Development of approach to support construction stakeholders in implementation of the last planner system

Development of an Approach to Support Construction Stakeholders in the Implementation of the Last Planner System

Emmanuel Itodo Daniel[1], PhD; Christine Pasquire[2], PhD; Graham Dickens[3], PhD

Abstract

The implementation of the Last Planner System (LPS) has gained prominence in the construction industry and its influence on the production system seems to be rapid and significant. However, recent studies reveal that the application of LPS principles on projects is fragmented. The aim of the current study, therefore, is to develop an approach to support construction stakeholders in the implementation of the LPS. Thirty semi-structured interviews and three in-depth case studies were conducted with construction stakeholders. The study developed a non-prescriptive but all-inclusive approach for supporting construction stakeholders in the implementation of the LPS on construction projects. This study contributes to knowledge in engineering management as it provides a new insight into how to apply the LPS holistically in the management of engineering projects. The study further provides evidence into the current practice and performance of the LPS in the management of civil engineering project as demonstrated in the case studies. Finally, the identification of the three "levels of support" (organisational, project, and external enabler) provides a focal point for construction practitioners to focus on in the implementation of the LPS in the management of civil engineering project.

[1] Lecturer, Department of Construction Management and the Built Environment, Southampton Solent University, East Park Terrace, SO14 0YN, Southampton UK. (Corresponding author: emmanuel.daniel@solent.ac.uk

[2] Professor, Centre for Lean Projects, School of Architecture Design and the Built Environment, Nottingham Trent University, 50 Shakespeare Street NG1 4FQ, Nottingham, UK. Christine.pasquire@ntu.ac.uk

[3] Senior Lecturer, School of Architecture Design and the Built Environment, Nottingham Trent University, 50 Shakespeare Street NG1 4FQ, Nottingham, UK. Graham.dickens02@ntu.ac.uk

Keywords: Last Planner System, path clearing approach, lean construction, production planning and control and implementation

Introduction

The Last Planner® System (LPS) was developed in the 1990s following a research in the industrial construction sector (Daniel *et al*., 2015; Ballard and Howell, 1994; Ballard and Howell, 1988). In reality, it creates a platform for stakeholders on the project to plan together in order to reduce uncertainty and improve the quality of the construction programme (Ballard and Howell, 2004). Priven and Sacks (2016) assert that the nature of conversations that occur within the LPS process supports the development of social networks among stakeholders in the construction process.

However, recent studies reveal that the application of LPS principles on projects is fragmented (Daniel *et al* ., 2017; Dave *et al* ., 2015; Koch *et al* ., 2015). For instance, Daniel *et al.*, (2017); Dave *et al*., (2015); Koch, *et al*., (2015) observed that the more complex and crucial elements of the LPS are not implemented in current practice in the UK. These complex elements include lookahead planning, make ready planning, root cause analysis and learning (Daniel *et al*., 2017; Alarcon *et al*., 2011). It is worth noting that the fragmented implementation of LPS is not only in the UK, a Norwegian study (Kalsaas *et al.* , 2014); a Vietnamese study (Khanh and Kim, 2015) and a Danish study (Lindhard and Wandahl, 2014) have also reported it. For instance, in Norway, phase planning is the most frequently implemented element (Kalsaas *et al*., 2014); in Vietnam, lookahead planning is done superficially (Khanh and Kim, 2015) and in Denmark lookahead planning not executed (Lindhard and Wandahl, 2014). All these shows there is a need to develop an approach to support construction stakeholders in implementing the LPS effectively. In view of this, this

study seeks to answer this research question: *How can construction stakeholders (client, main contractors, and subcontractors) be supported for rapid and successful implementation of the LPS?*

The need for supporting the implementation of new techniques, and practice using frameworks (Lindhard and Wandahl, 2014, Nesensohn, 2014; Sacks *et al*., 2010 and roadmaps (Ballard *et al*., 2017) has been acknowledged in the literature. Previous studies have attempted to propose an approach for implementing specific lean techniques such as LPS in construction, but they tend to focus more on the project level (Lindhard and Wandahl, 2014; Hamzeh and Bergstrom (2010), Dombrowski *et al*., 2010). For instance, Lindhard and Wandahl (2014) developed a framework that focused on supporting on-site scheduling; Dombrowski *et al*.'s (2010) framework focused more on the implementation of LPS components at the project level as it provides a detailed and compressive description of tasks that have to be done during LPS implementation as shown in LPS implementation detailed planning. Ballard *et al* ., (2007) suggested a general roadmap for lean implementation with a focus on the project level, while Hamzeh and Bergstrom's (2010) framework provided an operational guideline for LPS implementation that focused more on the project level. This is despite the fact that it has been suggested that the implementation of lean techniques should expand beyond project focus and include other organisational and human factors that could influence the process (Pavez and Alarcon, 2012). This study fills this gap by developing an approach to direct LPS implementation known as *Last Planner System Path Clearing Approach* (LPS-PCA) that incorporates an organisational path clearing level and external enablers alongside the project path clearing level.

Literature Review

The Last Planner System

The LPS is a lean construction approach. It is a production planning and control method that ensures collaboration among those doing the work and also enhances plan reliability (Ballard and Tommelein, 2016; Priven and Sacks, 2016; Gonzalez, *et al*., 2010). In the LPS, planning and control is an integrated process as opposed to the prevailing construction planning practice, where planning and control are viewed separately (Daniel *et al*., 2017). Ballard and Howell (2004) assert that the LPS focuses on integrating planning and production control as opposed to directing and adjusting (cybernetic model) in the traditional project management approach. The integrated approach used in the LPS supports plan reliability and leads to a reduction in task variation at the implementation stage of projects (Russell, *et al.*, 2015; Gonzalez, *et al*., 2010; Alsehaimi *et al* ., 2014). Wambeke *et al* 's, (2011) study found that the LPS method reduces variation in planned tasks, improves project performance and supports the achievement of higher productivity of 35% when compared to a similar project not managed by the LPS method. This finding is further confirmed in studies such as Fernandez-Solis, *et al*., (2012), and Nietro-Morote and Ruz-Vila, (2012). These studies show that the LPS method improves the reliability of planning and the quality of completed tasks. This shows the capacity of the LPS in managing the production process effectively on projects.

The "Last Planner" refers to the front line supervisors (Ballard and Tommlein, 2016). The LPS is based on five key elements; (1) the master planning or milestone planning, (2) collaborative programming/phase planning, (3) the Make-ready planning, (4) Weekly work plan and (5) Measurement and learning. These processes are described extensively in (Daniel *et al*., 2017; Ballard and Tommlein, 2016; Ballard, 2000). Through the application of these

elements, the LPS supports the development of a collaborative working relationship and on time delivery of construction projects.

However, the LPS has been criticised because the programme used in developing the phase planning is taken from the traditional programme developed with the Gantt chart (Koskela and Stratton, 2010). Additionally, Kim *et al.,* (2015) argued that too much focus on percent plan complete (PPC) in LPS implementation could make the subcontractors to modify the data. Nevertheless, the LPS process empowers the stakeholders doing work to contribute to the phase planning process so as to develop a reliable plan which makes it unique to the traditional approach to project management.

The LPS is based on twelve key principles and rules (Ballard and Tommelein, 2016; Ballard *et al*., 2009) and these principles are: (1) Keep all plans, at every level of detail, in public view at all times; (2) Keep master schedules at the milestone level of detail; (3) Plan in greater detail as the start date for planned tasks approaches; (4) Produce plans collaboratively with those who are doing the work being planned; (5) Re-plan as necessary to adjust plans to the realities of the unfolding future; (6) Reveal and remove constraints on planned tasks as a team; (7) Improve workflow reliability in order to improve operational performance; (8) Do not start tasks that you should not or cannot complete, commit to perform only those tasks that are properly defined, sound, sequenced and sized; (9) Make and secure, reliable promises; (10) Learn from breakdowns; (11) Underload resources to increase reliability of work release; and (12) Maintain workable backlog. Observations of these principles support LPS implementation at the project level.

A Review of Factors that Support Last Planner System Implementation

Table 1: Factor that Supports the Implementation of LPS in Construction Project

Insert Table 1 here

In other to understand existing factors that support LPS implementation, a literature review was conducted. Table 1 presents the factors that support LPS implementation as reported by different authors. Most of the studies reviewed identified the need for training. Liker in his book "The Toyota Way" highlighted the need for training in its 9th principle (Liker, 2004). The principle states that "Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others". Training as emphasised here is not just in having mere technical knowledge of the lean techniques, but rather, a mindset change training, which could further help in the implementation. This shows that any organisation seeking to deploy lean technique across its business must be committed to training at all levels. According to Fernandez-Solis *et al*., (2012) developing human capital within the organisation will enable the organisation to implement LPS effectively.

Last Planner System Implementation in Construction Projects

The implementation of the LPS has gained prominence in the construction industry. Its implementation in construction projects has an impact on process improvement (Castillo et al., 2015; Ballard 2000). Fernandez-Solis *et al.,* (2012) asserted that the implementation of the LPS helps in creating overriding improvement in project programme predictions, productivity, workflow, reduces project time and site accidents, increases profit, enhances collaboration, while giving due consideration to employee satisfaction, among others. A comprehensive review of conference papers published by the International Group for Lean Construction (IGLC) indicates that the LPS has been implemented in over 16 countries (Daniel *et al.,* 2015). Also, the Lean Construction Institute (LCI) and the IGLC have documented the implementation of the LPS on many projects (Fernandez-Solis *et al.*, 2012). In addition to this, Shang and Low, (2014) identified that the LPS is among the most implemented lean construction technique on construction projects. However, the

implementation of the LPS is still fragmented (Daniel *et al.*, 2017; Dave *et al.*, 2015; Koch *et al.*, 2015).

