LAST PLANNER SYSTEM – AREAS OF APPLICATION AND IMPLEMENTATION CHALLENGES

A Thesis

by

VISHAL PORWAL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Construction Management

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ABSTRACT

Last Planner System – Areas of Application and Implementation Challenges.

(December 2010)

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Chair of Advisory Committee: Dr. Jose Fernández-Solís

In recent years projects have increasingly used Last Planner System (LPS) in building construction. However project managers still struggle with figuring out how the LPS could be applied on their specific projects. One main reason for this struggle is that explicit instructions for systematically applying LPS are not available. This thesis offers practitioners and researchers an account of LPS implementation challenges and an indication of how LPS can be applied. The thesis qualitatively aggregates the results of 26 test case projects of LPS applications to show researchers and practitioners reasons why LPS was applied, what benefits were realized and what challenges were found during the implementation. Senior and mid-level managers in AEC industry were surveyed to assess the implementation challenges that they encountered. The main findings of this analysis are; (1) that practitioners have used LPS for the purpose of making plans more reliable, (2) get smooth work flow (3) improve productivity. The survey findings imply that improvements in LPS implementation strategies can be made which will facilitate LPS adoption by the industry. The findings of this thesis suggest that further research on the integration of LPS into work and business processes of

project teams is needed to further the widespread use of LPS throughout the building industry.

To my parents Urmila and Dinesh, my sisters Varsha and Vini, and my brother-in-law Sunny for all the sacrifices they have made.

ACKNOWLEDGEMENTS

First, I would like to thank Dr. Jose Fernández-Solís for his continuous guidance and support. Throughout the years of my research, he has always been there to provide me with valuable insights and challenges. His dedication to his research and his students deserve the greatest admiration. I would also like to thank Dr. Sarel Lavy and Dr. Zofia K. Rybkowski for playing a significant role in my journey. I also am grateful to Dr. Wei Yan for his teachings, patience, and support. His teachings have helped me gain additional perspective on my research. I would like to thank all four professors for working around the clock to help me finish my thesis.

Second, I would like to thank Stewart Trapino, director of learning, Linbeck and Johana Clark for giving me access to Lean Construction Institute (LCI) Houston meetings and workshops.

Third, I would like to thank Iris Tommelein, Greg Howell, Lauri Koskela, Alan Mossman, Min Liu, Stephen Knapp and Tariq Abdelhamid for giving me feedback on the questionnaire survey.

Finally, I would like to express my gratitude to my parents for their continuous love and support. They were always there for me when I needed them. I would like to thank my sisters and brother-in-law for their continuous caring and support.

NOMENCLATURE

CII	Construction Industry Institute
CIFE	Center for Integrated Facility Engineering
EGLC	European Group of Lean Construction
IGLC	International Group of Lean Construction
JIT	Just-In-Time
LCI	Lean Construction Institute
LPS	Last Planner System
PPC	Percentage Plan Complete
SAT	Study Action Team
TFV	Transformation-Flow-Value
TQC	Total Quality Control
WWP	Weekly Work Plan

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CHAPTER I

INTRODUCTION

Construction industry is facing a gradual decrease in labor productivity (Teicholz, 2004). Current initiatives for improving productivity and the adoption of differing project delivery strategies have failed to increase the industry productivity due to the systemic nature of the industry (Fernández-Solís 2007) showcased by three peculiarities: site production; one-of-a-kind production; and temporary production organization (Koskela 1992, Vrijhoef and Koskela 2005). According to Fernández-Solís (2007) and Tommelein (1999) these peculiarities translate into production complexity, variability, and uncertainty. These three conspire on the project production flow by increasing risk, and waste and therefore preventing the achievement of higher values for the owner and user of the projects.

Lean Construction is a relatively new philosophy (Koskela 2000), borrowed and adapted from manufacturing and guided towards construction production management to improve the production flow. Its main objective is the continual elimination of non – value adding activities (wastes) through a novel flow control. Ballard and Howell (1997) designed a new flow planning and controlling system, known as the Last Planner™ System[1] (LPS), which introduced fundamental changes in the way construction projects

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This thesis follows the style of *Journal of Construction Engineering and Management.*

[1] Last Planner System is a trademark of Lean Construction Institute

are planned and controlled. Projects in the early 2000's experimenting with LPS showed that the use of formal and flexible production planning procedures from the bottom up and tracking the fulfillment of promises made to deliver production are the first steps in keeping the production environment stable (Howell and Ballard 1994). LPS is therefore designed to shield production units from work flow uncertainty (Ballard and Howell 1997), and is proving to be an effective tool for enhancing plan reliability (Alarcón et al. 2008). Several industry professionals have successfully applied LPS to solve a range of problems associated with unstable work flow and uncertainty, the roots of unpredictability.

