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Review Article

Experiences from the implementation of last planner system® in construction project

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Lean practices have shown their potential in reducing environmental, economic, and social impacts during the construction phase, with an increase in the parameters of sustainability in the development of projects. Last planner system® (LPS) has gained prominence in recent times for its ability to increase the possibility of timely construction project delivery. However, LPS is yet to gain sufficient confidence from industry for wide spread implementation. The present paper intends to present the benefits, critical success factors, barriers and drawbacks of the LPS with the intent of promoting the applications in industry. An extensive review of literature published over last two decades has been done. The study has identified that improvement in the reliability of planning, visualization of future and planning transparency, reduction in project time as the major benefits, commitment from top management, training of the participants as the critical success factors, resistance to implement LPS, involvement of many parties in the project as the most significant barriers of implementation. The study has also presented the difficulties faced during LPS implementation which if addressed shall be able to improve the process of implementation, translate to project success, and instil confidence in the industry practitioners to implement the system widely.

Keywords: Last planner system, Planning & scheduling, Project management, Lean, LPS

1 Introduction

Infrastructure development and economic growth are linked very closely and it is essential that the construction projects complete on time within budget. However, research findings from early 90s indicate that only 54% of the commitments made on construction project were completed on time[1]. It has also been documented that 70% of all construction projects are over budget and delivered late[1]. One of the fundamental reasons for this has been assessed as inadequate project planning failure[2] in establishing a realistic plan which provides clarity on the objectives, timelines and removal of constraints needed to overcome to achieve the objectives in the near term. One of the most effective ways to increase productivity is to plan more efficiently and also improving production by reducing delays[3].

While critical path method (CPM) has been widely adopted as the system for establishing projects' master plan providing a strategic vision of the project, it has however failed to provide the operational clarity as to how to achieve the objectives. The CPM method focuses on the technological dependencies only, meaning that it does not support achieving the stable continuous workflow and handovers between project stakeholders on the operational level[4]. The CPM provides an overall strategic plan for the entire project but it does not address the operational clarity of who needs to execute the tasks and how it needs to be executed. In the CPM, deviations are not clearly visualized[5].

To overcome the shortcomings of the critical path method (CPM), and to augment the planning system with greater visibility, to improve the predictability and reliability of construction production[6], Last Planner System® (LPS) was proposed by Glenn Ballard[7]. The idea behind LPS originated in the need for control, with a strategy of increasing work flow predictability, and increased work plan predictability, through controlling the quality of assignments in weekly work plans[8]. The fundamental distinction of the LPS from CPM is to plan in greater detail as the work / assignment approaches, ensure that the constraints for the work are addressed proactively, and that all stakeholders of the work are fully aware

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of the work requirements. LPS aims at moving the focus away from individual workers and placing it on the workflow that connects them[9]. LPS is originated from the lean production philosophy with the main objective to reduce the waste within construction by maintaining constant flow, to provide maximum value to the product / project in a sustainable way, and to continuously improve over time[10].

The process benchmark[11] recommends twelve key principles in the LPS which are; (1) ensure that all plans at different levels are available to all project participants, (2) master schedules with milestone level of details to be ready, (3) ensure tasks are planned in increasing detail as the task execution approaches, (4) ensure tasks are planned with those who are directly executing the tasks, (5) Re-plan as necessary duly incorporating the changing circumstances and situations, (6) identify and remove constraints collaboratively for the planned tasks, (7) improve reliability of workflow to improve performance at the operational level, (8) commitment to start only those tasks which are well defined, sized, and sequenced, (9) ensure promises / commitments made are secure and reliable, and (10) continuously learn from failures that occur when executing tasks to prevent future reoccurrence, (11) Underloading of resources to increase reliability, and (12) maintaining a backlog of tasks which are ready to be executed.

The LPS systematically works to create a visible flow of tasks and provides greater operational clarity. Figure 1 adapted from Hamzeh *et al.*[12] shows the last planner system where activities are broken down from phases (boulders) to processes (rocks) then to operations (pebbles) across four planning processes with different chronological spans: master scheduling, phase scheduling, lookahead planning, and weekly work planning.

Master schedule is prepared during the initial stages of the tender submission, project initiation stages and provides the details of the overall work to be executed over the project lifecycle. The master schedule defines major milestones[11] and to be achieved / completed as per the requirements of the contract and project owner.

Phase schedule is carved out from the master schedule[7] by detailing the various components and phases of the project with clear identification of the hand-offs required between multiple project teams