Unpacking the Reasons for the non-Implementation of the Last Planner System: The Organisational Dimension

Researchers in lean construction (LC) have attempted to explain the factors that contribute to the failure of the LPS implementation in construction projects (Ballard, *et al.*, 2007; Fernandez-Solis *et al.*, 2012). For instance, Fernandez-Solis *et al.*, (2012) identified 13 factors that contribute to the failure of LPS implementation from the review of 26 case studies. The topmost factors identified from the review were organisational inertia or resistance to change ("This is how I've always done it" attitude), negative attitude towards the new system, lack of management support, and lack of human capital, among others.

Further review of the IGLC publications on the implementation identifies other factors that contribute to the failure of LPS implementation. Some of the factors identified include; resistance to change and human attitude (Fernandez-Solis *et al.*, 2012); use of incompatible procurement strategies and focus on cost (Johansen and Porter, 2003; Conte, 1998); low integration of the supply chain and subcontractors (Johansen and Porter, 2003), culture and structural issues within the organisation (Johansen and Porter 2003).

A closer look at the identified factors from earlier studies reveals that there are other organisational related dimensions such as, contract, culture, commercial terms, leadership, human behaviour and working relationship related factors within the industry that limit the implementation of the LPS, rather than the structure of the LPS itself. This assertion is further supported by Dave *et al.*, (2015) where they observed that majority of the factors that contribute to the failure of LPS implementation in construction projects identified from previous studies relate to the soft aspect i.e. organisation and people. It could be argued that

the lack of these organisational dimensions is holding back the full implementation of the LPS. For instance, Johansen and Porter, (2003) found that structural issues were among top factors holding back the full implementation of the LPS in the UK and the use of incompatible procurement strategies was one of the drawbacks from their implementation of the LPS. Furthermore, Conte, (1998) found that too much focus on cost, rather than building a relational contractual relationship contribute to the failure of the production system and Fernandez-Solis *et al*, (2012) found that organisational inertia, people attitude to the new approach and lack of leadership are among the factors holding back the full implementation of the system.

From the foregoing, it could be argued that the lack of consideration for the organisational dimension related factors could have contributed to the partial implementation of the LPS. More importantly, it highlights the need for path clearing at all levels for the successful implementation of the LPS on construction projects. The research question is: *How can construction stakeholder be supported to implement the LPS successfully in construction projects?* Successful implementation of the LPS requires deep-rooted organisational changes in thinking, culture and moving away from the old status quo and embracing the new way of working.

Hamzeh, (2009) classified the factors that contribute to the LPS implementation failure into local factors and general factors. The local factors relate to the project related challenges, while the general factors relate to the organisation implementing the LPS. This implies that the likely strategies or approach that would support the successful implementation of the LPS in construction projects should take due consideration for these classifications among others. While it is true that earlier studies have highlighted some factors that contribute to the failure of the LPS, no study has attempted offer a structured approach that incorporates the organisational level requirements, project-level requirements and external level requirements

191 in an integrated way with a view of overcoming these barriers for a smooth and successful
192 implementation of the LPS in construction projects as proposed in this study. This study fills
193 this gap by developing the "Last Planner System Path Clearing Approach".

194 ## Research Method

195 A multiplicity of qualitative research methods were used in gathering evidence for the study.
196 Evidence was gathered from semi-structured interviews and three case study. The qualitative
197 research approach was used since the study focuses on understanding human behaviour and
198 phenomena from the participant's point of view which is contrary to the positivistic approach
199 that tends to explain behaviour from the researcher's perspective (Bryman, 2012). However,
200 because the study aims to develop a model to support the implementation of the LPS, the
201 system view as suggested by Arbnor and Bjerke, (1997) was adopted. According to Arbnor
202 and Bjerke, (1997), the aim of the system approach is not to make a distinction between
203 existing knowledge and the new knowledge, rather it focuses on integrating new concepts
204 based on the current finding to the already known knowledge so as to present a better picture
205 and solution to an existing problem. In view of this, the current study was built on existing
206 literature that identified factors that support LPS implementation alongside empirical shreds
207 of evidence gleaned from the semi-structured interviews and the case study conducted to
208 develop the LPS-PCA.

209 The purpose of the literature review was to identify the underlying principles and practice of
210 the LPS (Ballard and Tommelien, 2016; Ballard *et al*, 2009; Ballard, 2000); current level of
211 implementation of the LPS across countries (Daniel *et al*, 2015; Dave *et al* , 2015; Koch *et*
212 *al*., 2015; Khanh and Kim, 2015; Kalsaas *et al*, 2014; Lindhard and Wandahl, 2014); to
213 identify the challenges and to unpack the reasons for the non/partial implementation of the
214 LPS in construction projects (Ballard, *et al* ., 2007; Hamzeh, 2009; Porwal, *et al* ., 2010;

Fernandez-Solis *et al* ., 2012; Johansen and Porter, 2003); to understand the organisational factors influencing the implementation of lean techniques and LPS in particular (Liker, 2004; Conte, 1998) and to understand the focus of previous approaches developed to support the implementation of lean techniques and LPS (Dombrowski *et al* . 2010; Lindhard and Wandahl 2014; Nesensohn, 2014).

The semi-structured interview instrument consists of three sections. The first section contained questions on the background of the respondents, section 2 centred on LPS practice and section 3 centred on how LPS implementation can be supported. The observed practice is not reported in this paper. The questions were open-ended to allow the respondents to consider the phenomenon under investigation, to reduce bias and to improve the richness of the findings. However, the questions were structured to keep the respondents on track.

Thirty in-depth interviews were conducted over a 12 month period. The interviewees comprised of 18 main contractors, 2 clients, 4 lean construction consultants, and 6 subcontractors. More main contractors and subcontractors were interviewed in the first phase of the study, this is because they are those involved in the implementation of the LPS. All respondents interviewed had over 3 years' experience in the use of LPS and were drawn from building construction, highways and infrastructures and rail sectors. Purposive sampling was adopted in selecting the respondents. Purposive sampling is a sampling approach that allows the researcher to select the appropriate population for the study so as to answer the research question adequately (Bryman, 2012). Purposive sampling was deemed appropriate for this study as there was no formal database for lean construction practitioners in the UK (Teddie and Yu, 2007). Furthermore, this ensured that only those with experience in LPS practice participated in the interview. However, Taylor and Bogdan (1984, p. 79) observed that no research method "can provide the detailed understanding that comes from directly observing

people and listening to what they have to say at the scene". In view of these, the semi-structured interview was supplemented with the case study approach that allows the study to observe the physical work environment, interview the people working in the environment and analyse relevant documents so as to answer the research question.

The Case Study

Yin, (2014) identified reasons for the choice of case study approach such as; (1) when the study seeks to answer research questions such as "how" or "why" (2) when the goal of the study is not to have full control over the phenomenon being investigated and (3) when the goal of the study is to focus on real-life situations in a given context. The case study approach has also been identified to align with the system approach adopted in the current study (Arbnor and Bjerke, 1997). In this study, the case study approach was adopted as it allows the study to understand how construction stakeholders can be supported to implement the LPS by gleaning evidence from the real-life situation (the project and its physical environment where the LPS is being implemented) and the individuals inhabiting it (the stakeholders on the project). Eisenhardt and Graebner, (2007); Amaratunga *et al*., (2002) observe that the case study approach allows the researcher to gain a deeper understanding of the research problem or the phenomenon in relation to the context in which the study is being conducted. However, the case study approach has been criticised for lack of rigour and defined procedure for carrying out the investigation. Nevertheless, Yin, (2014) asserts that the issue of lack of rigour can be overcome when different techniques and methods are used in collecting data known as triangulation.

In view of this, semi-structured interviews were used in the first phase of the study while multiple case study involving different techniques was used in collecting data in phase two of the study. These techniques include semi-structured interviews, document analysis, and unstructured observation. The documents analysed include contract documents, construction

programme, Look-ahead plan, weekly work plan sheet, progress reports, published PPC, published reasons for non-completion (RNC), and minutes of collaborative programming or phase planning meetings. In doing the observation, one of the authors attended the LPS meetings held on the three case study projects. Arbnor and Bjerke, (1997) observed that the system approach enable a study to aggregate evidence using secondary materials, observations and interviews. The evidence gleaned from the literature review could be termed as secondary in the context of this investigation. According to Yin, (2014) triangulating data through the use of multiple techniques and methods supports the development of the converging point for research findings and, thus strengthens the validity of the study.

Case Study Design

Multiple case study approach was used in the investigation. A literal replication case study design that uses content analysis of qualitative interviews, documents analysis including observation of the physical environment was adopted. According to Yin (2014), literal replication enables a study to understand how a process works or function across cases. In this study, the literal replication design, enables the study to identify factors that support the implementation of the LPS on the case studies observed. However, to use literal replications, a study must have prior knowledge of the cases to be selected (Yin, 2014). In view of this, a semi-structured interview was conducted by the author(s) in the first phase of the study to develop an understanding of the use of the LPS. The case study design also built on the theoretical literature review that unpacked reasons why the LPS is not fully implemented on construction projects (Ballard, *et al.*, 2007; Hamzeh, 2009; Fernandez-Solis *et al.*, 2012; Johansen and Porter, 2003). The literal replications design was used as it allows the study to glean empirical evidence on how the LPS was supported on the case study projects

investigated. It is worth mentioning that the use of multiple case studies in this investigation is not for sampling logic, rather it is to identify how the LPS can be supported from the emerging themes from the interviews, document analysis, observation and the existing theory. Yin, (2014) argued that the application of sampling logic to case study research could defeat its purpose.