Researchers have evaluated the effectiveness of LPS within different academic (Ballard et al. 2009, Ballard and Howell 2003, Mohan and Iyer 2005) and industrial (Alarcón et al. 2008) settings. In addition practitioners have acknowledged the potential of these new management tools (Picchi and Granja 2004, Huovila and Koskela 1998, Ballard et al. 2007, Senaratne and Wijesiri 2008). Even though Lean Construction popularity is rising exponentially, as attested by the increased number of LCI chapters formed each year throughout the USA, to date according to (Jorgensen et al. 2004, Mossman 2009, Johansen and Walter 2007), LPS is not accepted on a large scale by the construction industry. Mossman (2009) states that other contributing challenges to the adoption of LPS are the lack of acceptance to fragmented and complex nature of the construction industry, low tech workforce and processes, lack of soft skills, lack of lean education and lack of computer literacy among practitioners. These are some of the obstacles faced by LPS practitioners in developing a critical mass in a region, and one of

the objects of this research. As of 2010, the industry's dilemma is to produce a sufficient industry wide adoption momentum to enable the truly widespread use of LPS, the second object of this research. As a solution for this dilemma, Mossman in Lean Construction Institute White Paper (2009) argues that it is important to build from simple and useful cases of how practitioners have implemented LPS on their projects in the past to gain adoption momentum. To this end this research marshals a broad literature search and generates a survey that studies the root causes of LPS implementation challenges to come up with a plausible solution through action.

There is a substantial body of literature concerning the use of LPS on various construction projects; the author has identified case studies by academia by industry practitioners. Case studies report the use of LPS in different project settings (building design, building construction, heavy civil construction, supply chain management etc.), in different parts of the world (Chile, Brazil, Europe, the USA etc.), and for different project phases (definition, design, pre-design, construction etc.).

In addition to benefits, some academicians and some practitioners have reported through case studies research the challenges, and lessons learned faced by construction professionals during the implementation and use of LPS (initial training and kick off) and later use of LPS in different projects. Literature search indicates that Architects, Engineers and Consultant (AEC) professionals face challenges at two stages. First is the implementation stage, when the project team is introduced to LPS and pilot projects are in progress. These are organizational challenges faced by senior and mid-level management in the initial stages. A second stage can be identified from the literature

search when LPS is used by an experienced team where the technical challenges are associated with skill building and human capital enhancement.

This study identifies the challenges faced by AEC professionals during implementation and use of LPS based on a selected set of 26 case projects to identify and create the criteria behind LPS implementation challenges for a survey. Then senior and mid-level managers in AEC industry are surveyed to assess the current state of challenges faced by their organizations during the LPS implementation phase. The results are analyzed using quantitative statistical tools, inferences are made and conclusions are drawn based on the interpretation of the data.

CHAPTER II

LITERATURE REVIEW

Uncertainty in the production system leads to variable and complex production environment and results in waste, inefficiency and productivity loss (Tommelein 1999; National Academy of Sciences 2009; Eagan 1998, Howell and Ballard 1994). Howell and Ballard's (1994) study advocates that the use of formal and flexible production planning procedures is the first step to keep the production environment stable. In a series of research experiments since 1994, Howell and Ballard developed Last Planner System (LPS) of Production Control to make planning processes (flow) more reliable. LPS makes detailed plans by those who executes the work and reviews the plan near its execution, for collaborative planning, to remove constraint as a team and verify that the promises made can be executed correctly, completely, timely and without ambiguity.

2.1 LAST PLANNER™ SYSTEM (LPS)

As mentioned above, Lean Construction's response to the construction industry production variability is to create a practical solution, the LPS. However as we shall see, LPS has generated a complex web of integrated tools and solutions that in turn has created a problem of how to implement it.