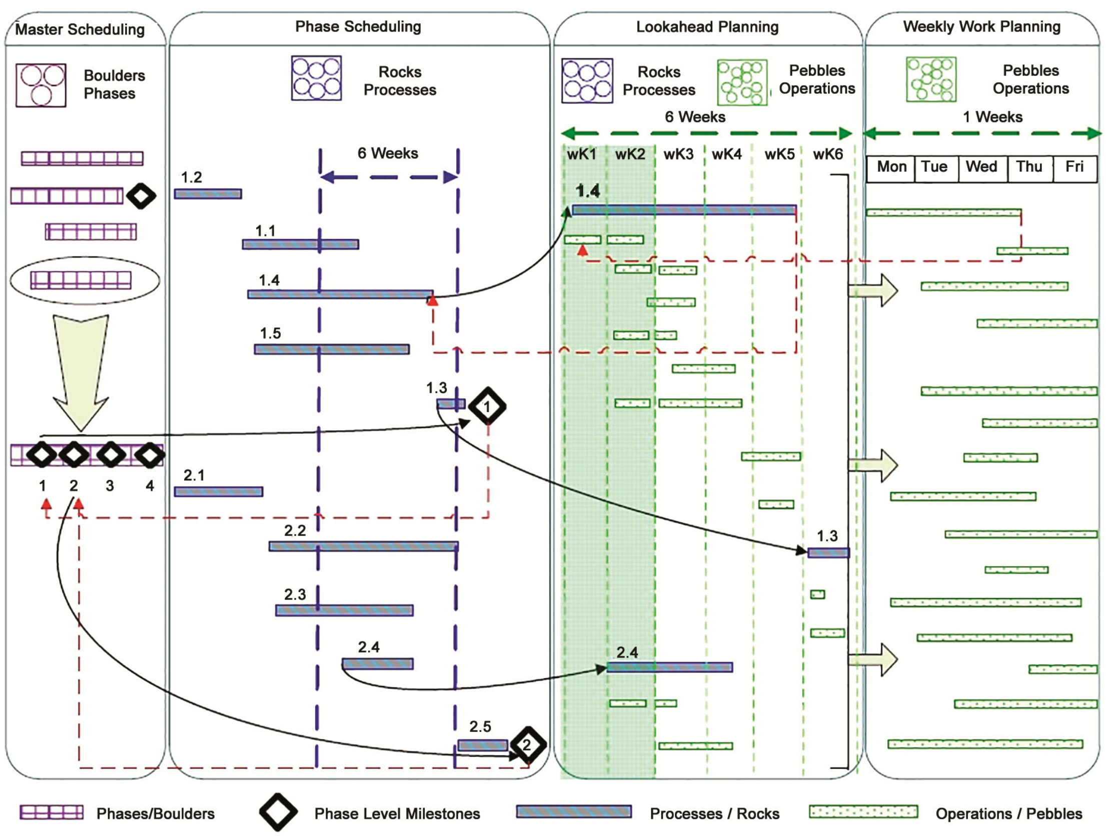

Fig. 1 — Last planner planning process[12]

from different disciplines. This phase defines various milestones to be achieved, identifies activities to be achieved and project team also performs reverse scheduling from the milestone.

The activities of the phase schedule are further magnified to produce the lookahead plan. The look ahead plan usually covering a period of six weeks (shown in Fig. 2) breaks down the processes into specific operations[12]. Look ahead planning is an intermediate process that connects the master or phase schedule to the weekly work plan[13]. The purpose of the look ahead plan is to identify the constraints for the execution of tasks and proactively remove these constraints. The plan is updated weekly where constraints that threaten reliable workflow are studied.

The weekly work plan is the most detailed plan in the system[14]. It directly drives the production process. Plan reliability at this level is promoted by making only quality assignments and reliable promises so that the production unit will be shielded from upstream uncertainty. At the end of each week, assignments are reviewed for completeness in order to measure the reliability of the planning system. The reasons for failure of the promises / commitments are also analyzed which provides the learning to prevent recurrences in future. LPS measures the performance of planning system through the percent plan complete (PPC) metric which is defined as number of tasks completed to number of tasks planned in a weekly plan.

The objectives of this review work are as below:

- To summarise the benefits, success factors and barriers of the LPS implementation in construction projects.
- To present the challenges and difficulties in the present framework of LPS implementation and future research directions

The present research study, through an extensive review of literature from over the last two decades has covered the concepts of LPS, implementation experiences from various countries and has summarised the benefits, difficulties, drawbacks and disadvantages in the present LPS implementation and scope for future research, aimed at improving the implementation and thereby contributing to construction industry and body of knowledge.

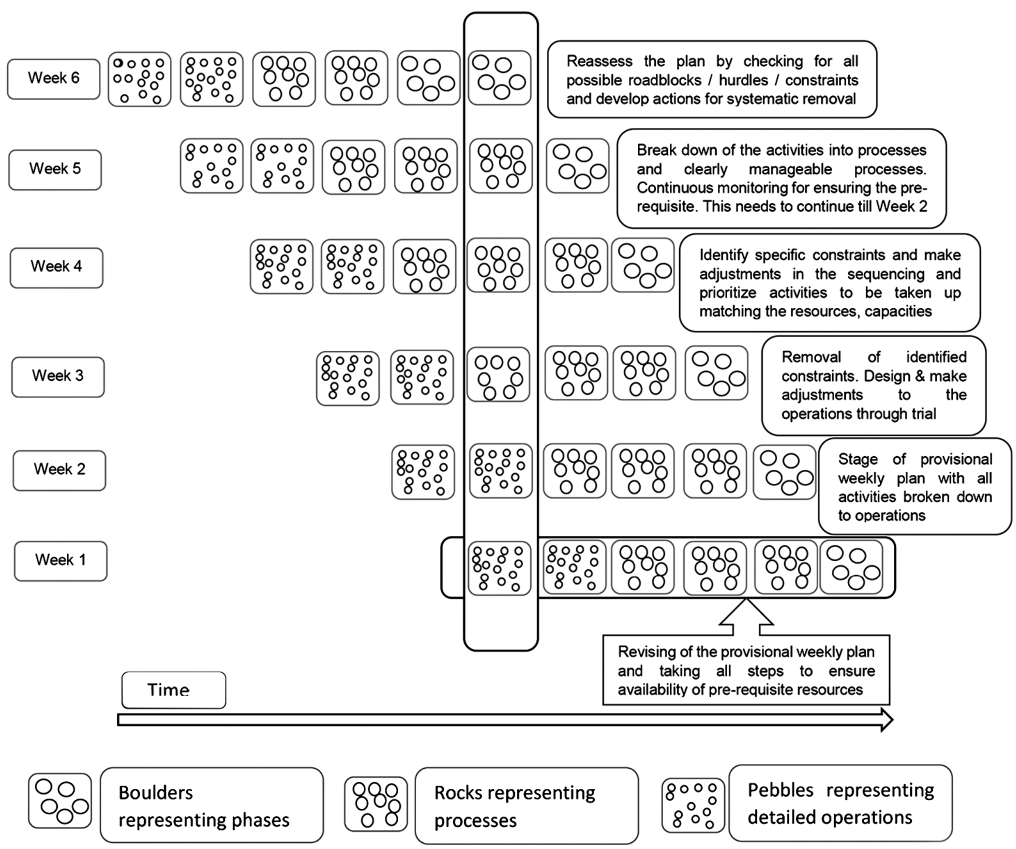

Fig. 2 — Typical process of six-week look ahead planning and activities.

2 Research Methodology

2.1 Literature search and selection

The research work started with the initial study of the lean construction principles from the publications of Lean Construction Institute. This lead to the full spectrum of available resources from Lean Construction Institute (LCI) and the vast rich information on LPS available in the conference publications of International Group for Lean Construction (IGLC) which are available at http://iglc.net/Papers. Keywords of LPS, Last Planner System were used for initial search of articles. The initially identified articles were screened in two stages. First, the title of the articles – gave an indication of the study / topic of work and this allowed to filter the articles for the purpose of this study. Secondly, a first-hand review of the abstract of screened articles were done. This study of abstract provided an indication of the study, methodology and area of concentration of the respective study, based on which the articles were further selected. In addition, review of these selected publications also paved way for identifying further works cited in various International journals of repute such as – International Journal of Project Management, Journal of Construction Engineering and Management, Construction Management and Economics, International Journal of Construction Management, Engineering Construction and Architectural Management, International Journal of Civil Engineering and others. Eighty six peer-reviewed research articles on various aspects of LPS were taken up for initial review and analysis. Table 1 summarizes the literature initially reviewed and Fig. 3 shows the literature search and selection process.

