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PLANNED PERCENTAGE COMPLETED IN CONSTRUCTION – A QUANTITATIVE REVIEW OF LITERATURE

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ABSTRACT

Although several systematic literature reviews have focused on the Last Planner® system (LPS) and lean construction, few reviews have focused solely on the planned percentage completed (PPC) value. In this light, the present quantitative literature review aims to synthesize individual PPC-related studies from around the world. The research data consisted of 36 peer-reviewed research articles and conference papers published between 1998 and 2021; in these, PPC values were presented such that they could be collected and analyzed quantitatively. As a main finding, a statistically significant difference was observed between the mean PPC values presented in studies published in lean-focused journals and other peer-reviewed journals. The mean PPC values published in lean-focused journals were lower than those published in other peer-reviewed journals. This may indicate that results with higher PPCs are selected for other peer-reviewed publications; therefore, a potential publication bias should be investigated further. The study also revealed mean PPC values over time and geography, thereby enabling an evaluation of the construction industry's global progress by using PPC values as a benchmark.

KEYWORDS

lean construction, last planner, planned percentage completed (PPC), literature review.

INTRODUCTION

The Last Planner® system (LPS) is a planning system that has been developed in lean construction. Unlike in traditional scheduling, LPS emphasizes the role of the "last planner," namely, the foreman (or last person before task execution) who is as close as possible to the task, in production planning (Ballard, 2000). According to Ballard (2000), the key to the production planning system is a good definition of the task, selection of the right work order and workload, and reasonableness of the work task chosen to be implemented (i.e., can it and should it be done?). Planned percentage completed (PPC) is a quantitative measure calculated as the number of planned activities executed divided by the total number of planned activities. According to Ballard and Tommelein (2016), the PPC value used in the LPS is considered a measure of workflow reliability, a measure that correlates with productivity and project progress, and a measure of a team's ability to reliably plan and execute work. PPC is also often considered a visual illustration of the reliability of the promises made by the project parties to each other (Koskela *et al*., 2010).

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Researchers broadly agree that the key to measuring the PPC in LPS is the measurement of the reliability of the parties' promises (Howell *et al*., 2004; Fauchier & Alves, 2013). The PPC value is often used in research and practice related to LPS and lean construction, although a holistic examination of PPC values in individual studies is limited. Aslam *et al*. (2020) conducted an extensive literature review of LPS-related studies between 1992 and 2019 and presented mean PPC values from 16 cases. Based on these case studies, they estimated that the average PPC value is approximately 68%, and they stated that this was below their expectations. Accordingly, they proposed that finding and removing the main barriers in LPS would improve the PPC. Singh and Kumar (2020) reviewed literature from 2008 to 2018 focusing on tools and methods of lean construction but collected no PPC information. Babalola *et al*. (2019) reviewed lean construction literature from 1930 to 2018 with a focus on lean construction practices and identified PPC, although they did not collect any related evidence. Fernandez-Solis *et al*. (2013) conducted a systematic literature review of 26 case studies from 2000 to 2009 that focused on how practitioners have used LPS methods, although they did not collect any PPC values.

Although some studies have focused only on the PPC, this systematic literature review of LPS and PPC shows that a more comprehensive sample of research papers that present the PPC value is possible. This study differs from previous ones in that it analyzed PPC from a larger set of articles and over a longer period. In addition, it aimed to take a meta-view by comparing PPC between journals focused on lean and other peer-reviewed journals. We also assessed the geographical differences in PPC in our study. Most similar studies, such as that by Aslam *et al.* (2020), focused on the project-specific PPC as a single value but not on its variation over the course of the study; the present study highlights this point more explicitly than previous studies did. Because the PPC is a fundamental metric in the use of LPS, this study systematically explores a substantial number of studies that presented PPC values and presents a broad view of PPC values recorded worldwide and over time.

METHODS

The heterogeneity of the published research and the prominence of case studies in LPS research hinder the use of statistical analysis, such as meta-analysis. Instead of using statistical analysis, a quantitative literature review that is applicable to incoherent research data was chosen as the research method (Pickering & Byrne, 2014). In this method, the results of individual studies are combined to focus on finding similarities, differences, or other interesting findings that are not visible in individual studies but are observable from the combined set of several studies. However, because the PPC is a number, these differences are analyzed and discussed in this study mainly from a quantitative viewpoint.