LPS is a planning, monitoring and control system that follows lean construction principles such as just-in-time (JIT) delivery, value stream mapping (VSM) and pull scheduling (also known as reverse phase scheduling).

Figure II-1 shows a systemic view of lean management in construction and Figure II-2 briefly explains the LPS planning process and its components.

Last Planner System planning process is a procedure of creating a master schedule, a look-ahead, and a commitment/weekly work plan through front-end planning using Lean Construction Planning techniques (Howell and Ballard 1994). Weekly work planning is referred as “commitment planning” because, at this stage, specific resource assignments need to be made so that work can actually be performed.

The primary function of LPS is the collaborative planning process that involves ‘last planners[2]’ for planning in greater detail as team gets closer to doing the work. Moreover, LPS incorporates ‘pull scheduling[3] ’ principle where only the work that CAN be done is promised by last planners in weekly work plan meetings as opposed to conventional ‘push scheduling[4]’ principle where the work that SHOULD be done is planned in weekly meetings and emphasis is on adhering to the master schedule. Constraint analysis is an integral part of LPS that is applied to take a proactive approach to problem solving as faced during the day-to-day life on construction projects (Ballard 2000).

[2] Someone (individual or group) who decides what physical, specific work will be done tomorrow. That type of plans has been called "assignments". They are unique because they drive direct work rather than the production of other plans. The person or group that produces assignments is called the "Last Planner" (Howell and Ballard 1994)

[3] A Pull technique is based on working from a target completion date backwards, which causes tasks to be defined and sequenced so that their completion releases work.

[4] Push scheduling method is to push inputs into a process based on target delivery or completion dates.

