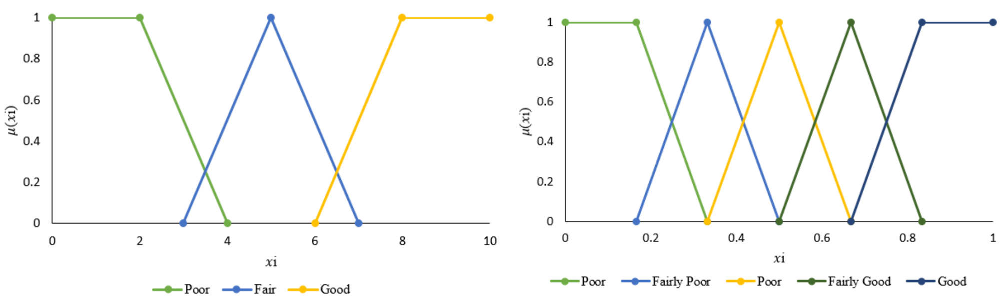


Figure 3 - The general structure of the proposed fuzzy expert system

Finally, the effect of the main factor will aid in evaluating the LPS performance. The input variables for this step have the fuzzy set of x_i and the output variable of y. The input variables are measured on a scale of 0 to 10, which is divided into 3 linguistic terms: Poor, Fair, and Good. Membership values are assigned to each linguistic term between 0 to 1 and are identified using modified horizontal method. The output variable is measured on a scale of 0 to 1, which is divided into 5 linguistic terms: Poor, Fairly Poor, Fair, Fairly Good, and Good. The output variable for this set represents the LPS performance. In Figure 4(a) and Figure 4(b), the membership functions of these variables are shown.



(a) (b)

Figure 4 - The membership functions of (a) inputs and (b) outputs

In this study, to define the fuzzy rules, scores of 1, 2, and 3 are given to the term's evaluation Poor, Average, and Excellent. When a rule is defined, the weighted average of the scores is calculated and compared to the predefined value that relates to the conclusion.

TOOL IMPLEMENTATION & DISCUSSION

To ensure proper and sustainable LPS implementation within an organization, practitioners can follow the model represented in Figure 5. After using the developed tool and obtaining LPS performance result as an output, users who employ this model for the first time must analyse different possible alternatives to enhance their LPS implementation performance. Such alternatives may include training, workshops, seminars, change in supplier choice, and readjustment of the process. Afterwards, trade-off analysis is performed. Trade-off analysis entails assessing and evaluating the outcomes of the different scenarios including the analysed alternatives. Once the trade-off analysis is performed, improvements that have been decided on must be implemented. Afterwards, the tool is used again to obtain a new LPS performance result. The second round or iteration entails comparing the current performance with the past performance. If an improvement in performance is observed, the current LPS implementation protocol must be maintained with continuous improvement to ensure its sustainability. Users must then continue using the LPS diagnosis tool to monitor and control their implementation performance. However, suppose the comparison between current and previous performance did not improve. In that case, the team's LPS implementation protocol must be re-established by incorporating core LPS principles, including key cultural aspects such as sharing rewards and failures, learning from failures, taking preventive measures, etc. Once a proper LPS implementation protocol is put into place, the LPS diagnosis tool is again employed to evaluate the new protocol's efficiency.