The search strategy was primarily aimed at LPS-related studies, because information related to the PPC, which is the focus of this study, was assumed to be found in these studies. Therefore, the Last Planner System alone was used as a search term. Notably, the term "PPC" is also used in cancer research and is a common abbreviation for "production planning and control"; therefore, PPC as a search term would have produced many incorrect and unnecessary search results. In this light, first, the search term "Last Planner System" was used, and then, papers with the PPC values of the method were screened. The researchers searched for LPS-related studies in two research databases: Scopus and Google Scholar. Information was collected between 2020 and 2022, first as separate targeted search events and later using the continuous alert functionality of the Scopus database. Data were collected using the search term "Last Planner" and 551 research articles, review papers, books chapters, and books were identified. The researchers downloaded the papers to which they had either open access or access through the university's library service (including paywall journals). The literature search strategy is presented in Figure 1.

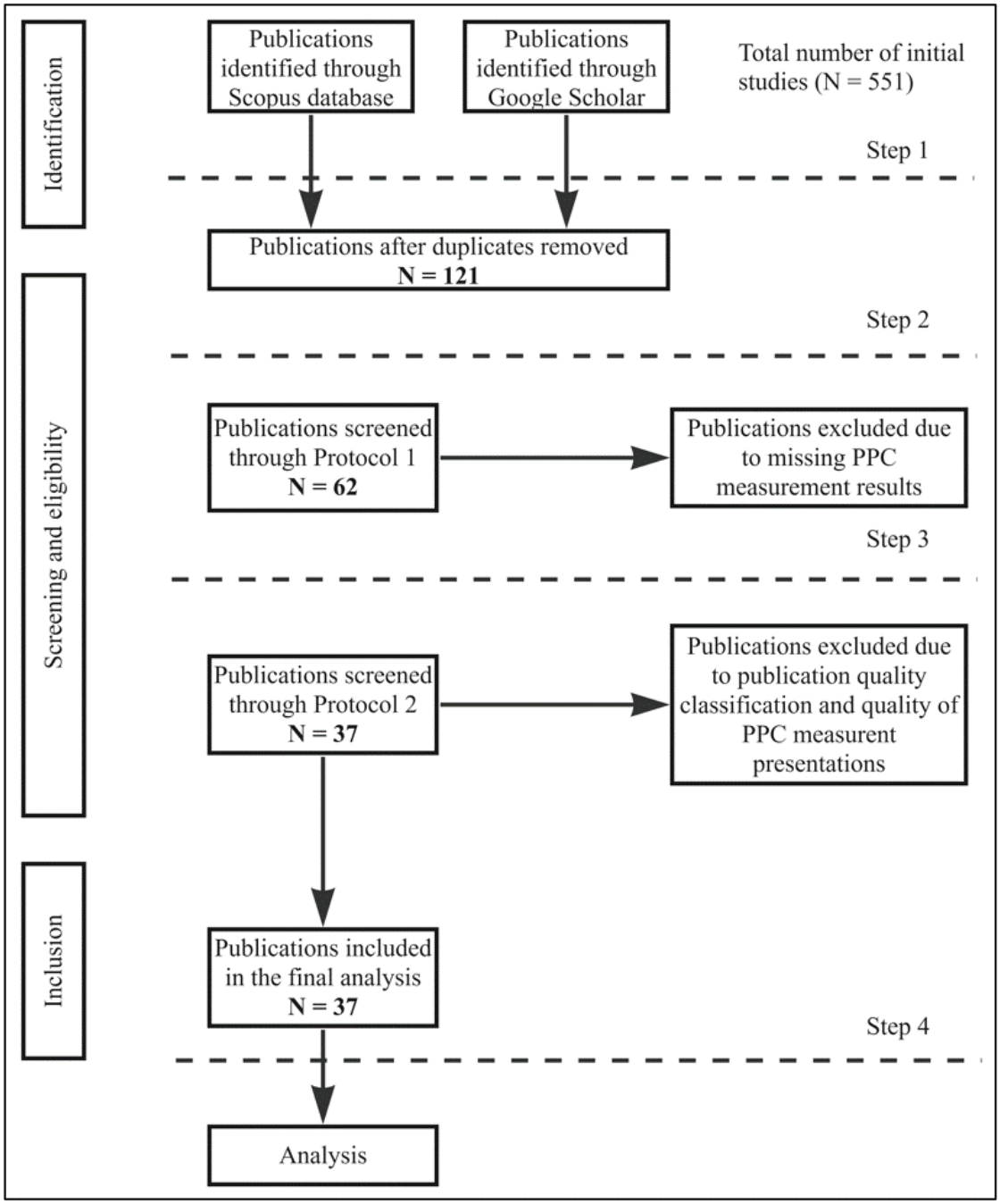

Figure 1: Literature search strategy.

In the first screening step, the researchers included only research articles and conference papers while also removing possible duplicates from different databases. Therefore, no book, part of a book, guidebooks, or industry reports about LPS were included. In the first step, 121 articles were processed. In the second step, the researchers scanned the research articles and searched for articles in which PPC values were presented in text, tables, or graphs; 62 such articles were found. In the third step, the researchers focused on the quality of the research and determined whether the research results were genuine results from actual case studies, action research, or runs from various project databases. All simulations, theoretical modelling, and design-related articles that included PPC results were also excluded. The quality of the study results was screened in this context, from which factors such as low-quality figures and tables or