2.2 Literature classification

The selected literature were categorised into different type based on the nature of investigation *viz.*, (a) literature review and surveys, (b) studies on developing metrics for measuring the project performance – LPS metrics, (c) conceptual studies proposing ideas on LPS, (d) integration studies focusing on integrating LPS with software / other methodologies, and (e) LPS implementation studies.

The literature were also categorised on the native country in which research was conducted to check and get an understanding on the coverage of the methodology across the world. The literature were also categorised on the type of article *viz.*, journal publication, conference proceedings etc. The summary of literature reviewed are summary is shown in Fig. 4.

Table 1 — Literature reviewed by source and time period.

Description	Literature reviewed & referred		
Type of Publication / Research Period	1991-2000	2001-2010	2011-2020
Journal articles	2	2	16
IGLC Proceedings	3	11	40
Other Conference Proceedings		2	3
Corporate publications & others		4	3
Subtotal	5	19	62
Total		86	

3 Results of Literature Review

A comprehensive review of the selected articles was done. The literature review focused on the evolution and journey of LPS implementation, challenges faced during the implementation, how the performance of LPS system was measured, extent of benefits realized by the implementation, success factors for implementation, barriers hindering the implementation and also reasons for non-completion of plans. In addition, the challenges faced during the implementation of last planner system as documented in the literature were also reviwed.

3.1 Benefits of last planner system implementation in construction projects

For the purpose of evaluating the benefits, a total of 29 research studies on LPS implementation, reviewed from various countries were considered. These studies are summarized in Table 2. Over a period of time, a number of studies with implementation of LPS have been carried out all over the world. Successful LPS implementations have resulted in many direct and indirect benefits[43] positive effects[44] on performance. This study has carefully reviewed all these implementation studies from different parts of the world which have brought out various benefits of LPS implementation in construction industry. The studies have captured various benefits such as reduction in project time, improvement in the planning reliability, addressing the variability in workflow to name a few. For the purpose of evaluating and ranking the most significant benefits of the implementation, the frequency of each of the benefit listed out by previous studies were considered.

In all, 36 benefits of LPS were identified from the literature which is depicted in Fig. 5, along with the frequency of the benefits. The top ten benefits from the implementation of the LPS are summarized in

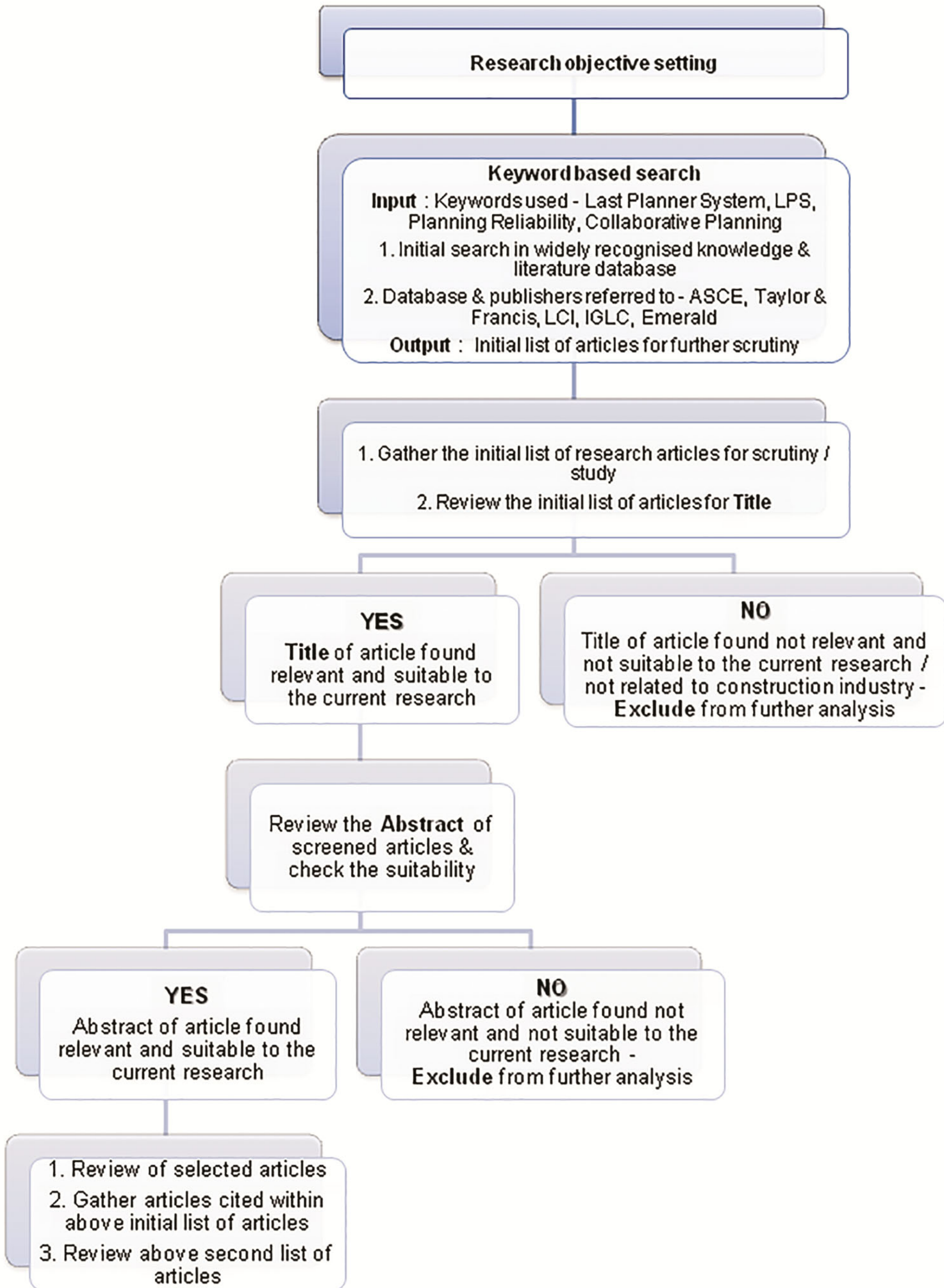

Fig. 3 — Process of literature search and selection.