The rationale for Case Selection

In selecting the cases, various factors associated with case study design as suggested in Yin (2014) and Bryman (2012) were adhered to. It is important that cases are selected carefully to avoid a condition where the evidence obtained is insufficient to answer the research question (Yin, 2014). In view of this, the authors ensured that the selected 3 cases were from the major sectors of the UK construction industry. Two of the cases are from the Highways and infrastructure and one from the building sector. No case was chosen from the rail sector as it has already been observed from the semi-structured interviews that rail projects, share similar characteristics (linear construction) with highway and infrastructure projects. The focus of the study was to develop an approach that could support LPS implementation across the UK construction industry, thus selecting case studies from the major sectors was considered appropriate. This was also to ensure that the proposed approach would be able to support the implementation of the LPS across these sectors. Purposive sampling was used in selecting the cases. Bryman (2012) stressed that purposive sampling allows the researcher to select a case(s) in order to answer the research question. The criteria used in selecting the cases are:

- The project must be managed with the LPS principles
- The project must be on-going

- The organisation involved should have implemented the LPS for not less than three years

. This was done to ensure only organisations with requisite experience in the use of the LPS were investigated. The authors were also given the opportunity to gather the required evidence through the observation of the physical environment. .

Data Collection

The case studies were conducted concurrently over a period of 12 months; this provided an opportunity to collect real-world evidence. In this study, for the purpose of confidentiality the case studies are described as CSP01, CSP02 and CSP03 (where C= case, S= study P=project). Evidence was gleaned from three major sources for each project. These are; documentary evidence, observations, and semi-structured interviews. The three approaches were used in deepening and authenticating the results (Yin, 2014). Data collection started with observations, document analysis and then semi-structured interview. This enabled further clarification on findings from observation and document analysis. Also, the first author attended the monthly Lookahead production planning meeting as an observer.

In each case study, senior managers (SM), middle managers (MM), operational managers (OP), and subcontractors (SC) were interviewed. Four of the SM and three of the MM interviewed were clients. This was done to ensure the views of the major stakeholders involved in managing the production process and those responsible for making a strategic decision on the construction projects were sought in the investigation. The interview instrument case consists of two sections; the background of the respondents and questions on the nature of support required for LPS implementation. A total of 28 research participants were interviewed, which include; SM = 9, MM = 6, OP = 6, and SC = 7. This shows the key stakeholders on the project were adequately involved in the study. Majority of the respondents claimed to have above 3 years' experience in the use of LPS in construction

projects and have over 10 years' experience in the construction industry, this means their response can be relied on.

Data Analysis

The data collected were grouped into a dataset and placed in folders/files; for the semi-structured interviews and for each of the case study. The interviews were transcribed verbatim and cross-checked with findings from documents analysis and observation. In doing this, the data were categorised based on qualitative data analysis techniques after Miles and Huberman (1994). The themes and code used for the analysis were based on the interviews questions and themes that emerged from the transcribed interview. The data analysis process was supported by Computer-Aided Qualitative Data Analysis (CAQDAS) software known as 'NVivo'. The software was used due to the large nature of the data. According to Silver and Lewin (2014); and Bryman, (2012) NVivo software does not only manage large data set, but it also supports transparency, replicability and validation of qualitative data. The emerging themes and sub-themes on the nature support required are discussed in the subsequent section.

Description of Case Study projects

Table 2 presents the study projects' attributes. The table shows that the case studies on which LPS application was investigated cuts across the major sectors of the UK construction industry.

Table 2: Case study project Attributes

Insert Table 2 here

Case Study Project One

The case study project one (CSP01) is a highway infrastructure project which is an upgrade to replace a dual carriageway with a three-lane motorway. It also includes the construction of

associated facilities such as bridges among others. The project comprises of different facets and many stakeholders, which requires coordination and management. For effective coordination and management of the project, the project was divided into three sections; the north, the south, and the central sections. All the sections of the project were managed using the LPS with three different supervisors and one central coordinator. The researcher observed CSP01 over a period of 10 months, which started at the construction phase. This enabled the study to gain insight into the nature of support to be put in place for effective implementation of the LPS. The procurement approach used is design and build (D&B) and the contractor claimed to have used the LPS to manage the construction process on their previous project. This means their previous experience in the use of LPS could contribute to the current research.

Case Project Two

The case study project two (CSP02) is also a highway infrastructure project. The aim of the project was to reduce congestion on the network using technology to vary speed limits. The project was divided into two main sections; Northbound and Southbound sections. The project was managed with the LPS. A single production planning session was held for both sections at the project site office. The LPS implementation was internally facilitated by the site agent with the support of the programme manager and the work package managers. The contractor had implemented LPS on their previous project. Based on the data collected, CSPO2 was procured with traditional design-bid-build (DBB). However, the subcontractors on the project were on a framework agreement. CSP02 was observed by the research team for close to 12 months. This shows the project had progressed enough to capture useful evidence for the study.

Case Study Project Three

The case study project three (CSP03) is a new educational building project. The main contractor on the project is one of the top UK building construction contractors with over 30 years' experience in the UK building construction industry. In the past, the main contractor had been involved in various construction process improvements championed by the UK Government, such as the Construction Lean Improvement Programme (CLIP) conducted by the Building Research Establishment and the Department of Trade and Industry. Also, the main contractor had been in a framework agreement with all its supply chain for over five years. The mode of procurement used is design and build (D&B). LPS principles were used in managing the production processes. The use of LPS on the project was motivated by the main contractor as it had been used on their previous projects. CSP03 was also observed for 12 months.

Performance of Last Planner System on the Case Study Projects

Table 3 shows that the LPS practice implemented across the three case studies include, phase planning, WWP, measurement of PPC and RNC.

Table 3: Performance of Last Planner System on the Case Study Projects

Insert Table 3 here.

The study shows that a daily huddle meeting was held on CSP03 and later on CSP01, but was not done on CSP02. Although daily huddle meeting was not part of the initial elements of LPS (Daniel *et al.,* 2015, Ballard *et al.,* 2009), its use in monitoring how the production system is performing on the day of production on site is on the increase (Daniel *et al.,* 2015; Salem *et al.,* 2006). This could be due to its potential in checking the production system on the day of production and to also re-plan in case of any deviation. For instance, it was not done on CSP01 initially, but it was later introduced.

Constraint analysis was observed on all the three case study projects, however only CSP03 developed a partial strategy to remove the identified constraints. On CSP03, constraints and action log were collaboratively developed by the team with actions assigned. However, the action log was only circulated via email to the distribution list at the end of the look-ahead planning meeting. It was also not published visually in the LPS meetings as expected. Publishing it visually not only improves process transparency but also keeps all the stakeholders on the project conscious of the actions required of them. On CSP01, constraints were only partially logged with no personnel given the clear action to address the identified constraints. Also, on CSP02, constraints were logged but not all the responsible persons for actions were usually available at the look-ahead planning session, especially the designers. Hence, another separate meeting had to be arranged with the team.

This show there is a lack of discipline in the constraint removal process on the case study projects. Previous studies have also shown that there is lack of rigour in the implementation of more complex elements of the LPS such as the make-ready process (Daniel *et al.*, 2015; Dave *et al.*, 2015; Lindhard and Wandahl, 2014; Ballard *et al.*, 2009; Alarcon *et al*, 2011). Furthermore, Table 3 reveals that CSP01 has the least PPC average of 72.29 %. Though this may seem good, however, going by the meaning and goal of PPC in showing workflow reliability (Ballard, 2000), this may not be true on CSP01. This is because it was observed from the interview that sometimes there were cases of over and underestimation in the amount of work to be done by those doing the work. For example, a PPC of 0% and 100% were observed in some weeks on CSP01 which further attests to this fact. In some cases, PPC could be 100% with work still behind schedule when tasks are not properly made ready (Hamzeh, *et al.*, 2012). According to Kim *et al*, (2015), too much focus on PPC could make the subcontractors to modify the data. This implies attention should be on achieving smooth workflow as good workflow would definitely improve the PPC.

Also, the reasons for non-completion RNC of tasks were recorded on all the three case studies. The main causes of RNC on CSP01 were previous work not done and underestimation, while on CSP02 it was the design changes and change of priority. On CSP01, the lack of rigour in the make-ready or constraint removal process could have contributed to the frequent occurrence of previous work not been completed on the project and also the lack of honesty in making promises. Dishonesty and insincerity in promising were seen as a barrier to LPS implementation on the three case study projects.

The study reveals that among the many LPS metrics, only PPC was measured on the projects. Metrics such as Task Made Ready (TMR), Task Anticipated (TA), and frequency of plan failure were not measured on any of the projects (Ballard, 2015; Ballard *et al.*, 2009). This could be due to the ignorance of the existence of such metrics and the level of maturity of the use of LPS. According to Hamzeh *et al.*, (2015); Ballard *et al.*, (2009), the above mentioned LPS metrics are less practised even on projects that claim to use LPS, this implies the situation is not peculiar to the UK construction industry alone.

The study reveals that some form of learning occurs on all the projects, however, the amount of rigour required to actively translate the learning to practice is inadequate. For instance, on CSP01, though RNC was recorded, one of the respondents stated that not much was done with it. Also, developing workable backlog was not done on any of the case study projects.

Results and Discussion

The aim of the current study is to develop an approach to support the client, main contractors, and subcontractors for the successful implementation of the LPS on a construction project. The emerging themes and sub-themes from the semi-structured interviews and the three case studies are presented and discussed.

Emerging themes and sub-themes from the semi-structured Interviews and the Case Studies.

From the analysis of the initial semi-structured interviews and semi-structured interviews on the three case studies, three core themes and other sub-themes emerged on the nature of support required for effective implementation of the LPS. These themes are:

1. Support required at the organisational level
2. Support required at the project level
3. External enablers

Support Required at the Organisation Level

The emerging sub-themes on the nature of support required for LPS implementation at the organisational level identified from the semi-structured interviews and case study are presented and discussed below.

The inclusion of LPS Practice in Contract Clause

The inclusion of LPS in the contract was mentioned in all the case studies and in the semi-structured interviews. For instance, one of the clients that participated in the semi-structured interview (EI) stated that:

> *We include LPS practice in the contract with our supply chain; they know they will be doing it. This means we have paid for it.* **[Client, Semi-structured interview].**

Another respondent observed that because the LPS was part of the contract, it motivated everyone on the project to get committed to the process **[CSP03, Senior Planner].** Also, a subcontractor on CSP03 stated that: *"It is part of the main contractor's policy, so if we do not want to do it, we can't go away with it. "By signing into it in the contract supports my commitment to it and it benefits us as subcontractors*" **[Subcontractor's, Senior Site Manager]**.