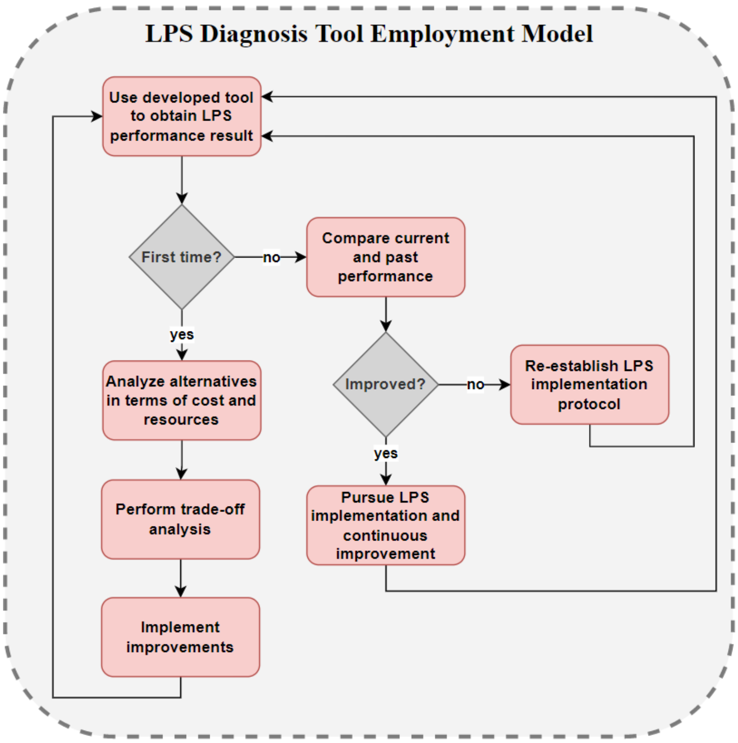


Figure 5 – LPS Diagnosis Tool Employment Model

EXPERT PANEL QUESTIONNAIRE CONDUCTION

The survey entails collecting LPS experts' ranking of the importance of the factors. The number of years of experience in LPS plays a vital role, where the higher the number of years, the more weight is given to expert's response. This part answered by three renowned academics and practitioners with sufficient experience in LPS. The number of years of experience in LPS was 12, 16, and 20 years. Two of the participants were academics with sufficient practical experience in LPS, while one participant was an experienced Lean facilitator and practitioner.

ANALYSIS

The important point about FIS is the need for calibrating the membership functions for each company and project. As the defined thresholds can be tighter or wider, in other words, what is deemed as a poor performance for a company may be a fair one for another company. Therefore, the evaluation that is done with the model should be used as a baseline for future reference and any comparison is a relative evaluation. In order to verify the developed tool, various scenarios with different values for each subfactor are randomly generated. Table 2(a) refers to the Phase/Pull Planning phase, Table 2(b) refers to the Lookahead Planning phase, Table 2(c) refers to the Weekly Work Planning phase, while Table 2(d) refers to the Post-WWP phase. The last column in each table shows the overall evaluation for the relevant phase. Only critical scenarios – highlighted in red - and other random ones were selected for comparison. As shown in Table 2(a), RPP5 is given a high score of 98 in the highlighted row. However, this value doesn't yield a good overall phase result, where RPP score is 50. This score is considered fair according to the developed model. The reason behind this result is the LPS experts' subfactor rankings, where RPP5 is given the lowest weighted fuzzy average among this phase's subfactors. It can also be noted that RPP3 with a score of 4, has the highest weighted fuzzy average, which influences the overall phase result for the mentioned scenario. Table 2(b) shows that the same phase performance score, a score of 50 for LP for instance, can be reached through different combinations of factor performance. This implies that even if efforts are exerted to enhance one aspect of a phase, if other factors are not considered, the outcomes might not be rewarding. Furthermore, each factor has different importance relative to the phase it belongs to. Therefore, careful decisions must be made when seeking performance improvements. As for Table 2(c) representing the Weekly Work Plan phase, the highlighted scenario yields highest WWP score (76), despite a low WWP6 score (35). This result may be attributed to low WWP6 LPS expert ranking, which decreases WWP6's influence on the overall phase result. An opposite case observed is the highlighted scenario in Table 2(d), which yields lowest overall PWWP result (20.5), even though PWWP4 is given a relatively high score of 79 and the lowest LPS expert ranking among other subfactors.

Among all randomly generated scenarios, the worst, best, and average cases are represented in Table 3. The numeric LPS result is calculated by de-fuzzifying the results obtained from integrating the results from the developed models for each phase. These numeric results are then translated into linguistic terms according to the specified membership functions in the developed FIS. The expert panel members performed face validation to confirm the reliability and efficiency of the developed model. Further validation may be performed by practitioners implementing the LPS on construction projects as part of a case study.