insufficient data were unclear. At this stage, articles that had been published in predatory journals were also excluded. After these screening steps, 37 peer-reviewed research articles and scientific conference papers were included in the final analysis.

In the analysis phase, basic information was collected from the research articles, such as the names of the authors, journal, and publisher; year of publication; country in which research data were collected; research method; and category to which the publication belonged. Two categories were defined: articles published in lean-specific scientific journals or peer-reviewed conferences and articles published in other peer-reviewed journals in the construction industry. Numerical data related to PPC were also collected from the articles, such as the mean, maximum, and minimum PPC values and their standard deviation. Regarding the duration of measurements of PPC values, we collected the number of PPC data points and the duration of the data collection process (in weeks). Information was collected from the text, tables, and figures of the articles. Data were stored and analyzed using Excel spreadsheets and Minitab 19 statistical software.

FINDINGS

The articles selected for the study are presented in Table 1. For each study, this table lists the mean (MeanPPC), maximum (MaxPPC), and minimum (MinPPC) PPC values and their standard deviation (StdPPC) as collected in the original study or calculated by the authors of the present study. For each study, the research method, geographic location, and information source were also collected (i.e., whether the PPC value was obtained from the text, tables, or figures of the study). In the table, the studies are presented in chronological order, and whether the study belongs to lean-focused publications ("LFB") or other peer-reviewed publications ("Other") is shown on the left-hand side next to the code. The code is a unique identification number (e.g., "33") assigned to a single study at the beginning of the study, and it contains subnumbers (e.g., "51.1") if the study has several cases in which a PPC value is presented. The abbreviation "Dat" implies the number of data points in the table (i.e., number of PPC measurements presented in the study), and the abbreviation "Dur" implies the duration of the study in weeks.

Table 1. Reviewed articles and research data.