Table 3. Improvement in the reliability of planning, addressing variability and workflow, reduction in project time, promote collaborative planning and cost savings were among the most significant benefits as evidenced from the literature.

The benefits as identified from the review of literature provide sufficient evidence that lean and LPS practices in construction industry can contribute significantly to the environmental, social sustainability through reduction in project time, reduced rework, improvement in work quality and economic sustainability with savings in cost.

3.2 Critical success factors for last planner system implementation in construction projects

Last planner system brings a fundamental change in the way construction projects were planned. The

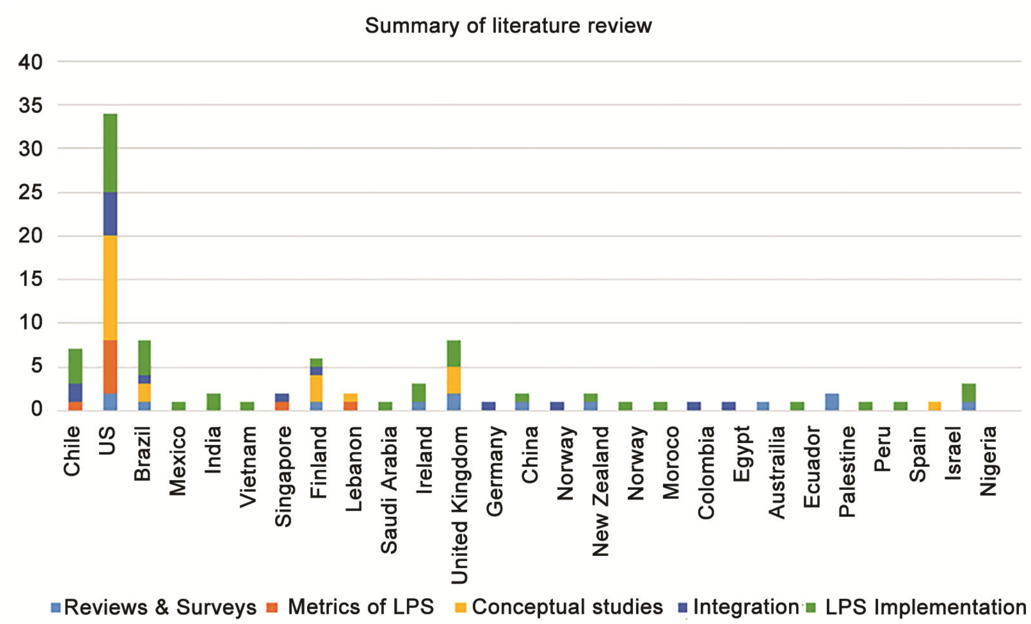

Fig. 4 — Summary of literature reviewed by category and by country.

concept is a significant shift from the traditional CPM method. CPM method is largely strategic in nature providing overall direction and sequence of the project whereas LPS is focused on the operational details and planning in greater detail. The method also calls for transparency and shared vision, goals of the project which in construction projects is not very easily attained. Hence, the method calls for some critical requirements to ensure the successful implementation.

Twenty five Critical Success Factors were identified from review of literature and which are depicted in Fig. 6, along with the frequency of the Critical Success Factors. Table 4 lists the top ten critical successful factors as documented in the literature. Commitment from top management, training of participants, awareness and enlightenment campaigns, formation of policies to suit LPS implementation, and appointment of lean champions were found to be the most critical success factors.

3.3 Barriers / challenges for last planner system implementation in construction projects

Construction industry is slow to embrace change. One of the fundamental characteristics of construction projects is the involvement of multiple organisations from different segments, varied qualifications, cultural backgrounds of the human resources deployed on the project. Acceptability for adaptation and implementation of a new system has lot of challenges. One of the fundamental formula of last lanner system is creating a transparent, collaborative work culture which may not be easily acceptable to all. Research studies have captured these challenges during the course of implementation of LPS and top ten barriers for LPS implementation are summarized in Table 5. Twenty five barriers were identified from review of literature and which are depicted in Fig. 7, along with the frequency of the barriers. Resistance to implement LPS, involvement of many parties in the project, lack of training, lack of commitment to change and innovation and poor collaboration were found to be the most significant challenges.

3.4 Reasons for failure / non-completion of the plans

One of the essential concepts of LPS is to capture the learnings on the project during the course of implementation and learn from failures to effectively remove constraints. A constraint can be defined as anything that would stop or disrupt the flow of project delivery in an organisation or on a project. Constraint analysis and feedback links are important to promote consistency between the set objectives[45] practices[46], guide work structuring decisions[47] and actions to implement project objectives. Before removing a constraint, it must be identified. This drives appropriate action in the make ready process to prepare the work for continuous flow[48]. Towards this, the LPS implementation studies have captured the various reasons for failure / non achievement of the

Table 2 — Summary of research studies on LPS implementation reviewed and analyzed.

Study	Country	Research Methodology	Description of Study	Type of projects covered
Abusalem[15]	Palestine	Literature review and survey	Literature review and data collection from 145 contractor responses	-
Adamu & Howell[16]	Nigeria	LPS Implementation case study	Implementation of LPS in Construction of 50 housing units	Buildings
Bortolazza & Formoso[17]	Brazil	LPS Implementation case study	96 projects - Industrial, Residential and Commercial buildings	Buildings
Cerveró-Romero *et al.*[18]	Mexico	LPS Implementation case study	Implementation of in seven pilot projects by a general contractor	-
Daniel *et al.*[19]	UK	LPS Implementation case study	Implementation, document analysis, observation in two Joint Venture Projects on Highways	Highways
Fauchier & Alves[20]	USA	LPS Implementation case study	On field observation of 15 teams on 9 projects utilizing LPS	-
Fiallo & Revelo[21]	Ecuador	LPS Implementation case study	Construction of 102 family units, measuring 80,000 square feet	Buildings
Formoso & Moura[22]	Brazil	Data collection and analysis	Data collection from 119 projects executed between 2002 to 2007, comprising residential, industrial and commercial projects	All types
Hamzeh *et al.*[23]	USA	LPS Implementation case study	Implementation study on a healthcare project in North America	Buildings
Habchi *et al.*[24]	Morocco	LPS Implementation case study	Implementation in 21 buildings residential project consisting of 396 housing units with four floor each	Buildings
Kemmer *et al.*[25]	Ireland	LPS Implementation case study	Interviews, planning meetings, site visits, document analysis in a house retrofit of set of houses	Buildings
Kerosuo *et al.*[26]	Finland	LPS Implementation case study	Implementation of the LPS tools in the design phase of a building	Buildings
Khanh and Kim[27]	Vietnam	Questionnaire survey and implementation case study	Questionnaire survey, expert survey, case study of two high-rise building projects and one factory project	Buildings
Kovvuri *et al.*[28]	India	LPS Implementation case study	Implementation in an automobile factory building	Buildings
Lévano[29]	Peru	LPS Implementation case study	Implementation in sanitation two lots of Sanitation works - Sedapal Lot 7 and Lot 10	Sanitation
Liu & Ballard[30]	USA	LPS Implementation case study	Construction of pipeline for an oil refinery plant in USA	Pipeline
Nieto-Morote & Ruz-Vila[31]	Spain	LPS Implementation case study	Implementation of LPS concepts in construction department of a chemical company	-
Ograbe *et al.*[32]	Nigeria	LPS Implementation case study	Implementation of LPS in Construction of student Hostel Buildings	Buildings
Paz & Oscar[33]	Chile	LPS Implementation case study	Implementation in the construction of 80 apartments of 56 m², in buildings of 4 stories high on a contractual period of one year	Buildings
Power & Taylor[34]	Ireland	LPS Implementation case study	Implementation in two capital projects	-
Porwal *et al.*[35]	USA	Literature survey	Literature survey on the challenges faced in LPS implementation	-