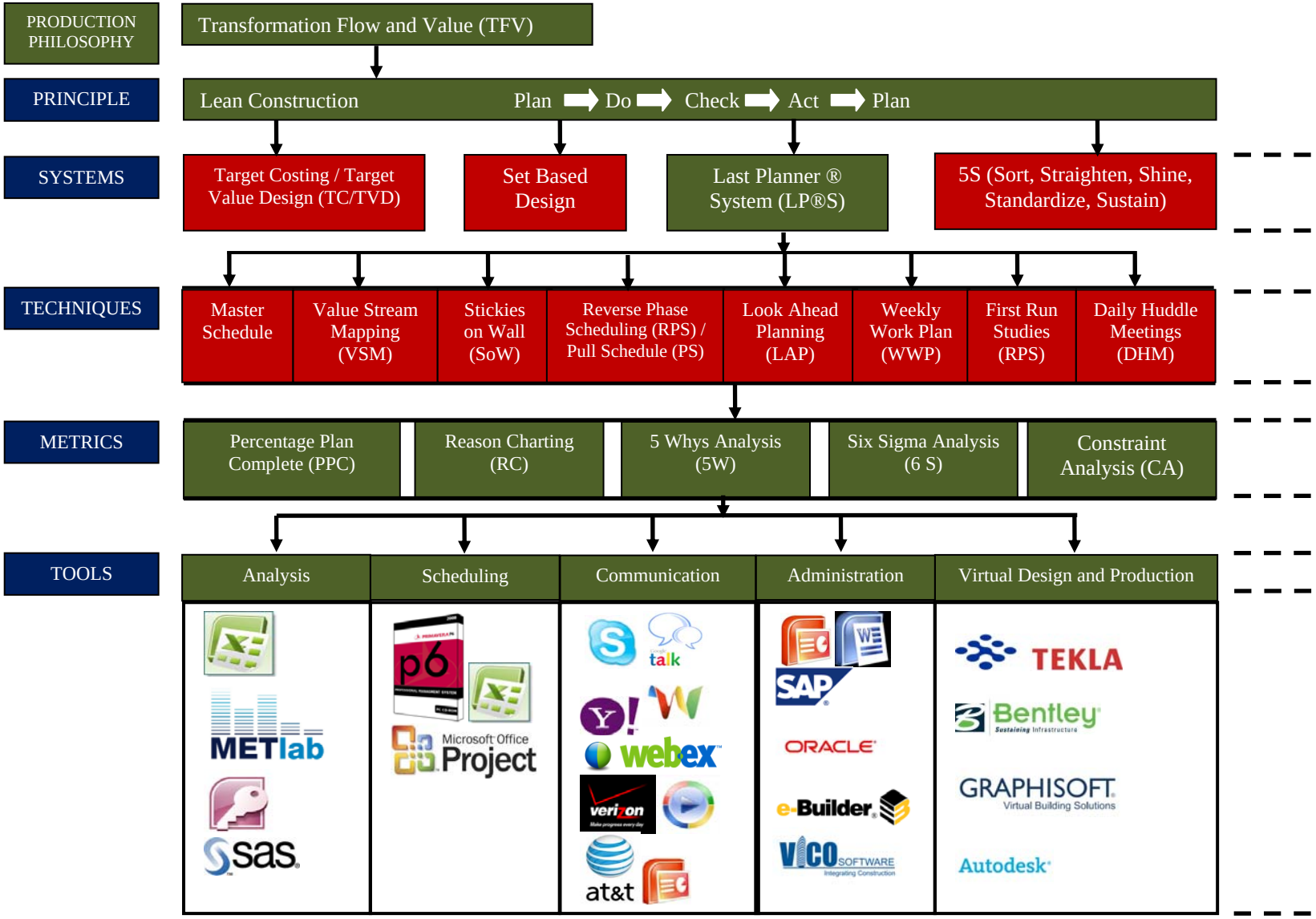

Figure II-1 A systemic view of lean management in construction (© Vishal Porwal & Jose Fernández-Solís 2009)