Code	LFB	Other	Mean PPC	Max PPC	Min PPC	Std PPC	Dat.	Dur.	Method	Country	Data type	Reference
33	X		84.8	100.0	75.0	8.4	9	9	Case study	Brazil	Figure	Junior *et al*., 1998
51.1		X	64.1	86.0	44.0	12.3	11	11	Dissertation	USA	Table & Figure	Ballard, 2000
51.2			57.1	71.0	46.0	8.1	10	10				
51.3			75.5	100.0	25.0	20.3	41	41				
51.4			84.0	93.8	51.3	8.8	27	27				
51.5			87.8	100.0	60.0	13.1	19	19				
43	X		61.0	N.A.	N.A.	N.A.	1	N.A.	Action research	Chile	Figure	Alarcón *et al*., 2002
36	X		77.4	88.0	63.0	7.2	10	2	Work sampling	USA	Text & Figure	Chitla & Abdelhamid, 2003
47	X		70.0	N.A.	N.A.	11.4	N.A.	N.A.	Data mining	Brazil	Table	Bortolazza *et al*., 2005
58.1	X		75.3	N.A.	N.A.	N.A.	3	12	Case study	South Korea	Text	Kim & Jang, 2005
58.2			74.0	N.A.	N.A.	N.A.	3	12				
60		X	64.0	90.0	40.0	16.5	11	11	Case study	USA	Figure	Beary & Abdelhamid, 2005
89	X		75.3	95.6	44.0	15.6	20	20	Case study	USA	Figure	Salem *et al*., 2005
65	X		70.4	93	38	11.99	N.A.	N.A.	Data mining	Brazil	Table & Figure	Bortolazza, & Formoso, 2006
93		X	76	N.A.	N.A.	N.A.	N.A.	N.A.	Case study	USA	Text	Salem *et al*., 2006
108.1	X		64.5	90.0	40.0	16.5	11	11	Case study	Not mentioned	Figure	Beary & Abdelhamid, 2006
108.2			76.1	100.0	48.0	16.8	9	9				
57	X		68.6	80.0	54.0	9.0	24	24	Case study	Not mentioned	Figure	Jang & Kim, 2007
81	X		51.1	62.5	33.3	9.4	13	13	Case study	Chile	Table & Figure	González *et al*., 2007
16.1	X		86.3	100.0	63.0	8.3	53	53	Case study	Not mentioned	Figure	Jang & Kim, 2008
16.2	X		84.0	100.0	65.0	8.6	53	53				
96	X		76.3	100.0	23.0	18.6	71	71	Case study	Not mentioned	Figure	Liu & Ballard, 2008
23.1	X		81.7	100.0	69.0	6.7	18	18	Case study	Saudi Arabia	Figure	AlSehaimi,*et al*., 2009
23.2			74.3	83.0	42.0	10.4	17	17				
55	X		76.03	100	22.14	N.A.	N.A.	N.A.	Data mining	Brazil	Table	Formoso & Moura, 2009
83	X		60.8	87.5	23.0	19.1	13	13	Action research	Norway	Figure	Kalsaas, *et al*., 2009
100.1	X		51.4	90.0	20.0	17.2	36	36	Case study	Not mentioned	Figure	Olano *et al*., 2009
100.2			66.2	90.0	27.0	16.8	37	37				
106	X		78	N.A.	N.A.	N.A.	N.A.	N.A.	Case study	Finland	Text	Seppänen *et al*., 2010
14	X		67.0	93.0	56.0	7.1	33	33	Data mining	Chile	Figure	Alarcón *et al*., 2005
45		X	75.6	100.0	0.0	20.5	106	106	Case study	USA	Figure	Liu *et al*., 2011
21	X		89.4	98.0	70.0	8.7	10	10	Action research	Nigeria	Figure	Adamu & Howell, 2012
42.1	X		71.9	N.A.	N.A.	16.9	N.A.	N.A.	Case study	Not mentioned	Table & Figure	Alarcón & Zegarra, 2012
42.2			68.7	N.A.	N.A.	20.9	26	26				
42.3			57.7	N.A.	N.A.	23.5	N.A.	N.A.				
42.4			56.1	N.A.	N.A.	34.1	N.A.	N.A.				
42.5			58	N.A.	N.A.	17.8	18	18				
104.1	X		72.6	92.0	55.0	8.1	28	56	Case study	USA	Figure	Hamzeh *et al*, 2012
104.2			77.7	100.0	51.0	15.5	23	46				
18	X		83.2	100.0	32.0	15.8	29	29	Case study	Peru	Figure	Rosas, 2013
71	X		75.1	100.0	40.0	15.3	22	22	Design science research	Nigeria	Figure	Ahiakwo *et al*., 2013
75	X		87.4	95.0	75.0	3.8	50	50	Case study	USA	Table	Hamzeh,& Aridi, 2013
78.1	X		58	N.A.	N.A.	N.A.	17	17	Case study	Peru	Table	Pereira *et al*., 2013
78.2			50.6	N.A.	N.A.	N.A.	17	17		Portugal		
102.1	X		71.9	N.A.	N.A.	16.9	26	26	Case study	Peru & Chile	Table & Figure	Zegarra & Alarcón, 2013
102.2			68.7	N.A.	N.A.	20.9	26	26				
102.3			57.7	N.A.	N.A.	23.5	26	26				
102.4			56.1	N.A.	N.A.	34.1	26	26				
102.5			58.0	N.A.	N.A.	17.8	26	26				
73.1		X	82.1	100.0	68.0	7.2	18	18	Action research	Saudi Arabia	Figure	AlSehaimi *et al*., 2014
73.2			73.9	85.0	43.0	10.1	18	18				
94	X		62.7	81.0	40.0	11.6	19	19	Case study	India	Figure	Vaidyanathan *et al*., 2015
50	X		43.7	76.0	17.0	15.1	30	38	Case study	Marocco	Figure	Hicham *et al*., 2016
59.1		X	61.5	81.0	33.0	12.4	36	36	Case study	Finland	Figure	Sacks *et al*., 2017
59.2			94.4	100.0	82.0	5.1	19	19		USA		
59.3			93.9	99.0	87.0	3.1	19	19		USA		
59.4			86.5	95.0	80.0	3.3	19	19		Finland		
68.1		X	54.4	89.0	0.0	23.0	10	10	Dissertation	UK	Figure	Daniel, 2017
68.2			82.0	99.0	47.0	11.8	20	20				
30		X	78.0	100.0	15.0	19.1	21	21	Action research	Finland	Figure	Elfving, 2021
121		X	80.7	100.0	61.0	9.1	110	113	Design science research	USA	Figure	Hamzeh *et al*., 2019