(*contd.*)

Table 2 — Summary of research studies on LPS implementation reviewed and analyzed. (*contd.*)

Study	Country	Research Methodology	Description of Study	Type of projects covered
Ribeiro & Costa[36]	Brazil	LPS Implementation case study	Implementation and evaluation of the LPS on two case studies - in a clinical facility and a commercial building, on various phases of works – foundation, structure, masonry, facade etc.	Buildings
Ryan *et al.*[37]	Ireland	Questionnaire survey of LPS users	Questionnaire survey of professionals in Pharma and Fit out sector	Buildings
Samudio & Alves[38]	USA	LPS Implementation case study	Implementation of LPS in a 2,80,000 square feet laboratory replacement project	Buildings
Sundararajan & Madhavi[39]	India	LPS Implementation case study	Implementation of LPS in the finishing activities of a building	Buildings
Tayeh *et al.*[40]	Palestine	Literature review and survey	Literature review and questionnaire survey of 98 contractors	-
Tayeh *et al.*[41]	Palestine	Literature review and survey	Literature review and collection of data from 89 companies	-
Viana *et al.*[42]	Brazil	Survey and Interview of LPS users	Survey, Interview with site engineers, foremen from 16 companies	-
Wesz *et al.*[9]	Brazil	LPS Implementation case study	Implementation in design process for fast and complex steel work	-

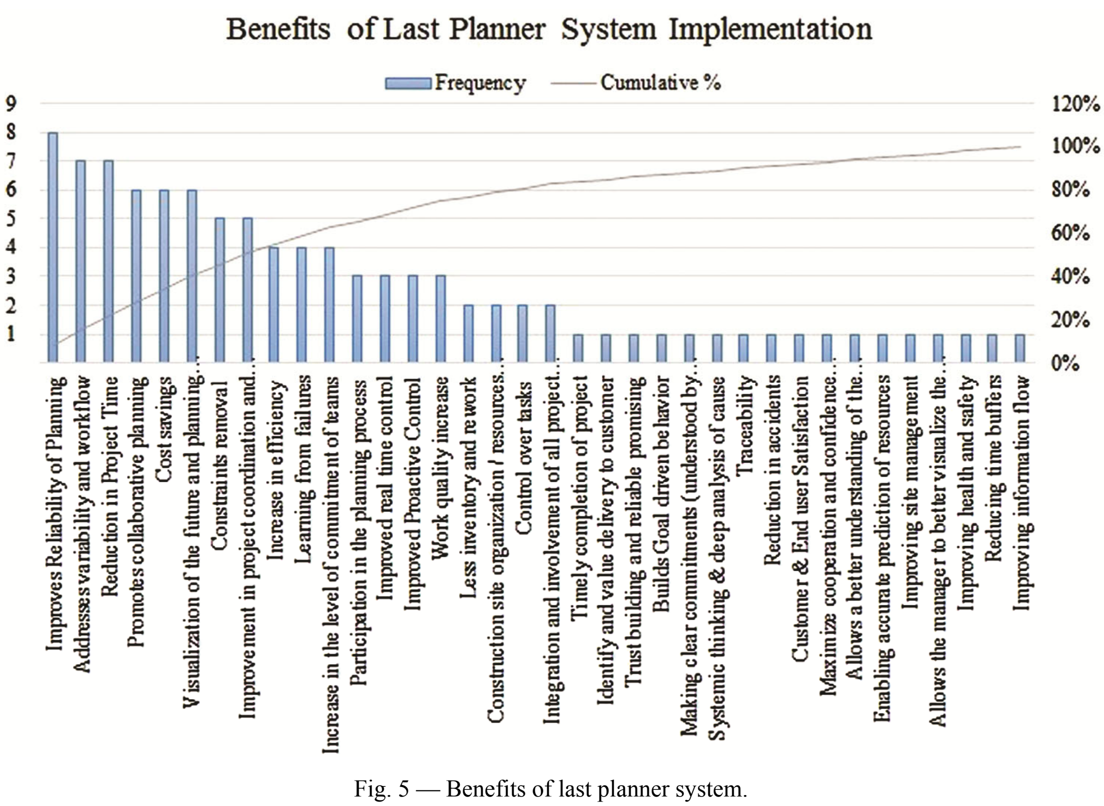

Fig. 5 — Benefits of last planner system.

planned assignments. A sample constraint log is shown in Fig. 8.

Having this system in place essentially helps improve the process of planning and also identify the various constraints and take appropriate actions in time for their removal. Addressing these constraints and their removal gradually will eventually lead towards an improvement in the accomplishment of the tasks as planned and improve the reliability of planning process on the project. Twenty four reasons / constraints were identified from review of literature and are depicted in Fig. 9, along with the frequency.

Table 3 — Benefits of last planner system.