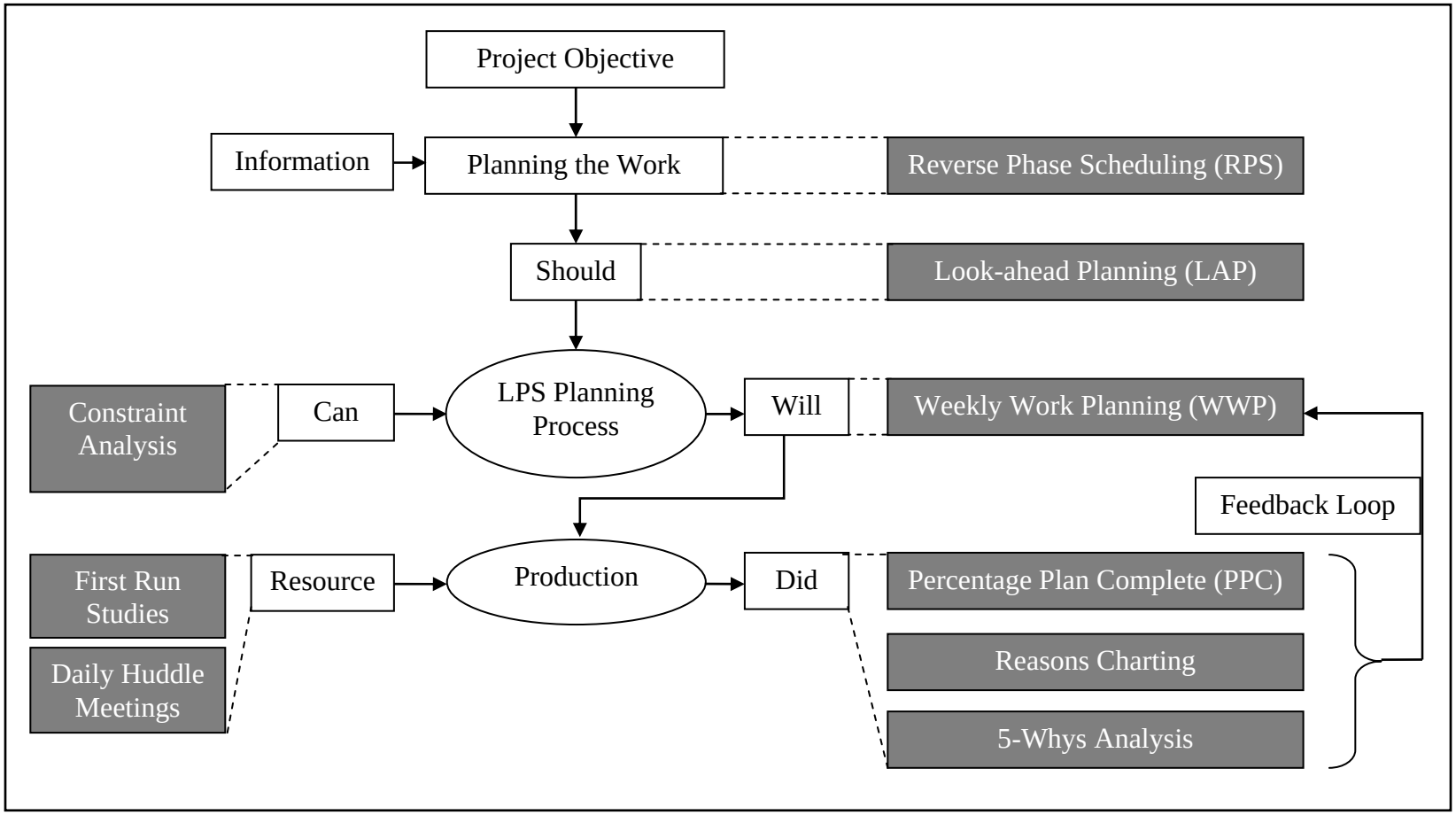

Figure II-2 Last Planner System planning process and its components (Ballard 2000)

The Plan-Do-Check-Act (PDCA) principle is followed by LPS as it encompasses a protocol to identify the reasons for non compliance to plan using the ‘five-why’s’ analysis and maintaining a feedback loop. The LPS planning system can be used to support decision making throughout the process (Tzortzopoulos et al. 2001).

Ballard writes: *Last Planner™ System of production control can be characterized in terms of the principles that guide thinking and action, the functions it enables to be performed, and the methods or tools used to apply those principles and perform those functions* (Ballard et al. 2009). Integration of construction companies and their suppliers should be achieved by involving the strategic suppliers in the implementation of the lean principles and techniques that are encrypted in LPS, such as pulling production, reducing variability and increasing flow reliability (Sterzi et al. 2007).

2.1.2 Principles of LPS

(1) Plan in greater detail as you get closer to doing the work (2) Produce plans collaboratively with those who will do the work (3) Reveal and remove constraints on planned tasks as a team (4) Make and secure reliable promises (5) Learn from breakdowns.

2.1.3 Functions of LPS

(1) Collaborative planning (2) Making Ready (2a) Constraints identification and removal (2b) Task breakdown (2c) Operations design (3) Releasing (4) Committing (5) Learning

The functions of the LPS include: productive unit and work flow control, and completing quality assignments. In addition, it makes it easier to get to the root of the problems, and to make timely decisions regarding adjustments needed within the operation, in order to execute actions opportunely, thereby increasing productivity (Fiallo and Revelo 2002).

2.1.4 Components of LPS

The following sections briefly describe LPS techniques and metrics for measurement.

2.1.4.1 Phase Scheduling

Phase scheduling is a collaborative planning process, where the team: (1) defines a project phase or milestone, (2) breaks it down into constituent activities, and (3) schedules activities backward from the milestone. After incorporating input from different project partners and identifying hand-offs between specialists, the team performs reverse phase scheduling back from important phase milestones (Hamzeh 2009). Development of a phase schedule is an integral part of the application of the LPS to a project. In fact, the phase schedule is the basis for a 6 week look-ahead plan and ultimately the weekly work plan, all essential components of the LPS (Lean Construction Institute White Paper #7 2000).

2.1.4.2 Look Ahead Planning (LAP)

Compared to long-term planning resulting in a master or phase schedule and short-term planning resulting in weekly work plan, look-ahead plans are the outcomes of

mid-term planning showing activities initially at the level of processes and subsequently at the level of operations (Hamzeh 2009).

The construction industry commonly uses look-ahead schedules to focus supervisors' attention on what work is supposed to be done in the near future. Ballard (2000) followed a set of rules for allowing scheduled activities to remain or enter into each of the three primary hierarchical levels (i.e. master schedule, look-ahead schedule, and weekly work plan) of the scheduling system:

> Rule 1: Allow scheduled activities to remain in the master schedule unless positive knowledge exists that the activity should not or cannot be executed when scheduled.
>
> Rule 2: Allow scheduled activities to remain in the look-ahead window only if the planner is confident that the activity can be made ready for execution when scheduled.
>
> Rule 3: Allow scheduled activities to be released for selection into weekly work plans only if all constraints have been removed; i.e., only if the activity has in fact been made ready.