This view was further reiterated from other research participants on CSP01 and CSP02. *"There should be a point where it has to be mandated and written into the contract and*

benefits should be shared" **[CSP01, Excellence Manager]***".* Respondents on CSP02 suggested that the process should be formally included in the contract by the organisation **[CSP02, Site Engineer; CSP02, Site Agent].** Doing this is essential as it makes it a formal process on the project, thus encouraging more commitment to the process. Also, it would ensure that all the required stakeholders get engaged in the process as expected.

Furthermore, construction is filled with many formal processes (Kadefors, 2004), which sometimes may not even support the goal of the project. However, the goal of LPS is to engender collaboration among the project team, while also focusing the team to achieve the common goal of the project (Ballard and Howell, 2004). According to Kadefors (2004), formalisation of the construction process should not be in relation to cost alone, but should include other practices that would support the actualisation of the project objectives. The LPS should be considered to be among such formal practices or processes too.

Involvement of the Commercial Arm of the Business in LPS Meetings

The inclusion of the commercial arm of the business in the LPS implementation loop by the organisation was considered to support the implementation of the LPS. Some of the interviewees on CSP03 believed that the inclusion of the commercial team such as the quantity surveyor, commercial managers, cost controllers, and cost engineers among others in the LPS process would further support the system. One of the respondents stated that on CSP03:

> *"I think the built environment team and the planning team are involved in this process, the commercial side of the business tends not to be in the loop in term of delays or acceleration in the programme. The commercial side of the business should be kept in the loop"* **[Subcontractor's, Contract Manager].**

The place of involving the commercial team in the process cannot be overemphasised, since every change in the programme from the LPS meetings as a result of reliable promising has its own commercial implication to the project. Hence, their involvement in the production planning meeting as and when required could reduce the time required in making decisions that relate to commercial matters (cost, contractual implication etc.) during the make-ready and look-ahead planning sessions. However, this must be done with caution, as it has been observed that when the production shifts too much attention to cost, the production system could fail (Conte, 1998).

Provision of Training

Some of the respondents suggested that the organisation must be committed to the training of its employees on the new approach. The respondents on CSP01 stated that:

> "*There is need to educate others on the project on LPS and invite other site representatives to be involved in the process"* [**CSP01, Section Engineer].** Also, the main contractor stated that: "*for an organisation that is venturing into it, there is need to provide training and demonstration of tangible benefits from previous implementation"* [**Main contractor, semi-structured interview)**

On the CSP02 majority of the respondents, including the subcontractors identified the need for the provision of training by clients and main contractors. For instance, some of the respondents stated that: *"There is a need for guidance on LPS right from conception by the management, we do receive some training on LPS"* **[CSP02, Project Manager]**. The need for the provision of training was also identified by the programme manager *"Training is very essential, without it the facilitation would not work"* **[CSP02, Senior Manager, representing the client].**

This shows that at the organisational level, a procedure should be put in place to support training and facilitate the practice of LPS across different business units. The nature of

training to be provided should be tailored for each stakeholder on the project. For example, the initial training for the smaller subcontractor should be to explain the benefits of the process to them in order to get their buy-in before full implementation. Previous studies have shown that training, management support, and early involvement of stakeholders are essential for LPS implementation in construction projects (Hamzeh and Bergstrom 2010 and Ballard *et al*., 2007).

Support required for LPS Successful Implementation at the Project Level

The emerging sub themes on the nature of support required for LPS implementation at the project level identified from the semi-structured interviews and case study are presented and discussed below.

Last Planner System Facilitator and Champions

At the project level, the need for a facilitator and the appointment of champions to drive the process was identified in the three case studies. On CSP02, some of the respondents interviewed stated that:

> *"A facilitator is needed to promote the benefits of LPS, an external facilitator within the 1-4 weeks and internal facilitation to continue the process. Also, appoint lean managers, both at the project and organisational levels to promote the practice across the business"* **[CSP02, Programme Manager]**. "*The LPS session should be facilitated by someone who has knowledge of the work involved to present a bigger picture"* **[CSP02, Site Agent].** "*Have a champion to promote it"* **[CSP02, Section Engineer].**

This was also echoed by research participants on CSP01, one of the middle managers stated that: "*A facilitator is needed to coordinate the process for the initial start, this is an early stage support"* **[CSP01, Section Engineer].** A client in the semi-structured interview stated

that: *"A* facilitator is required within the organisation and on the project to drive the entire process across the business**" [Client, semi-structured interview].** This is because the process cannot really progress if it is not duly facilitated. However, some of the respondents were of the view that facilitators should be limited to the early stage only **[CSP01, Programme manager]**

The above statements from respondents show the need for facilitators and champions for driving the process. The statement further suggests that the facilitator should have some level of understanding on the nature of work executed**.** This is crucial as the process would not progress if there are no capable and experienced personnel to manage the process. Previous studies have also identified the importance of facilitators in the implementation of the LPS (Alarcon *et al.*, 2011). On all the case study projects investigated, the process was internally facilitated. However, on CSP01, it was argued that after the initial facilitation, the process should be left with the team. As good as this may seem, it could lead to the abandonment of the entire process as each member of the team has a specific role to perform on the project. Leaving the process to the team to do it, means no one would be held accountable. However, on all the three projects, LPS facilitation was the primary responsibility of the facilitators which yielded better results.

Honesty, Transparency and Reliable Promising

The need for discipline, transparency, and truthfulness, especially in conversation and making promises by the stakeholders in production planning sessions were considered essential at the project level on all the three case studies. Some of the respondents interviewed on CSP03 stated that honesty in making promises and giving out of information, especially at the production planning meetings is essential. Some of the respondents stated that: *"Some subcontractors agree dates knowing they cannot achieve it!!!"* [**Subcontractor's, Senior Site Manager].** *"The process is fine, one of the barriers is people committing to things they*

582 *cannot do and also unrealistic expectation from the main contractor"* **[Subcontractor's,**
583 **Contract Manager].**

584 The statements above further highlights why the stakeholders at the project level should not
585 be pressurised into making promises or commitments, as such promises could turn out to be
586 unrealistic sometimes. In making promises in the LPS approach of managing construction
587 projects, workers are not pressured into making promises, rather, they are empowered to
588 make promises of what they can do. This approach supports reliable promising. This
589 underscores the importance of realistic expectations and promises. Macomber and Howell,
590 (2003) identified five elements in making a reliable promise among project stakeholders.
591 These are: (1) understanding the condition of satisfaction (2) competency to perform the task
592 (3) capacity to perform the task (4) sincerity and (5) commitment to clean the mess, if failing.
593 This clearly suggests that in making promises during production planning sessions, the team
594 must be transparent and sincere that the capacity required to deliver the task is available
595 before making the promise. It is through reliable promising in the LPS that trust and
596 confidence increases/develops among the project stakeholders (Issato *et al*.,2015).

597 ***Involvement of all the Required Stakeholders***

598 The respondents believed that full engagement of all "required stakeholder" (those that have
599 the required capability to make decisions during production planning meetings), is essential
600 for its success at the project level. Some of the respondents stated that:

601 "*The collaborative programming sessions should involve the client, the designers,*
602 *main contractors, and subcontractors"* **[CSP02, Manager]. "***Based on my experience*
603 *from previous of LPS implementation on our past projects, having the right people in*
604 *the room is essentials"* **[Client, semi-structured interviews]**

Again, this call by the respondents shows that not all the required stakeholders are engaged in the collaborative programming sessions. For instance, it was observed on CSP02 that the designers were not usually involved in the session due to the nature of the procurement used. The implication of this *non*-all-inclusive engagement of the stakeholders in the process is that the make-ready and constraint removal process would be incomplete. This increases the level of uncertainty in the activity scheduled.

Pre-planning by the Team before Production planning session.

The respondents interviewed on CSP02 observed that pre-planning by the subcontractors and work packages managers before the Last Planner session is essential for success at the project level. Some of the respondents stated that:

"The subcontractors must come with a realistic programme, not just the duration on the contract programme" **[CSP02MM02, Site Agent]**. *"Prepare a plan before the collaborative planning session (base programme)"* **[CSP02SM02, Production Planning Manager].**

The need for pre-planning before the collaborative production planning sessions cannot be overemphasised, as it keeps the team in the right state to make a meaningful contribution during the session. On CSP03, the need for the team to make a realistic plan before coming to the session was also echoed. One of the subcontractors stated that: *"The way the process is facilitated supports our buy-in and it is great to see that some subcontractor use to do some homework before coming to the Last Planner meeting but some are not willing which prolongs the conversation.* **[Subcontractor's, Contract Manager].**

External Support Required for LPS Implementation

The emerging sub-themes on the external support required for the implementation of the LPS as identified from the semi-structured interviews and case study are presented and discussed below.

Process Standardisation

On CSP02, the respondents observed that a common or standard approach to LPS implementation would support its rapid implementation. Some of the respondents interviewed are of the opinion that the approach seems to vary from one project to another. One of the subcontractors stated that: "*People tend to view or practice the Last Planner differently, there is a need to have one format or approach. There should be one approach across projects"* **[CSP02SC01, Subcontractor's Project Manager].**

Again, this shows that there are variations in the current implementation of LPS principles on the projects investigated in the UK. Previous studies in the UK and elsewhere have also reported the partial implementation of the LPS in construction project (Daniel *et al.,* 2017; Dave *et al.,* 2015; Koch *et al*., 2015; Khanh and Kim, 2015; Lindhard and Wandahl, 2015).

These shows that external support is needed as it will be too simplistic to conclude that the LPS does not need improvement. Studies have shown that the LPS is dynamic and it is now being incorporated with BIM, Location-based management, and Takt planning among others (Daniel *et al.*, 2015; Seppanen *et al.*, 2010; Sacks *et a* ., 2009). Also, it is interesting to note that the LPS has been benchmarked by Glenn Ballard with input from current practitioners, research institutes, consultants, and the academia to improve the initial framework on which it was developed (Ballard and Tommelein, 2016).