Benefits	Studies confirming the benefits	No. of studies confirming the benefit
Improves Reliability of Planning	1,4,10,12,18,19,22,23	8
Addresses variability and workflow	6,11,18,24,25,27,29	7
Reduction in Project Time	1,2,11,13,14,19,27	7
Promotes collaborative planning	6,9,12,18,22,29	6
Cost savings	1,13,14,18,19,27	6
Visualization of the future and planning transparency	4,6,22,27,28,29	6
Constraints removal	10,12,19,24,28	5
Improvement in project coordination and communication	4,6,9,11,12	5
Increase in efficiency	1,15,25,28	4
Learning from failures	7,22,23,29	4

* Study numbers are as per Table 2

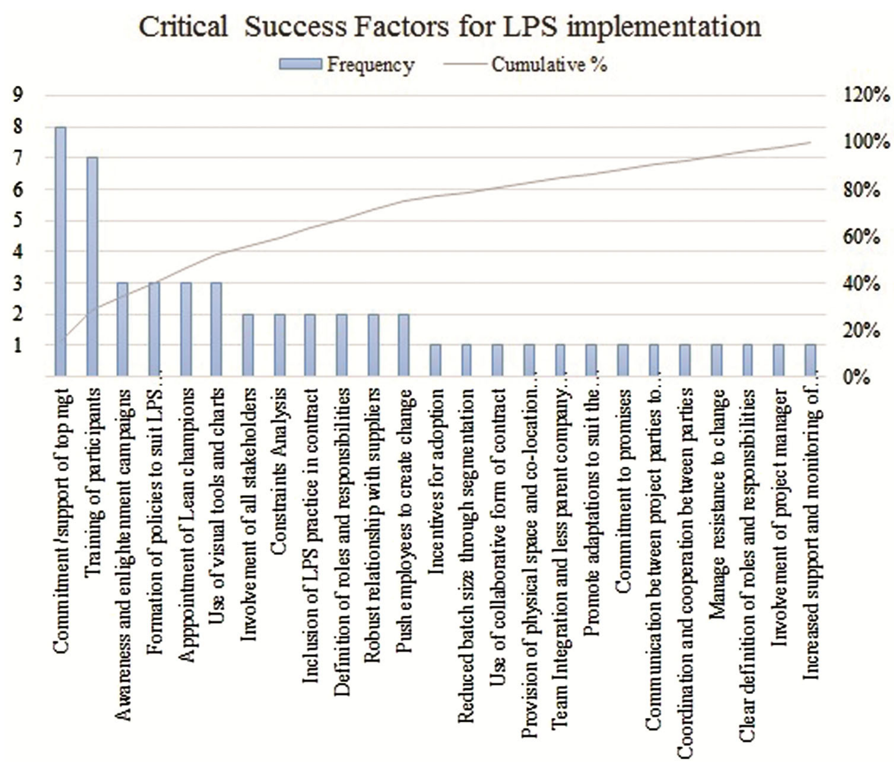

Fig. 6 — Critical success factors for last planner system.

The top ten reasons for incomplete assignments are summarized in Table 6. Incomplete design information, poor weather, problems with the labour supply / availability and material availability were found to be the major reasons for the incomplete assignments.

3.5 Implementation gaps, drawbacks in the present framework of LPS implementation

The introduction of the LPS as a concept has offered many advantages during the course of implementation which have been brought out already in the previous section of this study. However, many of the studies have brought about drawbacks of the system which probably could be one of the reasons as to why implementation of the system has not gathered significant momentum. The next sections of the paper summarize these drawbacks, gaps, possible alternatives and scope for further research aimed at addressing these gaps towards successful implementation.

3.6 Process of implementation of LPS

LPS as a process requires significant effort to implement and evaluate its effectiveness in

Table 4 — Critical success factors for last planner system.

Critical Success Factors	Studies confirming the success factors	No. of studies confirming the factors
Commitment /support of top management	1,8,9,12,17,20,28,29	8
Training of participants	1,8,14,16,17,25,29	7
Awareness and enlightenment campaigns	8,25,29	7
Formation of policies to suit LPS implementation	8,25,29	6
Appointment of Lean champions	14,17,25	6
Use of visual tools and charts (for information flow)	8,9,25	6
Involvement of all stakeholders	8,20	5
Constraints Analysis	4,28	5
Inclusion of LPS practice in the contract	14,25	4
Definition of roles and responsibilities	1,8	4

* Study numbers are as per Table 2

Table 5 — Barriers for LPS implementation.

Barriers	Studies confirming the barriers	No. of studies confirming the barriers
Resistance to implement LPS	4,5,18,19,21,26	6
Involvement of many parties in the project, especially subcontractors and suppliers	1,4,13,20,21,26	6
Lack of training for the managers when planning and controlling the project	1,10,13,21,26	5
Lack of commitment to change and innovation	1,12,18,21,26	5
Poor collaboration	1,10,11,21,26	5
Low understanding of LPS concepts	2,13,19,26	4
Lengthy approval procedure by client	1,13,21,26	4
Adaptation to the new culture	4,12,19,28	4
Partial / Late start of implementation	18,21,26	3
Weak communication and transparency among participants	13,14,26	3

* Study numbers are as per Table 2

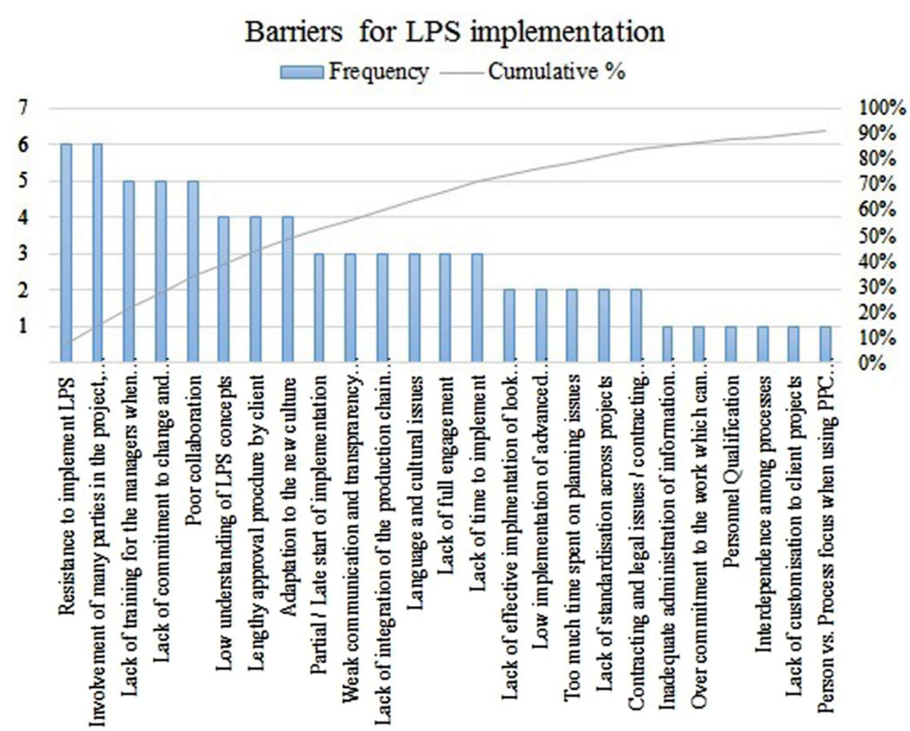

Fig. 7 — Barriers for last planner system implementation.