2.1.4.3 Constraint Analysis

Once assignments are identified, they are subjected to constraints analysis. Different types of assignments have different constraints. The construction example includes contract, design, submittals, materials, prerequisite work, space, equipment, and labor; plus an open-ended category for all other constraints.

Constraints analysis requires suppliers of goods and services to actively manage their production and delivery, and provides the coordinator with early warning of problems, hopefully with sufficient lead time to plan around them. In the absence of constraints analysis, the tendency is to assume a throw-it-over-the-wall mentality; to become reactive to what happens to show up in your in-box or lay down yard (Ballard 2000).

2.1.4.4 Weekly Work Planning (WWP) or Commitment Planning

Weekly work plans are the most detailed plans in the LPS. These plans are developed in collaborative weekly meetings where last planners representing all project stakeholders are present. Last planners are team leaders and frontline supervisors directly overlooking work execution such as team leaders overlooking design planners. The purpose of these weekly meetings is to increase plan reliability and reliable promising by making quality assignments, requests, and commitments (Hamzeh 2009).

2.1.4.5 Daily Huddle Meetings

Meetings where team members quickly give the status of what they had been working on since the previous day's meeting, especially if an issue might prevent the completion of an assignment (Schwaber 2001). This tool is similar to the lean manufacturing concept of employee involvement, which ensures rapid response to problems through empowerment of workers, and continuous open communication through the tool box meetings.

2.1.4.6 First Run Studies

First Run Studies are used to redesign critical assignments (Ballard and Howell 1997), part of continuous improvement effort; and include productivity studies and review work methods by redesigning and streamlining the different functions involved. The studies commonly use video files, photos, or graphics to show the process or illustrate the work instruction. The first run of a selected craft operation should be examined in detail, bringing ideas and suggestions to explore alternative ways of doing the work. A PDCA cycle (plan, do, check, act) is suggested to develop the study: 'Plan' refers to select work process to study, assemble people, analyze process steps, brainstorm how to eliminate steps, check for safety, quality and productivity. 'Do' means to try out ideas on the first run. Check is to describe and measure what actually happens. Act refers to reconvene the team, and communicate the improved method and performance as the standard to meet.

2.1.4.7 Percentage Plan Complete (PPC)

PPC (Percent Plan Complete) gauges the reliability of the planning system. PPC is the number of planned activities completed divided by the total number of planned activities, expressed as a percentage. PPC measures the extent to which the front line supervisor's commitment (WILL) was realized (Ballard 2000). Unlike other project performance criteria or variance analysis (e.g., earned value method) that measure whether the project is on schedule (e.g., schedule index or schedule variance) or on budget (e.g., cost index or cost variance), PPC measures whether the planning system is able to reliably anticipate what will actually be done. Determining whether an

assignment was completed or not according to the plan is mandatory in calculating PPC, but elaborating on reasons for failure to complete the work as planned is even more important (Choo 2003).

A weekly analysis of the PPC results in identifying the reasons for the disruption of the pace observed in the work and, consequently, contributes to systematic learning on the jobsite, generating a mindset effectively geared to improving competitiveness in construction companies (Conte et al. 2002). Focus on process improvement can be achieved through the use of the indicator PPC (Tzortzopoulos et al. 2001).

2.1.4.8 Reasons for Non-Compliance and Feedback Loop

The first thing needed is identification of reasons why planned work was not done, preferably by front line supervisors or the engineers or craftsmen directly responsible for plan execution. Reasons could include:

1. Faulty directives or information provided to the last planner; e.g. the information system incorrectly indicated that information was available or that prerequisite work was complete.
2. Failure to apply quality criteria to assignments; e.g. too much work was planned.
3. Failure in coordination of shared resources; e.g. lack of a computer or plotter.
4. Change in priority; e.g. workers reassigned temporarily to a "hot" task.
5. Design error or vendor error discovered in the attempt to carry out a planned activity.

This provides the initial data needed for analysis and improvement of PPC, and consequently for improving project performance. (Ballard 2000)

2.1.4.9 Five-Whys - Root Cause Analysis

Five-Whys technique is based on root cause analysis where “Why” is asked five times for any reason for non compliance to plan. Root cause analysis (RCA) is a class of problem solving methods aimed at identifying the root causes of problems or events. The practice of RCA is predicated on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. By directing corrective measures at root causes, it is hoped that the likelihood of problem recurrence will be minimized.