The partnership between the Industry and the Academia

A partnership between the construction industry and academic institutions on research, with a focus on LPS, was suggested as an external support required. One of the managers on CSP01 suggested that:

> *"There is a need for more alliance between the academia and the industry. More articulation and pro-activeness in communicating improvement and findings to the industry. More emphasis should be placed on the correlation between the industry*

654 *and the institution"* **[CSP01, Excellence Manager].** A client also stated that*: "Our*
655 *partnership with Universities is helping us to support our supply chain in the*
656 *implementation of the LPS on our projects"* **[Client, semi-structured interviews]**

657 This partnership is important, as academic institutions would be able to communicate recent
658 developments on its application and principles to the industry practitioners. For example, in
659 Brazil, it was reported that the active engagement between construction companies and
660 academic institutions in the LPS principle implementation on projects has yielded positive
661 results and similarly in Chile (Alarcón *et al* ., 2011; Formoso *et al* ., 2002). In the UK,
662 institutions such as Nottingham Trent University, University of Cardiff, University of
663 Salford, Lean Construction Institute, UK and Costain Plc among others are into such research
664 partnership with Highways England.

665 Some of the respondents believed that higher education institutions which provide training in
666 construction project management, and civil engineering among others, have a role to play in
667 passing on the knowledge to their students. This could support the implementation of the
668 process. One of the respondents argued that:

669 "*There is a need to adopt some of this concept such as the Last Planner in their*
670 *training and teaching. The curriculum should be updated with what is happening in*
671 *the industry, LPS should be included in the construction project management*
672 *programme"* **[CSP02SM02, Production Planning Manager].**

673 This shows that construction management and civil engineering training should not only
674 focus on the hard or technical skills alone, but other soft management skills such as those
675 encouraged in lean principles should also be taught**.**

Results from Documents Analysis and Physical Observations on the Case Studies

To understand how LPS implementation can be supported, the first author participated in various LPS meetings held on the case studies project investigated and observes the physical environment. The observation was unstructured; this was to allow the study to capture a wide range of relevant evidence as they emerge. Relevant documents were also analysed. The emerging themes are discussed as follow:

Provision of Production Planning Control on the Site

On all the three projects observed (CSP01, CSP02 and CSP03) the first author observed that there were designated permanent rooms for LPS meetings. The respondents were of the view that a designated room for LPS meetings should be provided on site. One of the subcontractors stated that: *"Allow for a suitable rooms/facility on site for LPS meetings and session"* [**CSP01, Project Manager]**. This is essential as such room/facility could further provide information visually to other members of the team who were unable to participate in meetings in real time. Also, visiting the room would give everyone an idea of project activities on site. However, setting the room outside the project site could reduce such benefits and could contribute to non-value adding activities. This is because it would require site workers travelling to the head office to view the board. But the siting of the production planning and control centre on site would create a feeling of belonging to the site team.

Proactive Involvement of Construction Manager

The result of the physical observation reveals that on CSP01 north section, CSP01 central section, CSP02 and CSP03, the construction managers were actively involved in the LPS meetings. However, this was not the case on CSP01 south section. Also, the participation of the subcontractors in LPS meeting in CSP01 south section was poor compared to the north and central section on CSP01. This could be due to none active involvement of the construction manager. The involvement of the construction or project manager at the project

level would help the project team to see the process as the company process of delivering its business. Practically, this entails attending and contributing in production planning meetings by the project manager. According to Hamzeh and Bergstrom, (2010), when a process on a project is viewed as external or ad hoc, there would be less commitment from the team.

Use of Collaborative Form of Procurement

The result of document analysis and physical observation in the three case studies indicates a form of collaborative procurement was used. The collaborative form of procurement include; early contractor involvement (ECI); framework agreement, Design and Build and joint venture. Evidence from the investigation shows that on CSP02, design bid build (DBB) was used in procuring the project. However, because the supply chain had been in a framework agreement, the collaborative relationship had developed which enhanced and supported the implementation of the LPS on the project. The contractual behaviour that occurs there could be better explained with relational contracting theory. Macneil, (1980) observed that as parties to the contract have more and frequent conversation on the project, the relationship begins to develop. Furthermore, the assurance of the possibility of securing a future job, for example, in a framework agreement, could motivate the team to get committed to each other on the project. According to Harper, (2014) when there is shared expectation between teams on a project, it would influence their behaviour on the project. This means the use of a collaborative form of procurement at the organisational level would support LPS implementation in a construction project.

Development of the Last Planner System Path Clearing Approach

The approach to support LPS implementation in construction projects was developed based the literature review on the LPS presented in the literature review section, the evidence gathered from the 30 semi-structured interviews, and the three case studies conducted as presented and discussed in the result and discussion section. The developed approach is

known as *the Last Planner System Path Clearing Approach* (LPS-PCA). It is called LPS-PCA because it clearly shows what needs to be in place for a rapid and successful implementation of the LPS on construction projects.

The rationale for the Last Planner System-Path Clearing Approach

As earlier mentioned in the literature review, the need for supporting the implementation of new techniques has been acknowledged in the literature (Nesensohn, 2014; Sacks *et al.*, 2010, Ballard *et a* ., 2007). However, studies that have attempted to propose an approach for implementing specific lean techniques such as LPS in construction tend to focus more on the project level (Lindhard and Wandahl, 2014; Hamzeh and Bergstrom 2010; Dombrowski *et al.,* 2010). The absence of a holistic approach to supports construction stakeholders in the implementation of the LPS informed the development of the LPS-PCA. The objectives of the proposed Last Planner System Path Clearing Approach (LPS-PCA) are as follows:

- To highlight the foundational factors or path levels that need to be in place for the rapid and successful implementation of the LPS in construction.
- To offer a structured and holistic view on LPS implementation in construction.
- To offer an insight on how to sustain the implementation of the LPS in construction using a systemic view.

Theoretical Overview of the Proposed Approach

The proposed approach is built on various theories that have been used to explain the working of LPS in construction. Some of these include: Transformation, Flow, and Value theory (Koskela, 2000); management-as-planning (Johnston and Brennan, 1996) and Hayek's, (1945) comment about the way knowledge needed for planning is dispersed among individuals. The proposed approach is also explained by a relational contracting theory perspective (Macneil, 1980).

Koskela developed the *Transformation Flow* and *Valu*e (TFV) theory mostly referred to as TFV theory (Koskela, 1992; Koskela, 2000). It has been observed that the current approach used in managing construction project tends to support only the *transformation view*. The transformation view focuses on the conversion of input into output with less regard to what happens in the project environment (Koskela and Howell, 2008). However, such view is false and counterproductive due to the uncertainty and variability inherent in the construction environment. In view of this, Koskela, (2000) proposed that the Flow and Value concept should be added to the Transformation concept on which the current theory of project management is conceptualised. The understanding and usefulness of the flow concept have been demonstrated in lean construction and in the LPS (Liu and Ballard, 2011; Sacks, 2016, Koskela and Howell, 2008). The LPS uses the flow concept to identify and ensure task preconditions are satisfied before sending them to the work phase. The flow concept is applicable in the proposed LPS-PCA at the project level which relates to the alignment of the current practice within the organisation to LPS standard practice that supports workflow at the project level. The practice that supports smooth workflow at the project level is the Make-ready planning where the project team collaboratively identifies constraints and develop strategies to remove them within the six weeks lookahead window before the actual commencement of the task (González *et al*, 2010). This practice supports workflow at the project level in the proposed LPS-PCA.

Furthermore, the management-as-organising (MAO) view as presented in Johnston and Brennan, (1996) supports LPS implementation. In this approach, it is believed that each sub-unit in the system has the capacity to plan, sense and act, thus, the planning decision should not be left with "the managerial part" alone. This theory further justifies the inclusion of all the required stakeholders in the LPS meeting as an essential requirement for LPS implementation at the project level in the proposed LPS-PCA. In reality, the engagement of

the required stakeholders supports the development of the reliable plan (Javanmardi *et al*, 2017). For instance, Javanmardi *et al*, (2017) found that synergy between subcontractors reduces variability and improves plan reliability. A related theory that supports this view is that proposed by Hayek, (1945) in economics where it was argued that the knowledge needed for making a decision is dispersed among people. This goes to show that the decision on planned construction activities should not be left to the chief planner alone, but should also include those doing the work as advocated in the LPS (Kalsaas, 2012) and proposed in the LPS-PCA. These two theories align with the theme that emerged from the current study on the need to involve all required stakeholders in the LPS meetings at the project level.

The relational contracting theory proposed by Macneil, (1980) posits that as parties to the contract have more and frequent conversation on the project, the relationship begins to develop. This view aligns with the result of the document analysis and the physical observation where it was observed that most of the contractors are into one form of collaborative relationship such as framework agreement. This means the use of a collaborative form of contract that allows the project organisation to develop a long-term relationship supports LPS implementation. This emanates from the better understanding the project organisations would have developed about each other over time.

Description of the Composition of the LPS-PCA

The LPS-PCA comprises three main components (known as path clearing levels) as shown in Figure 1. These include:

1. Organisational level
2. Project level
3. External enablers level
4.

Figure 1: Last Planner System Path Clearing Approach

Insert Figure 1 here

Organisational Level Path Clearing

Organisations play a central role in the implementation of lean principles and techniques. At the organisational level, it is essential to create an enabling environment that supports a long-term relationship that is built on collaborative practice and process. The theory that aligns with this is the relational contracting theory proposed by Macneil, (1980). The theory argued that collaborative relationship develops between different organisation and parties when they work together over a long period of time. Harper, (2014) argued that when there is shared expectation between parties in a contract, it would influence their action and commitment. This explains why -the inclusion of LPS in the contract, use of a collaborative form of contract, relational contracting and collaborative working culture supports LPS implementation at the OL.