Constraint Log									
Project	Construction of Highway from Section A to Section B						Update Date : 04 Jan 2021		
Project No.	44								
Project Leader	Mr. John Smith								
Constraint Number	Activity ID / Number	Constraint Description	RFI No	Responsible Person	Responsible Organisation	Date of Identification of constraint	Constraint needs to be resolved by date	Date promised for resolution	Actual resolved date
42	321	Material not available	12	Steve	ABC	28-Dec-20	02-Jan-21	02-Jan-21	03-Jan-21
43	452	Insufficient labour strength	14	Jerry	ABC	31-Dec-20	01-Jan-21	02-Jan-21	01-Jan-21

Fig. 8 — Sample illustration of constraint log.

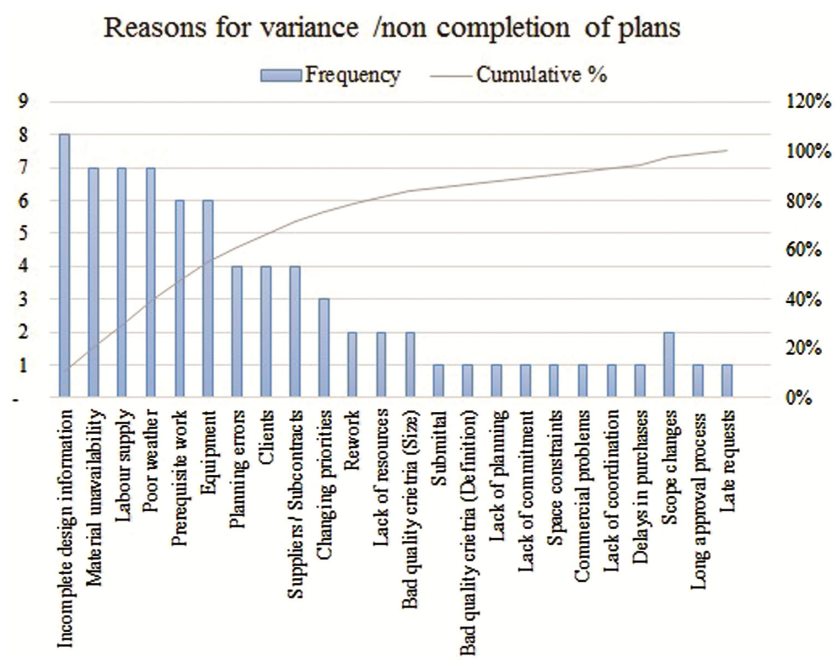

Fig. 9 — Reasons for variance / non completion of plans.

Table 6 — Reasons for incomplete assignments.

Reasons	Studies confirming the reasons	No. of studies confirming the reasons
Incomplete design information	5,8,10,16,24,26,28,29	8
Material unavailability	5,8,15,16,24,28,29	7
Labour supply	5,8,16,17,24,26,29	7
Poor weather	5.8,15,16,17,24,29	7
Prerequisite work	8,15,16,17,22,29	6
Equipments	5,8,15,24,26,29	6
Planning errors	5,10,15,24	4
Clients	5,10,16,24	4
Suppliers / Subcontracts	5,17,24,29	4
Changing priorities	10,17,22	3

* Study numbers are as per Table 2

implementation. Many of the implementation studies have critiqued LPS for the sheer effort that goes in the implementation cycle. During the implementation, (Emdanat S. & Azambuja, M, 2016)[49] experienced that significant effort was required to maintain alignment between the lookahead plans, the constraint logs, and the master schedule. In addition, the cycle time to synchronize near-term plans, constraints, and update the master schedule exceeded the duration of the planning cycle time. The users of the system experienced difficulty when trying to update, track and transfer information. Consequently, the Week Score Plan could not be accurately completed due to the lack of information[50].

3.7 Missing integration of long term and short term plan

LPS focuses on producing the plans in greater detail as the tasks are nearing execution. One of the essential principles of LPS is to screen the tasks and appropriately size the assignments to the available resource capacities to ensure that these tasks are completed. This inherently builds a short term planning and lacks a focus on long term[51].

Studies over the years have highlighted that there is a risk of losing sight of the big picture if LPS is not sufficiently integrated with high level planning and tracking. In LPS, as shown in Fig. 10, Post it™ notes are typically used as a scheduling and tracking tool. This way of visualization may work only in short (commitment/weekly) and medium term planning (lookahead) periods, that too for projects of lesser size and small bucket of activities. This manual way of managing the activities and constraints does not synchronise with other planning and scheduling systems. Thus, while in the near term, LPS may be able to provide visualization of the tasks, but the essential part of integration with master planning, tracking, monitoring and detailed prioritisation, and conflict resolution are missing[52]. Better integration between near-term planning and long-term planning can improve workflow reliability[53-55]. While lookahead planning is built on master scheduling, a connection is rarely maintained between these two [12, 56] and there is a lack of adherence between planning levels. The use of LPS required that during weekly planning and review, the phase planning be contrasted to the current progress[24] which itself can be time consuming involving significant effort in a mega infrastructure project. It was observed that in some cases, without all the planning functions being deployed, and the collaborative planning function not being deployed properly, the plans did not function well either, resulting in overall confusion[57].