2.1.5 Why LPS?

Bertelsen (2004) points out that LPS provides all of the following:

- A work plan of what should be done
- An organization chart -who does what?
- An agreement between trades - when to start and when to finish
- A logistics plan - when we need materials, trade teams, drawings etc
- A tool for workflow control - when we want to do which tasks
- A basis for monitoring progress

The main purpose of the LPS is to shield workers from the uncertainties they do not control. (Ballard and Howell, 1997) propose that weekly work plans are effective when assignments meet specific quality requirements.

Critical quality characteristics of an assignment:

- The assignment is well defined.
- The right sequence of work is selected.
- The right amount of work is selected.
- The work selected is practical or sound; i.e., can be done.

“Well defined” means described sufficiently that it can be made ready and completion can be unambiguously determined. The "right sequence" is that sequence consistent with the internal logic of the work itself, project commitments and goals, and execution strategies.

The "right amount" is that amount the planners judge their production units capable of completing after review of budget unit rates and after examining the specific work to be done. "Practical" means that all prerequisite work is in place and all resources are available.

According to the Lean Construction Institute, each level of the LPS has a very specific purpose (Choo, 2003).

The purpose of master schedule is to:

1. Demonstrate the feasibility of completing the work within the available time,
2. Display an execution strategy that can serve as a basic coordinating device,
3. Determine when long lead items will be needed

The purpose of the look-ahead schedule is to:

1. Shape work flow in the best achievable sequence and rate for achieving project objectives that are within the power of the organization at each point in time,
2. Match labor and related resources to work flow,
3. Produce and maintain a backlog of assignments for each frontline supervisor and crew, screened for design, materials, and completion of perquisite work at the CPM level,
4. Group together work that is highly interdependent, so the work method can be planned for the whole operation, and
5. Identify operations to be planned jointly by multiple trades

The purpose of the weekly work plan is to:

1. Identify make ready actions and assessing their feasibility prior to making assignments so as to shield production units from uncertainty
2. Make best use of the production unit's capacity and acknowledge individual's differences in light of the schedule loads

An empirical study on the use of LPS in Brazil proposes that physical flows at construction sites must be made transparent by collecting data and using modeling tools. Uncertainty and variability minimization can be achieved through process analysis and standardization, using process and flow diagrams as a starting point, as well as by using a shielding mechanism for increasing the reliability of task assignments (Alves and Formoso 2000).

2.1.6 Importance of Commitments and Commitment Loop

The basic element of a coordination process is a closed loop that connects two parties. One of them (the 'performer') promises to satisfy a request of the other (the 'customer'). As shown in Figure II-3, the loop consists of four stages separated by four speech acts (Denning and Medina-Mora 1995):

1. Request: The customer makes a request to the performer (or accepts an offer made by the performer) (“I request”);
2. Negotiation: They negotiate on the conditions that will satisfy the customer, culminating in the performer's promise (implied contract) to fulfill those conditions (“I promise”);
3. Performance: The performer does the work and ends by declaring that it is done (“I am done”);
4. Satisfaction: The customer accepts the work and declares satisfaction. Satisfaction means that the implied contract has been fulfilled; it means neither gratification nor a psychological report about the customer (“I am satisfied”).

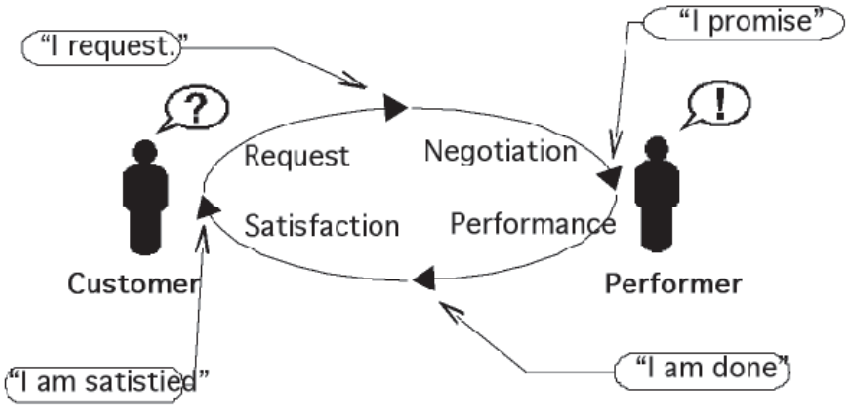

Figure II-3 The commitment Loop (Denning and Medina-Mora, 1995)

A great part of information flow problems that happen among make-to-order supply chains (for example building elevator and cut and bent rebar supply chains) can be traced back to the way that commitment among people and firms are managed along such chains (Azambuja et al. 2006). By listening to all the members that interact directly in planning - last planners- a moral obligation is acquired by all those involved in the construction project (Fernando et al. 2005).