The reviewed studies were published between 1998 and 2021. The highest number of studies in which PPC values are presented (26 out of 37) were published between 2005 and 2013. Geographically, the reviewed articles containing PPC values were mainly from South and North America and Western Europe. Africa and Asia accounted for three and four studies, respectively. Further, no studies were from large regions such as China, Russia, Australia, Canada, and Central and Eastern Europe. The geographical locations in which the reviewed articles were published are shown in Figure 2.

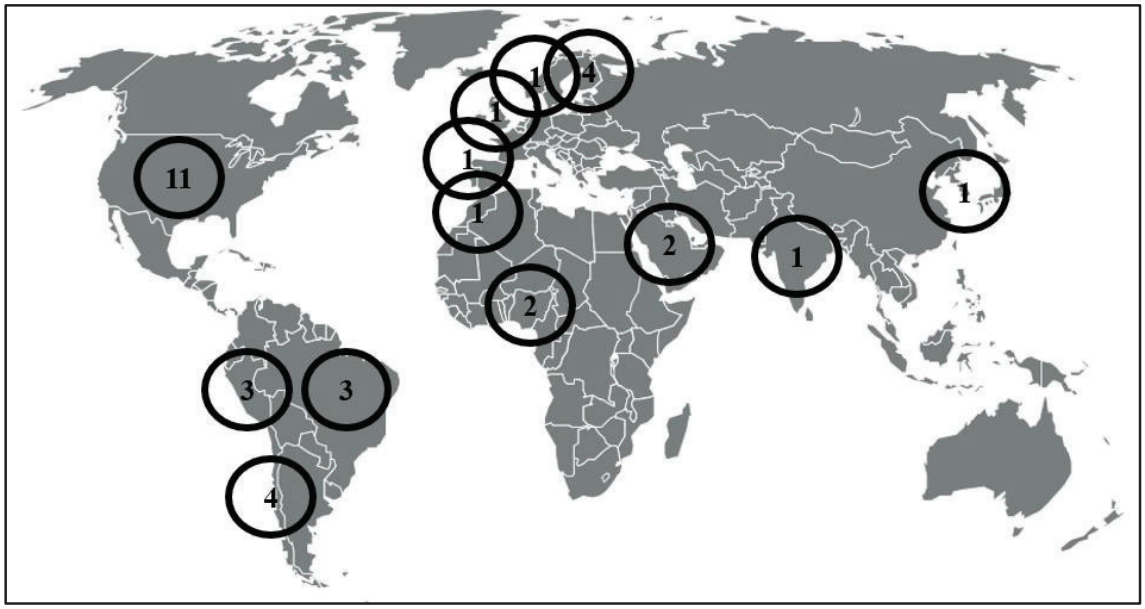

Figure 2: Geographical locations in which reviewed articles were published.