3.8 The LPS metrics of performance

The effectiveness of implementation of LPS is most commonly measured at the lookahead stage and the weekly work plan stage. These are designed to measure the performance of the project against the lookahead plans and the weekly work plans. Table 7 provides the summarization of various metrics documented in the literature. However, project might be successful despite poor LPS implementation, as well as project failure despite successful LPS implementation. Therefore, it is difficult to directly correlate LPS implementation with project success based on LPS metrics[58]. The most commonly used metric - PPC measures the performance against the weekly plan. PPC can be gamed by a project team on a real-life project to appear high by under-committing[59]. The PPC ratio indicates the reliability of the weekly assignments and does not indicate the true status of the project. PPC ratios should accompany the traditional schedule analysis when evaluating the project status[60]. It can also be the case wherein PPC ratio could be 100%, but when compared with the master plan, project might still be behind schedule[11]. Alarcon *et al.*[61] argued that to

Fig. 10 — Scheduling and tracking using post it™ notes.

ensure a reliable and consistent performance, it is not enough to have high weekly PPCs, but also that the variation of PPC values remain in small range. Adoption of LPS may have resulted in improvement of percent plan completion (PPC) of the implemented projects. However, because of isolated, partial implementation of the LPS, lean practitioners are still unable to complete more than 30% of weekly assignments. Due to certain limitations, most studies have been conducted based on a small number of case studies using mostly qualitative evidence[27]. Also, it is difficult to directly correlate LPS implementation with project success based on LPS metrics. While, the technology and digital tools may aid in the integration of plans, the clients and contractors in developing countries may adapt these solutions only once they realize the ease of implementation and benefits.

3.9 Type of projects and contracts covered

The review of literature as summarized in Table 2 brings out two important characteristics of LPS implementation. Firstly, the research studies have implemented the LPS largely on building projects except one or two of them which have focused on highways and other sectors. By their nature, all the resources in building projects are working within a confined boundary and may not expose the real challenges involved in implementation of mega infrastructure projects. Secondly, contract procurement methods can have significant impact on the application of the LPS[73]. The studies so far have hardly explored the influence of various contract types on the implementation of LPS and the performance in various contract environments. This is an important element as the procurement methods are evolving day by day from the traditional DBB methods to DB & EPC contracts.

3.10 Integration of last planner system with other tools / methodologies

Having realized the potential of the last planner system, some of the recent studies have explored integrating the concepts and methodologies of LPS with other tools such as critical chain[74], location based management systems[75-77], building information modeling[78-80], takt planning[81,49], fuzzy logic systems[82], earned value method[83,84], integrated planning[10,85], line of balance[86], simulation studies[24] etc. to integrate the synergies of these tools and systems with LPS and have found the interactions to be meaningful. These studies have looked into the aspects of combining each of these tools and systems with LPS, so as to combine the unique advantages, synergies and enable to provide better visualization, location based tracking and build a collaborative planning and tracking systems for improved project realization. Research in this area is continuing aimed at assessing the conformance and improvement in the LPS implementation.

Table 7 — Metrics of last planner system.

Metric	Formula	Study Reference
Percent planned complete (PPC)	Did / Will	Ballard[62], LCI [63]
Tasks made ready (TMR)	Did / Can	Ballard & Howell[64],Ballard[65], Ballard[66], Hamzeh *et al.*[67]
Tasks anticipated (TA)	Anticipated tasks / Total tasks on Weekly work plan	Ballard & Howell[64],Ballard[65], Ballard[66], Hamzeh *et al.*[67]
Planned work ready (PWR)	(Work expected to be in the look ahead/Work that should be performed)	Mitropoulos[68]
Percent constraint removal (PCR)	(Ready / Can)	Jang & Kim[69]
Performance factor (PF)	(Actual labour hours / Earned labour hours)	Ballard[66]
Project productivity index (PPI)	($\sum$ Activity productivity indexes / N) X 100	Gonzalez *et al.* [70]
Planning reliability index (PRI)	(Actual progress / Planned progress) X 100	Gonzalez *et al.* [70]
Construction flow index (CFI)	$10 \sum W_i P_i^{Xi}$	Sacks *et al.*[71]
Commitment level (CL)	Required will / should	(Emdanat S & Azambuja M)[49]
Percent required complete and ongoing (PRCO)	(Required completed + required on going on track) / Required should	(Emdanat S & Azambuja M)[49]
Capacity to load ratio (CLR)	Total completed / Weekly work plan	Rizk *et al.* [72]
Required capacity ratio (RCR)	Required completed / total completed	Rizk *et al.* [72]
Required percent complete (RPC)	Required completed / total required	Rizk *et al.* [72]

4 Conclusions & Future research directions

The present study has summarised literature from the stages of conceptual development to the recent studies with implementation across many countries and the learnings from the implementation. The study has identified

(i) Improvement in the reliability of planning, addressing the variability and workflow, reduction in project time, promoting of collaborative planning and cost savings as significant benefits of the LPS implementation.

(ii) Commitment of top management, training of participants, awareness and enlightenment campaigns, formation of policies to suit LPS implementation and appointment of LPS champions in the project as the critical success factors

(iii) Resistance to implement LPS, involvement of many parties in the project, lack of training, lack of commitment to change and innovation and poor collaboration as the major barriers for implementation.

(iv) Incomplete design information, material unavailability, labour supply and poor weather were found to be the major reasons for variance and non-completion of plans.

This study has not only covered the positive attributes of the implementation but also has presented the drawbacks in the LPS implementation and difficulties faced by practitioners which is hindering the widespread application and acceptance. The study has identified the drawbacks and gaps in the LPS implementation viz., the level of effort required to track, update the activities on a continuous basis, missing integration of performance of the project in the short term and long term and link of LPS implementation with project performance in the long term.

To address these gaps, build confidence and acceptability in the industry, the present LPS implementation needs strengthening by further research with focus on:

(i) Conditions and factors preventing construction industry especially in developing economies, from adapting the lean practices and embracing collaborative planning practices and systems

(ii) Development of a framework with metrics which shall measure the depth and success of LPS implementation at each stage and can relate the implementation with short term and long term performance of the project, correlate with traditional EVM metrics

(iii) Implementation studies on varied projects other than building projects especially larger mega infrastructure projects to showcase the suitability and success on varied projects

(iv) Measuring the impact of varied nature and form of contracts on the success of LPS implementation, as different contract environments can create conditions which can either support / hinder collaborative working conditions in a project.

(v) Benefits and challenges of LPS software solutions – whether the software solutions are enabling the LPS implementation process and are they crea+ting conditions favourable for LPS implementation

5 Limitations

The articles for the review in this study were selected from various reputed international journals and IGLC conference proceedings based on key word based search criteria. A more systematic literature search from Scopus & Web of Science (WoS) database based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) process may be able to pool more articles which may reveal deeper insights on implementation experiences.

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