The conditions required at the organisational level (OL) for rapid and successful implementation of LPS as shown in Figure 1 are categorised into (1) *organisational process input factors* and (2) *organisational contextual input factors*. The process input factors are discussed below.

Organisational Level Process Input Factors

This refers to the processes that need to be created and practised at the organisation level in the implementation of LPS. As it is called, it defines the processes that need to be in place at the organisational level (OL) for the LPS implementation. These include;

- identifying the imperative for LPS implementation/ leadership
- identifying and understanding the drivers for LPS implementation
- strategic capability commitment to support LPS implementation
- creating awareness on the strategic capability across the business

a. The Imperative for LPS Implementation and Leadership

An organisation must identify the imperatives for the implementation of the LPS in its business. The imperative here is beyond having a goal of fulfilling an expectation from the client. For instance, in the UK, the demand from some public sector clients seems to be among the top imperative factors driving some supply chain companies in the implementation of the LPS. Such an imperative factor or driver cannot sustain the implementation of the LPS and indeed is a weak imperative factor.

Ideally, the imperative for LPS implementation should be based on the desire to become an active agent to support collaborative behaviour among employees. This implies that both the client and supply chain have a role in championing the LPS implementation. Also, it shows that the LPS implementation should not be championed by client companies alone, as perceived by some supply chain companies. In addition to this, a high-level leadership support is required to drive the process. Previous studies have shown that top management support and leadership are essential in the successful implementation of lean techniques such as the LPS (Hamzeh and Bergstrom 2010).

b. Identify and Understand the Drivers and Benefits for LPS Implementation

The specific drivers for the implementation of LPS should be identified. This is important as the drivers for LPS implementation in a client organisation could vary from that of a contracting organisation and even from one client or contracting organisation to another. This implies each organisation must identify its own drivers. The early identification of these drivers is an essential process input which should be in place, as it has the capacity to put pressure on organisations (client and supply chain companies) to create the needed change that could support the implementation. According to Ogunbiyi, *et al.,* (2014) identifying the drivers for lean implementation could support the change in the organisation.

c. Strategic Capability Commitment to Support LPS Implementation

After identifying the imperatives and drivers for LPS implementation, it is important to develop a clear strategy and capability to support the implementation. Without a clear strategy, the LPS implementation cannot be sustained in the organisation. Both construction clients and supply chain companies must create their own strategy. This should focus on deliberate commitment to developing the required capability at the OL that would support the implementation. Findings from this study reveal that cultural issues were among the most reported barriers to the implementation of the LPS. This could be minimised through the development of the right strategy and creating policies that could influence the organisational culture in the implementation process. This implies that the strategy should not be selected in isolation. Karim and Arif, (2013) observed that selection of the wrong strategy in the implementation of lean principles could lead to the disruption of the process it intends to improve. The strategy could include the provision of training for staff and the supply chains, supply chain assessment, changes to the contract, and the creation of a lean business department, among others.

d. Create Awareness on the Strategic Capability Commitment for LPS

The identified strategic commitment capability for LPS implementation and the process created to formalise them at the OL must be communicated through training at all levels. This could entail the use of company intranet to communicate such an approach and information. The information guiding such an approach should be located in areas where it would be prominent and accessible. Also, workshops and training on the strategic capability and commitment required should be organised at all levels. Specific avenues and approaches that could be used to create awareness on this include:

- company intranet, newsletters, updates from formal project meetings
- workshops, training, and

- monthly project briefing among others

This would enable all the departments within the business to understand what the organisation is doing, which would influence their own individual commitment to the strategic capability identified at the OL. The importance of creating awareness on company strategy at all levels has been emphasised in the literature (Elving, 2005).

Contextual Inputs Factors (Behaviours arising from the contract)

As shown in Figure 1, contextual input factors are the appropriate behaviours that should be in place at the OL to support the strategic capability commitments for LPS implementation. It focuses on the behaviours arising from the contract and its application in the process. The importance of having the right behaviour in the implementation of lean techniques cannot be overstressed as previous studies have shown that cultural and structural issues are among the factors that contribute to the failure of implementation of lean techniques. Johansen and Porter (2003), found that cultural and structural issues are the factors impeding the implementation of the LPS in the UK. Having the right behaviour in place helps in formalising the strategic capability identified. Thus, it should form the key components of the strategic capability commitment process. The behaviours arising from the contract include:

- the inclusion of LPS in the contract
- use of acollaborative form of contract
- use of relati onal contracting
- collaborative working culture and
- keeping the business arm of the organisation in the LPS loop

a. The inclusion of LPS in the Contract

Findings from this research reveal that LPS practice was formally included in the contract agreement between the main contractor, client, and subcontractors on most of the projects investigated. The essence of its inclusion in the contract was to encourage all the required

stakeholders to get involved and benefit from the process. This is necessary because of the numerous formal processes that dominate the construction industry. It has been suggested that the formal process should not be in relation to cost alone, rather it should include other soft practices that contribute to the project success (Kadefors, 2004). Undeniably, the LPS process is not an exception to this, and thus should be formalised.

b. Use of Collaborative Form of Contract

The use of a collaborative form of contract is an essential element in the contractual behaviour that needs to be in place at the OL for LPS implementation. Empirical evidence from this study reveals that on most of the projects investigated, a collaborative form of contract was used. This include; framework agreement, ECI, D&B and joint venture. The study reveals that even when design bid build (DBB) is used on a project, and the supply chains are into a framework agreement. This implies that a collaborative relationship would still develop. The contractual behaviour that occurs there could be better explained with relational contracting theory. According to Macneil, (1980) as parties to the contract have more and frequent conversation on the project, the relationship begins to develop.

c. Inclusion of the Commercial Arm of the Business in the LPS Loop

Another contractual behaviour that should be keyed into the organisation's strategy is the inclusion of the commercial arm of the business in the LPS implementation loop. Although this was only mentioned on one project, it seems to be an essential pre-condition to be considered at the OL. Currently, the commercial arms on projects are less involved in the production planning meetings in the LPS process. The involvement of this business group in the production planning session could improve the make-ready process, as it could enable the team to make real-time decisions that require commercial judgements.

Project Level Path Clearing

The project level (PL) factors are linked to the organisational level factors. The implication of this is that the strategic capability commitment for LPS implementation at the OL must be allocated appropriately at the project level. The two theories that explain the working of LPS at the PL are; the TFV model (Koskela, 2000) and the management as organising (MAO) (Johnston and Brennan, 1996). The "F" in the TFV model shows that in the LPS implementation the focus is in achieving smooth workflow rather than on converting the input to output which is the common practice in the traditional approach to project management. The smooth workflow is usually achieved through the make ready and lookahead planning (El-Sabek and McCabe, 2018b). Additionally, the MAO view explains why the inclusion of the subcontractors (i.e. the subunits) in the decision-making process on tasks contribute to the development of a reliable programme at the PL. For instance, Rincón et al, (2019) found that LPS implementation influences the behaviour of subcontractors as an autonomous agent. While El-Sabek and McCabe, (2018b) found that relationship building and communication among the last planners support the coordination of activities.

The PL is sub-divided into pre-project and project implementation activities as shown in Figure 1. Similar to the OL, the project level (PL) consists of the process input factor and contextual input factor.

Project Level Process Input Factors

This refers to the processes that need to be created and practised at the project level in the implementation of LPS. It defines the processes that need to be in place at the project level (PL) for LPS. This includes:

- Project level strategic capability commitment
- Identify and understand production planning practice on the project
- Evaluate practice with LPS principle and theory

- Adopt standard approach
- Create enabler for implementation
- Implement and gauge implementation

a. Align and Allocate Strategic Capability with Project Level Strategy

It is essential for a strategy to also be developed at the PL, and aligned with the OL strategy. This is important as the team on the project would be coming from different organisations. For example, an organisation can tell its employees it wants them to embrace a process and educate them on why. However, projects should develop their own identity due to the vast array of companies required to deliver a project. In view of this, the project set-up; the companies involved including client, contractor, suppliers and designer should establish a joint strategy that considers the unique characteristics of the project. This should be aligned with the strategic support for LPS implementation.

b. Identify and Review Production Planning and Control Practice

At this point, it is essential for the production planning and control practice to be understood and streamlined to meet the strategic support allocated to the PL for the LPS implementation. To achieve this, the current production planning practice should be evaluated with an enhanced production planning and control principles such as the LPS principles.

c. Evaluate and Review Practice Using the LPS Principles

The LPS is a production planning and control method developed for the construction industry and it is among the most used lean techniques in construction (Ballard and Tommelein, *et al*, 2016; Daniel, *et al*, 2015). Thus, the production planning and control practice on the project could be evaluated and reviewed for alignment with the advocated principles/theory of the LPS (Ballard, 2000). The underlying theories of the LPS revolve around planning, execution, and control (Ballard *et al.*, 2009). The LPS is based on 12 principles (Ballard and

973 Tommelein, 2016). Evaluating the practice based on the LPS principles would enable the
974 identification of areas that need improvement in the actual implementation.

975 *d. Adoption of Standard Approach (Specific Capability commitments required)*

976 Based on the evaluation and review, a standard LPS approach should be adopted. The
977 absence of such typical approach could result in a varied implementation of the process
978 across projects executed in the same organisation. This means a project could be reinventing
979 its own wheel which could hinder the intended benefits from the system. It is worth noting
980 that the standard approach is not rigid, thus, it could be positioned to meet the reality of the
981 project. However, since the LPS has standard components (Ballard, 2000), the team should
982 develop the specific capability commitments required for the implementation of the
983 components on the project.