PPC measurements were performed for an average duration of 28 weeks, and the longest study lasted for 113 weeks. The average of all mean PPCs was 71.3%. The average mean PPC was 69.2% in lean-focused journals and 76.2% in other peer-reviewed journals. No significant development trends or patterns were observed in PPC values over time. Figures 3 and 4 show the mean PPC values of articles published in lean construction journals and other peer-reviewed journals, respectively. In these figures, the larger solid black dot indicates the mean PPC of each study, and the smaller dots indicate other measurement results such as the distribution of PPC in each study. Studies showing only a solid black dot only contain mean PPC data and lack other metrics. The horizontal axis of the figure shows the studies identified by code number in chronological order.

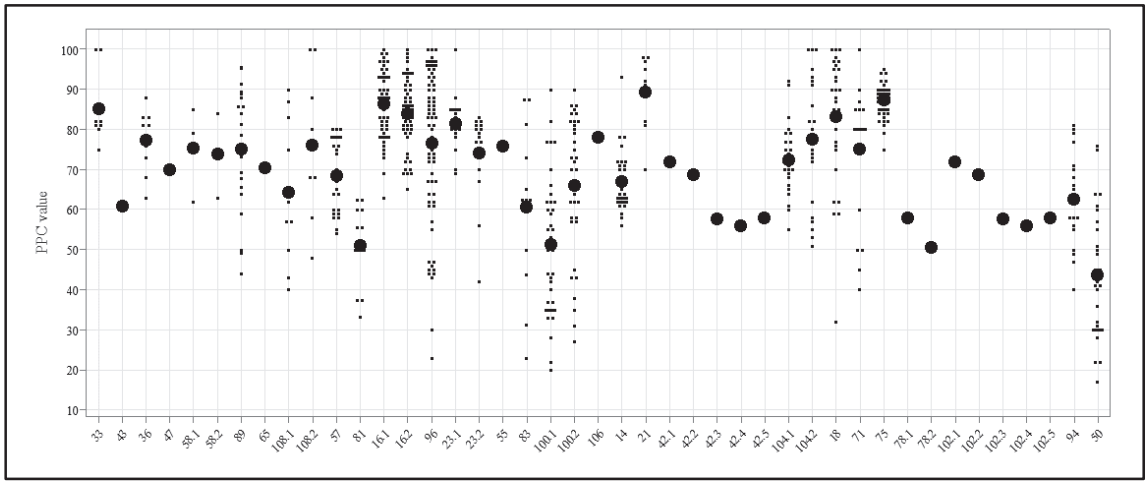

Figure 3: PPC values of articles published in lean construction journals.