Table 2 – Scenario Results for (a) Phase/Pull Planning, (b) Lookahead Planning, (c) Weekly Work Planning, and (d) Post-WWP

RPP1	RPP2	RPP3	RPP4	RPP5	RPP
1	1	1	1	10	16.5
3	3	2	3	64	24.5
6	9	4	9	98	50
5	8	7	9	35	76.5
9	9	9	9	90	83.5

(a)

LP1	LP2	LP3	LP4	LP5	LP
1	1	1	10	1	16.5
8	5	2	15	7	50
7	9	6	47	3	50
1	5	6	22	9	50
8	5	3	38	9	50
9	9	9	90	9	83.5

(b)

WWP1	WWP2	WWP3	WWP4	WWP5	WWP6	WWP
3	5	1	2	6	68	22.5
3	7	1	3	6	97	24
3	9	8	8	4	88	50
7	9	1	6	4	35	76

(c)

PWWP1	PWWP2	PWWP3	PWWP4	PWWWP
5	1	1	14	16.5
1	3	1	79	20.5
4	5	4	68	50
9	8	1	99	83.5

(d)

Table 3 – Final LPS Performance Results for 3 Scenarios

RPP	LP	WWP	PWWP	Numeric LPS Result	Linguistic LPS Result
16.5	24	22.5	20.5	11	Poor
76.5	50	50	20.5	50	Fair
83.5	83.5	76	83.5	66.5	Fairly Good

CASE STUDY

In order to validate the developed tool, a case study is conducted through a contracting company, where LPS was being implemented on a project. As the case is in the first stages of the implementation it can be considered as an illustrative example to present the application of the proposed tool; in later stages of the implementation, the results can be used to validate the model. LPS implementation included technical, practical, and cultural aspects. Technical facilitation included employing a software application providing a cloud-based solution supporting Lean production planning. It may be downloaded on computers, phones, or tablets, allowing for easy-to-access and real-time updates directly from the site. The company adopted the software's usage, and software developers adjusted some of the software's features to accommodate the company's needs. Cultural implementation of LPS called for adequate introduction of key project participants to LPS. Such introduction included carrying out training sessions led by LPS experts, inviting participants to attend a short online conference on LPS, and promoting some LPS concepts such as continuous improvement, learning from failures, performing root cause analysis, and planning proactively. Finally, practical implementation entailed applying LPS principles and practices, including the four major phases of LPS, reliable planning, appropriate identification and removal of constraints, and proper documentation of reasons for non-completion/noncompliance. Two out of the phases included in the developed survey were validated through project participants in this company, as the project is still in its early stages. The two phases were the Lookahead Planning phase and Phase/Pull Planning phase. The remaining two phases will be validated by conducting the second part of the survey in the upcoming weeks as part of a future research study for an all-inclusive tool validation.

CONCLUSION

Proper implementation of Lean concepts is crucial for successful implementation of LPS in construction projects. Although various studies have already tackled the issue of healthy implementation of Lean construction, no study has been found to present a generic LPS diagnosis model. Therefore, this study presents a novel artefact for standardizing LPS diagnosis process across the industry. Aiming at achieving this objective without holding the potential of excessive subjectivity, the study employs FIS to analyze experts' and practitioners' opinions on the state of various factors influencing each phase in LPS. First, a list of factors influencing LPS phases is developed based on extensive literature. Then, an expert panel questionnaire is conducted to evaluate the importance of each factor relative to the phase it belongs to. Afterwards, an FIS model is developed and randomly populated as part of the model verification process to simulate LPS performance based on different potential scenarios of factors' performances. A brief discussion of obtained results is finally presented. The developed tool can be used to evaluate the LPS implementation in the project and find the best areas to focus on, regarding the constraints of the project. Therefore, the decisions made by using this tool are project and company-specific and should be compared to the baseline conditions of their LPS performance. This study lays the cornerstone for further research, where more accurate calibrations of the outcomes' membership functions may be studied. This may help in enhancing the performance of the developed tool in diagnosing the LPS implementations. Further research can also include giving different weights to the four phases of LPS, based on criticality of each phase. For example, Post-WWP phase may be given the highest weight due to the included concepts such as learning from failures and continuous improvement, which can influence the overall LPS implementation outcome. Finally, recommendations for improving implementation performance may be suggested.

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