984 *e. Create Implementation Enablers for LPS implementation*

985 For the adopted standard approach to work, implementation enablers should be created. The
986 implementation enablers are grouped into two: physical and human factor enablers. The
987 physical factors entail the allocation of designated room for production planning and control.
988 This should include creating physical space such as co-location for working and visual
989 production planning and control centre. Such location should be readily accessible to all the
990 required stakeholders on the project including the subcontractors. The human factor, on the
991 other hand, is concerned with the appointment of facilitators and lean champions in driving
992 the process on site. In the context of this study, all the research participants identified
993 facilitation as an essential process that needs to be in place for the successful implementation
994 of the process at the project level. It includes both external and internal facilitation. External
995 facilitation such as the use of proven lean construction consultants could prove useful at the
996 initial start. However, over-reliance on consultants should be avoided.

f. Gauge Practice

As the implementation process continues, it is important that the practice is constantly gauged using both internal and external mechanisms. To gauge the practice internally, the Planning Best Practice (PBP) guide that has been used to access the level of implementation of the LPS in different parts of world such as Brazil, Israel Chile, and UK among others (Daniel *et al*, 2017; Priven and Sacks, 2016 Alarcon *et al.*, 2011) could be used.

In addition, the LPS implementation maturity guide could be used. The guide was originally developed by Gregory Howell in 2005; one of the inventors of the LPS (Lean Project Consulting, 2005). Through this, the efficacy of implementation could easily be assessed internally and areas that need improvement could be identified and addressed appropriately. Gauging of the practice also requires input from the external enabling factors.

Project Level Contextual Input Factors (Social Behaviour)

To successfully implement the adopted common approach, contextual input factors embedded as social behaviours are required at the project level. Social behaviours are those soft skill behaviours that need to be practised by the team on the project for the successful implementation of the LPS at the PL. These factors include:

- transparency and discipline,
- honesty, trust and truthfulness in promising,
- selection and involvement of all the required team,
- pre-planning before production planning, and
- proactive involvement of the construction manager and subcontractors

These are among the social behaviours that should be in place at the PL for the rapid and successful implementation of the LPS. The need to be cautious about lack of honesty and poor promising in the implementation of the LPS has been explained theoretically from the Language/action perspective theory (Issato *et al.*, 2015). Practically, it entails making

promises that are realistic and achievable within the timeframe. This suggests that no stakeholder on the project should be pressurised into making undue commitments. The five conditions for making reliable promise should be adhered to in LPS implementation (Issato *et al*., 2015). The action expected here is informed by social information exchange (conversation) (Priven, and Sacks, 2016) as opposed to the technical information exchange that dominates traditional project management (Ballard, 2000). In such social conversations, as advocated in the LPS, every stakeholder is empowered to make promises which could be YES! or NO!.

External Enablers (External Level Path Clearing)

External enablers can help in gauging practice and can bring in new strategies and innovations to improve current practice both at PL and OL as shown in Figure 1. The theory that shows the need for the external level path clearing is the economic theory proposed by Hayek, (1945) where it posits that the knowledge needed to solve a problem is usually dispersed among different people. However, sometimes this knowledge may exist outside the project environment. This shows the importance of engaging with the external enabling factors. In reality, it supports innovation and sustains the implementation of the LPS.

These external enablers include:

- research partnership between the industry and the academia
- CPD training courses on LPS
- engagement with proven lean construction consultants, and
- Lean Construction Institute events.

There is a need to deliberately engage with the identified external enabling factors presented above. This is essential as it has been observed that the LPS is dynamic and it uses various avenues to improve practice, for example, its use of theory to explain practice (Daniel *et al.,*

2015). Such external forum and partnership could be an avenue for communicating and learning about improvements or findings. Research partnership with the industry and facilitation of the process supports the implementation of the LPS. Previous studies have also shown that research partnership with the industry and facilitation of the process by proven facilitators could support the success of the LPS implementation in construction (Formoso *et al*., 2002).

Continual Learning Action and Feedback Loop

The continual learning action is the loop that sustains the implementation of the LPS. According to Mohd-Zainal et al., (2013) there is a strong relationship between organisational learning and sustaining of lean practice. It focuses on learning and taking action at each level. The continual action learning advocated occurs at every point in the process as shown in Figure 1. This implies that learning does not just occur at the end of the entire process only since there is an internal feedback loop. As shown in Figure 1, there is an internal feedback loop between the OL and PL; this is done to ensure issues that need addressing are attended to before the process is rolled out completely. For instance, with the rollout of a set of strategies, unintended consequences may occur and it is helpful to understand these sooner than later. This shows the importance of creating an internal feedback loop as shown in Figure 1. In the implementation of the LPS "bad news early could be said to be good news".

Conclusion

The aim of the current study is to develop an approach to support construction stakeholders in the implementation of the LPS. Accordingly, the study developed a non-prescriptive but all-inclusive approach for supporting construction stakeholders (client, main contractors and subcontractors) in the implementation of the LPS in construction project known as "Last Planner System Path Clearing Approach" that includes organisational, project and external path clearing levels. This expands previous approaches to the implementation of the LPS in

construction which focused more on the project level. Additionally, the developed LPS-PCA would potentially minimise the fragmentation observed in the implementation of the LPS because of its capacity to inform the various stakeholders involved in the implementation process to recognise what is required of them at each point.

This study contributes to knowledge and the future application of production planning and control principles in construction engineering and management as follows: The proposed approach provides a new insight into how to apply the LPS holistically in the management of engineering projects. These include civil engineering and infrastructure projects and other complex construction projects. Furthermore, the current study adds to the existing body of knowledge in production planning and its application in management engineering by identifying and categorising the nature of support required for a rapid and successful implementation of the LPS gleaned from the literature review and the empirical study. The study also provides insight into the current practice and performance of the LPS in the management of civil engineering project as evidenced in the two case study reported from the highways and infrastructure projects.

In terms of contribution to practice; the practical application of the developed LPS-PCA would enable construction stakeholders (clients, main contractors, and subcontractor, among others) to understand what needs to be in place for the successful implementation of the LPS in the management of civil engineering and infrastructure projects. This includes both intending and current users of the LPS thus, enabling them to make the right decision with regard to the process and the behaviour required in the LPS implementation process. Furthermore, the identification of the three “levels of support” (organisational, project, and external enabler) provides a focal point for construction practitioners to focus on in the implementation of the LPS in the management of civil engineering project.

The LPS-PCA developed reveal that the organisational level, project level and external activities identified should be done by every contributing organisation so as to clear the path for smooth implementation of the LPS. This means LPS-PCA is not just for the main contractor or client, rather it is for all the organisations involved in the project, including the subcontractors. This further shows how complex applying the LPS is, in particular for smaller subcontractors which participate in several projects at the same time.

Although the LPS-PCA developed is limited to empirical evidence gathered mainly from the UK, it could be adopted and serve as a lens to direct future implementation of the LPS elsewhere in the world. Furthermore, it is worth noting that the use of LPS-PCA in construction project would require experienced LPS facilitators embedded within the organisation which may be an additional cost to the project. An extended implementation of LPS-PCA in construction has been reported in Ebbs *et al*., (2018).

Data availability acknowledgement:

Data generated or analysed during the study are available from the corresponding author by request.

Reference

Alsehaimi, A. O., Tzortzopoulos Fazenda, P., and Koskela, L. J., (2014). "Improving construction management practice with the Last Planner System: A case study". *Engineering, Construction and Architectural Management*, 21(1), 51-64

Alarcón, L.F., Diethelm, S., Rojo, O. and Calderón, R., 2011. Assessing the impacts of implementing lean construction. *Revista ingeniería de construcción*, *23*(1), pp.26-33.

Arbnor, I. and Bjerke, B., 2008. *Methodology for creating business knowledge*. London, Sage.

Amaratunga, D., Baldry, D., Sarshar, M. and Newton, R., (2002). "Quantitative and qualitative research in the built environment: application of "mixed" research approach". *Work Study*, 51 (1), 17-31

Ballard, G. and Howell, G., 1998. Shielding production: essential step in production control. *Journal of construction Engineering and Management*, *124*(1), pp.11-17.

Ballard, G. and Howell, G., (2004). Competing construction management paradigms. *Lean Construction Journal*, *1*(1), 38-45.

Ballard, G., Hammond, J., and Nickerson, R. (2009), "Production Control Principles". In, Cuperus, Y. and Hirota, E.H. Eds proceedings of *17th Annual Conference of the International Group for Lean Construction, Taipei, Taiwa,* 489-500.

Ballard, H. G. (2000), *The Last Planner System of Production Control*. PhD. Thesis, University of Birmingham, Birmingham UK.

Ballard, G. and Tommelein, I., (2016) "Current process benchmark for the Last Planner® System". *Lean Construction Journal*, 57-89.

Ballard, H.G., Kim, Y.W., Jang, J.W. and Liu, M. (2007), *Roadmap for Lean Implementation at the Project Level,* CII Research Report No. 234-11 Construction Industry Institute, The University of Texas, Austin, TX,

Bazeley, P., (2013). *Qualitative data analysis: Practical strategies*. London, UK, Sage.

Bryman, A. (2012). *Social research methods.* Oxford university press, Oxford, UK

Castillo, G., Alarcón, L.F. and González, V.A., 2014. Implementing lean production in copper mining development projects: Case study. *Journal of Construction Engineering and Management*, *141*(1).

Creswell, J. (2013). *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks: SAGE Publications.

Daniel, E.I., Pasquire, C., and Dickens, G. (2015), "Exploring the implementation of the Last Planner® System through IGLC community: Twenty one years of experience". In,

Seppänen, O., González, V.A. and Arroyo, P. (Eds.) *23rd Annual Conference of the International Group for Lean Construction,* Perth, Australia,.153-162,

Daniel, E.I., (2017) *Exploratory study into the use of Last Planner® System and collaborative planning for construction process improvement* , Doctoral dissertation, Nottingham Trent University, Nottingham, UK.

Daniel, E.I., Pasquire, C and Dickens, G. Ballard, G. (2017). "The Relationship between the Last Planner® System and Collaborative Planning Practice in UK Construction". *Engineering Construction and Architectural Management Journal.* 24(3), 407-425

Dave, B., Hämäläinen, J-P., and Koskela, L., (2015). "Exploring the recurrent problems in the Last Planer implementation on construction projects. In: *Proc. Indian Lean Const. Conference,* Mumbai, India.