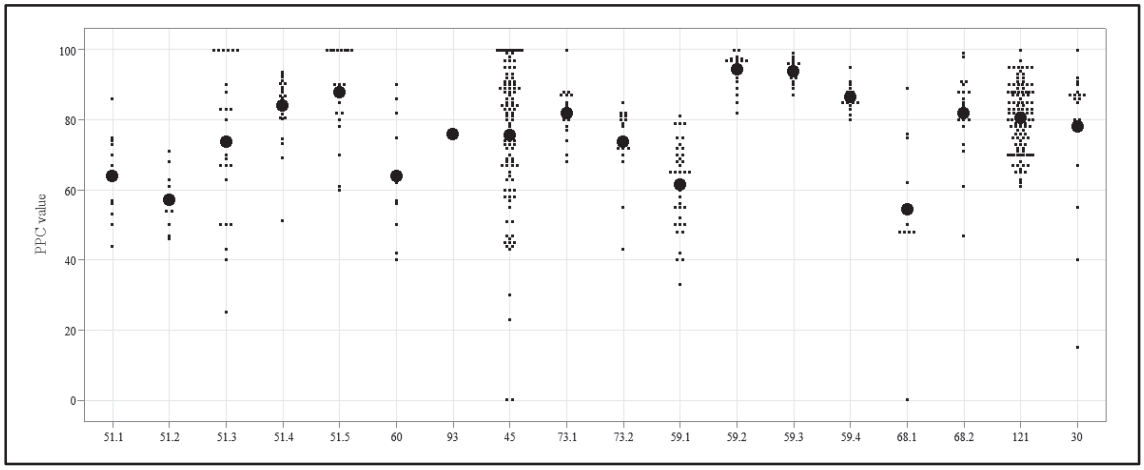

Figure 4: PPC values of articles published in other peer-reviewed journals.

The mean PPC seemingly differed between lean-focused journals and other peer-reviewed journals. Therefore, the researchers first verified that the PPCs of both groups were normally distributed. The fact that they were meant that they could subsequently analyze these two groups using the analysis of variance (ANOVA) method. The ANOVA revealed a statistically significant difference between the groups. The ANOVA results are shown in Table 2.

Table 2: ANOVA results.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	618.7	618.7	4.79	0.033 < 0.05
Error	59	7627.0	129.3		
Total	60	8245.7			

Factor	N	Mean	StDev	95 % CI
PPC Mean of lean-focused journals	43	69.20	11.16	(65.73; 72.67)
PPC Mean of other peer-reviewed journals	18	76.18	11.86	(70.82; 81.54)

Pooled StDev = 11.3697

Source = source of the variation in the data, DF = degrees of freedom, Adj SS = adjusted sum of squares, Adj MS = adjusted mean sum of squares, N = total number of PPC observations per group, StDev = standard deviation, CI = confidence interval.

One-way ANOVA revealed a statistically significant difference in PPC between the two publication groups, with an F-value of 4.19 and a p-value of 0.033 ($p < 0.05$).

Figure 5 shows the mean PPC values of the research articles by continent. The larger solid black dot indicates the average of the mean PPC of all results for a continent, and the smaller dots indicate the mean PPCs of individual studies.

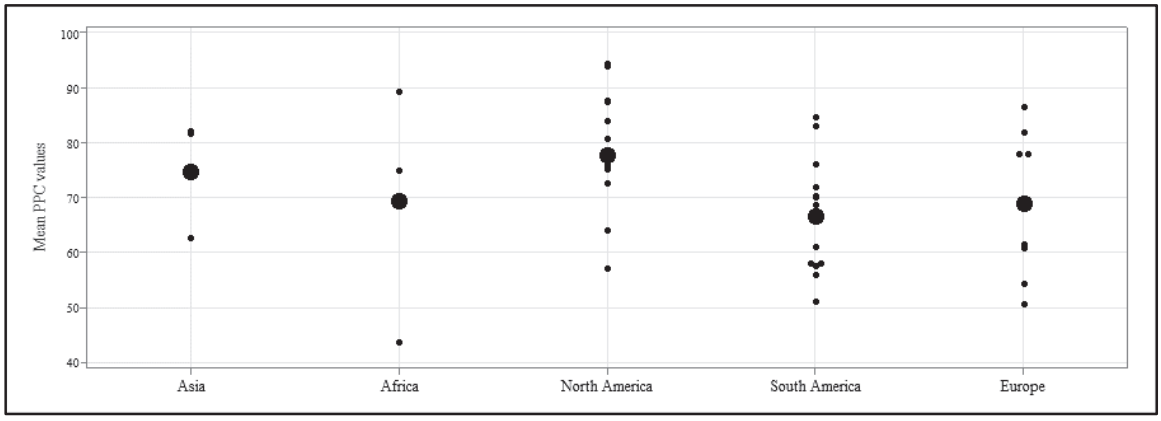

Figure 5: Mean PPC values presented in the reviewed journals by continent.

When compared geographically, the highest mean PPC average was in North America (77.7%, N = 16) and the second-highest one was in Asia (74.9%, N = 7). Europe (69.0%, N = 8) and Africa (69.4%, N = 3) were almost at the same level, and South America (66.7%, N = 14) had the lowest value. Most studies presenting PPC values were in North and South America, followed by Europe, Asia, and Africa.

DISCUSSION AND CONCLUSIONS

With the PPC value constantly at or below 50% on average, the foreman's job is essentially a roll of the dice (Ballard & Tommelein, 2016). Our findings from a large sample of studies in which PPC values have been presented show that the published PPC values are approximately 71% (±5%), although they differ by case and continent. This finding agrees with the findings by Aslam *et al*. (2020) of a mean PPC of 68% (N = 16). Further, no developing (or declining) trend was observed in the data, even though the studies were analyzed between 1998 and 2021. Howell and Macomber (2002) argued that a PPC value of 80% is "good" and one less than 60% is "poor," and very mature teams can maintain a daily PPC of 85%. These findings suggest that the case studies in which the PPC value is close to the "good" level are published in peer-reviewed journals, and a wider range of cases, including some in which the PPC value is "poor," are published in lean-focused journals. At the same time, among case studies presenting PPC that were published in other peer-reviewed journals, only three had PPCs that remained above the 80% level throughout the monitoring period. By contrast, none of the studies published in lean-focused journals had PPCs that maintained this "mature" level of 80% throughout the monitoring period. This might indicate that the PPC level of 80% is too high to be consistently reached and maintained or that construction planning still lacks an understanding of feasibility and that the promises made during LPS meetings continue to ignore and stress all the barriers that might impact task execution. From a learning and development perspective, future research should focus on starting levels of PPC from the cases and evaluate the PPC changes during the studies.

Another study finding was the statistically significant difference between the results of articles published in lean-focused journals and those published in other peer-reviewed articles. The fact that research results showing higher PPC values are published in non-lean focused journals may indicate a publication bias (Thornton & Lee, 2000). These findings raise the questions of whether articles presenting low PPC values remain unpublished in peer-reviewed journals and if so, the effect it has on LPS-related research. However, the findings indicates that studies with lower PPC values are compiled in lean-focused journals and conference publications, possibly indicating that the publishers are trying to prevent publication bias. The findings also raise the questions of whether journals focusing on lean will not publish even

lower PPC values or whether the lowest samples of PPC values will be published. This finding requires further qualitative research, because the PPC value itself is not necessarily relevant in the published research. What has been studied is how the results have been interpreted based on PPC and what conclusions have been drawn.

The third finding is the geographical differences in published PPC values, which raises several interesting questions for further research. First, are the geographical differences in PPC due to the more extensive and long-term use of LPS, different ways of applying LPS, or different cultures and societies in the continents? For example, cultural differences can affect how low values can be presented in different cultures. There is evidence of differences in the use of LPS; however, the connection to variations in PPC has not yet been investigated (Power *et al*., 2021). Similarly, in relation to takt production, researchers have observed three different geographically distributed schools in the implementation of the method (Lehtovaara *et al*., 2021); this observation may indicate similarities in the use of LPS as well. Further research into the questions arising from these observations is recommended.

The research is limited by the heterogeneity of the material and the variation in the quality of images and tables. Consequently, the researchers had to perform visual evaluations and manual work, especially on the figures; this could affect the accuracy of the individual PPC values. However, no significant loss in reliability occurred because articles with low-quality figures and tables were excluded. Another limitation is the that the majority of the research data contained individual studies that had combined databases containing several projects, implying that they were an "average of averages" and not individual measurement periods. The third limitation is the meta-nature of the study, in which values are averaged; therefore, the reader should exercise care when interpreting the findings. Averages always conceal variations and other valuable information that may exist in the individual studies considered in this study, and the authors recommend familiarizing oneself with not only the results of these studies but also the original research articles. The fourth limitation is that PPC values can vary depending on the type of project, tasks included in the weekly plan, project constraints, uncertainties and risks, and several other variables that make a project a unique achievement. PPC evaluation is flawed if these variables are not considered, and further research should also assess the impact of these variables and how they appear in different academic publications. In further research on PPC, it is essential to expand toward qualitative methods that will provide deeper insights into the statistics and phenomena.

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