Dombrowski, U., Zahn, T. and Mielke, T., (2010). "Roadmap for the implementation of Lean Production Systems". In *Proceedings of the 5th Americas International Conference on Production Research,* Bogota, Coulombia.

Ebbs, P.J. , Pasquire, C.L. and Daniel, E.I. 2018, 'The Last Planner® System Path Clearing Approach in Action: A Case Study' In:, *26th Annual Conference of the International Group for Lean Construction.* Chennai, India, 18-20 Jul 2018. pp 724-733

Eisenhardt, K.M., and Graebner, M.E., (2007). "Theory building from cases: opportunities and challenges". *Academy of Management Journal*, 50 (1), 25-32.

El-Sabek, L.M. and McCabe, B.Y., 2018. Coordination challenges of production planning in the construction of international mega-projects in the Middle East. *International Journal of Construction Education and Research*, *14*(2), pp.118-140.

El-Sabek, L.M. and McCabe, B.Y., 2018b. Framework for Managing Integration Challenges of Last Planner System in IMPs. *Journal of Construction Engineering and Management*, *144*(5), p.04018022.

Elving, W.J., (2005). "The role of communication in organisational change. Corporate Communications": *An International Journal,* 10(2), 129-138.

Fernandez-Solis, J. L., Porwal, V., Lavy, S., Shafaat, A., Rybkowski, Z. K., Son, K., and Lagoo, N. (2012). "Survey of motivations, benefits, and implementation challenges

of last planner system users". *Journal of Construction Engineering and Management*, 139(4), 354-360.

Formoso, C.T., Tzortzopoulos, P., and Liedtke, R., (2002). "A model for managing the product development process in house building. *J. Engr. Const. and Architectural Management*, 9(5-6), 419-432.

González, V., Alarcón, L.F., Maturana, S., Mundaca, F. and Bustamante, J., (2010). "Improving planning reliability and project performance using the reliable commitment model". *Journal of Construction Engineering and Management*, *136*(10), pp.1129-1139.

Hayek, F. A. (1945). The use of knowledge in society. *The American economic review*, pp. 519-530

Hamzeh, F.R., and Bergstrom, E. (2010). "The Lean Transformation: A framework for successful implementation of the Last Planner System in Construction". In , *Proc. 46th Ann. Int'l Conf. of the Associated Schools of Construction*, ASC, Boston, Massachusetts, USA.

Hamzeh, F.R. (2009). *Improving Construction Workflow – The Role of Production Planning and Control*, PhD Dissertation, University of California at Berkeley, Berkeley, CA, USA.

Harper, C. M, (2014). *Measuring Project Integration Using Relational Contract Theory*. PhD dissertation, University of Colorado.

Isatto, E.L., Azambuja, M. and Formoso, C.T., 2013. The role of commitments in the management of construction make-to-order supply chains. *Journal of management in engineering*, *31*(4), p.04014053.

Javanmardi, A., Abbasian-Hosseini, S.A., Liu, M. and Hsiang, S.M., (2017). Benefit of Cooperation among Subcontractors in Performing High-Reliable Planning. *Journal of Management in Engineering*, *34*(2), p.04017062.

Johansen, E. & Porter, G. 2003, 'An Experience of Introducing Last Planner Into a Uk Construction Project' In:, *11th Annual Conference of the International Group for Lean Construction.* Virginia, USA,

Johnston, R.B. & Brennan, M. 1996. Planning or Organizing: the Implications of Theories of Activity for Management of Operations. *Omega, Int. J. Mgmt*. Sc., Vol. 24, No. 4, pp. 367-384.

Rincón, J.L., Fernández-Solís, J.L., Lavy, S. and Du, J., 2019. Effect of Autonomous Agents on Last Planner System Performance in Texas. *Journal of Management in Engineering*, *35*(1), p.04018050.

Kadefors, A., (2004). "Trust in project relationships—inside the black box". *International Journal of Project Management*, 22(3), 175–182.

Kalsaas, B.T., Grindheim, I. and Læknes, N. (2014), "Integrated Planning vs. Last Planner System". In, *Kalsaas, B.T., Koskela, L. and Saurin, T.A.,eds. 22nd Annual Conference of the International Group for Lean Construction*, Oslo, Norway, 639-650.

Kalsaas, B.T., 2012. The Last Planner System Style of Planning: Its Basis in Learning Theory. *Journal of Engineering, Project & Production Management, 2*(2).

Khanh, H. D., and Kim, S. Y. (2015). "A survey on production planning system in construction projects based on Last Planner System". *KSCE Journal of Civil Engineering*, 20(1), 1-11.

Karim, A. and Arif-Uz-Zaman, K., (2013). A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations. *Business Process Management Journal*, 19(1), 169-196.

Kim, S.C., Kim, Y.W., Park, K.S. and Yoo, C.Y., 2015. Impact of measuring operational-level planning reliability on management-level project performance. *Journal of Management in Engineering*, *31*(5).

Koch, C., Sage, D., Dainty, A. and Simonsen, R. (2015), "Understanding operations strategizing in project-based organisations: middle managers' interaction and strategy praxis", *Engineering Project Organization Journal*, 5 (2-3), 106-117.

Koskela, L. J., Stratton, R., and Koskenvesa, A. (2010). "Last Planner and critical chain in construction management: comparative analysis". *In Proceedings of the 18th Annual Conference of the International Group for Lean Construction,* National Building Research Institute, Technion-Israel Institute of Technology, 538-547

Koskela, L. (2000). *An exploration towards a production theory and its application to construction.* PhD Dissertation, Helsinki University of Technology.

Koskela, L. and Ballard, G (2006). "Should project management be based on theories of economics or production?", *Building Research and Information,* 34 (2) , pp. 154-163.

Koskela, L. and Howell, G., 2008. The Underlying Theory of Project Management Is Obsolete. *IEEE Engineering Management Review*, *2*(36), pp.22-34.

Koskela, L. (1992). Application of the new production philosophy to construction (No. 72). (Technical Report No. 72, Center for Integrated Facility Engineering, Department of Civil Engineering). Stanford, CA: Stanford University

Lindhard, S. and Wandahl, S., (2014). "A lean framework for production control in complex and constrained construction projects. In *Optimization and control methods in industrial engineering and construction*, 233-257.

Macneil, I.R., (1980). *The new social contract: An inquiry into modern contractual relations*. Yale University Press, Yale, USA

Macomber, H. and Howell, G., (2003). Linguistic action: contributing to the theory of lean construction. In: *Proceedings of the 11th Annual Meeting of the International Group for Lean Construction*, Virginia, USA, pp. 1-10.Colorado, USA.

Miles, M. B., and Huberman, A. M. (1994). *Qualitative data analysis*. Beverly Hills: Sage Publications.

Nesensohn, C., Bryde, D. J., Ochieng, E., & Fearon, D. (2014). "Maturity and maturity models in lean construction". *Australasian Journal of Construction Economics and Building*, 14(1), 45-59.

Nieto-Morote, A. and Ruz-Vila, F., (2012). "Last planner control system applied to a chemical plant construction". *Journal of Construction Engineering and Management*, *138*(2), 287-293.

Ogunbiyi, O., Goulding, J.S. and Oladapo, A., 2014. An empirical study of the impact of lean construction techniques on sustainable construction in the UK. *Construction innovation*, *14*(1), pp.88-107.

Perez, A.M. and Ghosh, S., 2018. Barriers faced by new-adopter of Last Planner System®: acase study. *Engineering, Construction and Architectural Management*. Vol25, Issue 9, pp.1110-1126.

Pavez, I. and Alarcón, L.F., (2012). "The Lean Construction Professional Profile (LCPP): Implementation in Chilean Contractor Organizations". *Global Perspective on Engineering* Management 1 (3), 59-66

Priven, V. and Sacks, R., (2016). "Impacts of the Social Subcontract and Last Planner System Interventions on the Trade-Crew Workflows of Multistory Residential Construction Projects". *Journal of Construction Engineering and Management*, *142*(7).

Russell, M.M., Liu, M., Howell, G. and Hsiang, S.M., (2014). "Case studies of the allocation and reduction of time buffer through use of the last planner system". *Journal of Construction Engineering and Management*, *141*(2), p.04014068.

Sacks, R., Koskela, L., Dave, B.A. and Owen, R., 2010. Interaction of lean and building information modeling in construction. *Journal of Construction Engineering and Management*, *136*(9), pp.968-980.

Sacks, R., 2016. What constitutes good production flow in construction?. *Construction Management and Economics*, *34*(9), pp.641-656.

Sacks, R., Treckmann, M. and Rozenfeld, O., (2009). "Visualization of Work Flow to Support Lean Construction". *ASCE, J. Constr. Eng. Manage.*, 135(12),1307- 1315

Seppänen, O., Ballard, G. and Pesonen, S., (2010). The Combination of Last Planner System and Location-based Management System. *Lean Construction Journal*, 6(1), pp.43-54.

Shang, G. and Pheng, L. S. (2014). "The last planner system in China's construction industry-a SWOT analysis on implementation", International *Journal of Project Management* 32(7), 1260–1272.

Silver, C., and Lewins, A. (2014). *Using Software in Qualitative Research: A step-by-step Guide* (2nd Edition.). Sage Publications, London, UK

Smith, J. K. (1983). Quantitative versus qualitative research: "An attempt to clarify the issue". *Educational researcher*, 12(3), 6-13.

Teddlie, C. and Yu, F. (2007), "Mixed Methods Sampling: A Typology With Examples", *Journal of Mixed Methods Research*, Vol. 1 No.1, pp.77-100.

Taylor, S. and Bogdan, R. (1984), *Introduction to Qualitative Research Methods*, Wiley, New York.

Viana, D.D., Formoso, C.T. and Isatto, E.L., (2017). Understanding the theory behind the Last Planner System using the Language-Action Perspective: two case studies. *Production Planning and Control*, *28*(3), pp.177-189.

Yin, R.K., (2014). *Case study research*: *Design and methods.* Sage publications, London, UK