Sacks and Harel (2006) modeled the behavior of subcontractors and general contractors using game theory. They conclude from the model that subcontractors will provide fewer resources than requested and the GC's project manager will ask for more than that is needed. Neither has the knowledge of what the other is doing. This is the equilibrium case. The situation changes when they are using LPS.

Sharing information about reliability (PPC) changes the behavior and consequently the equilibrium state. Both parties are more likely to ask for and provide for exactly what is needed:

- When plan reliability is made transparent by means of PPC
- Plan reliability continues to improve
- Honesty improves
- The entire project moves to a higher performing situation

2.2 LPS IMPLEMENTATION AND USE IN CONSTRUCTION INDUSTRY

LPS implementation typically starts with a pilot project in the majority of companies (Hill et al. 2007). Sutter Health, headquartered in Sacramento, California, implemented LPS on five pilot projects (David Medical Office Building, Modesto 8 Storey Bed Tower, Delta, Roseville Emergency Department, Roseville Parking Structure) as a part of the organization's lean initiative in 2004 (Ballard et al. 2007). After a series of experiments, LPS is in use on a number of Sutter Health construction projects (Hamzeh 2009). In Finland four major companies (YIT Rakennus Oy, Skanska Talonrakennus Oy, NCC Rakennus Oy and Rakennusosakeyhtiö Hartela) implemented LPS on four different pilot projects and developed a systematic implementation approach (training and theoretical justification workshops etc.). These pilot projects were followed with the second set of pilot projects. Productivity, safety, quality and schedule benefits were realized in these projects (Koskenvesa and Koskela 2005). In 80,000 square feet housing project in Quito, Ecuador the usefulness of LPS as an effective planning and work control tool was confirmed and its application resulted in a high level of commitment on the part of the production units (Fiallo and Revelo 2002).

In another example, the use of LPS improved communication and coordination among subcontractors on a multi-storey residential construction project (Song et al.

2008). LPS has an important role to play in batch-size reduction and there is a positive interaction between reductions in building time and batch-size on one side and the LPS together with the concepts of partnering and supply chain management on the other (Nielsen and Thomassen 2004). A Brazilian study concluded that the deployment of production managed models based on lean production principles and techniques such as LPS are feasible and can be applied to any type of construction venture, regardless of the execution technology employed. (Conte et al. 2002) reported that an average reduction of the expected construction time between 20% and 30% of the initial estimate, and a reduction of the production cost between 5% and 12% of the total amount can be achieved in totally different projects, like the construction of McDonald's stores or churches or the execution of horizontal residential condos.

2.2.1 Benefits Realized by LPS Implementation

In several instances of LPS implementation improvements in plan reliability, project delivery time, labor productivity, safety, and quality have been reported (Alarcón et al. 2008, AlSehaimi et al. 2009, Ballard et al. 2009, Ballard et al. 2007, Court et al. 2009, Fernando et al 2005, Formoso and Moura 2009, Friblick et al. 2009, Garza and Leong 2000, Khonzade et al. 2008, Mohan and Iyer 2005, Salem and Solomon 2006). In some instances it was not possible to quantify the benefits by LPS implementation; however, continuous improvement in time, quality and cost indexes has been reported.

2.2.2 Challenges Faced During the Implementation and Use of LPS

The introduction of the LPS to a site, into a company or into a country is not an easy and uncomplicated task (Koskenvesa and Koskela 2005). In addition to certain benefits, academicians and practitioners have reported the challenges faced by AEC professionals during the implementation of using LPS. An observation during the implementation of LPS in seven Chilean companies involving 13 construction projects shows that there is a positive correlation between the discipline in the implementation and the effectiveness of the results (Alarcón and Diethelm 2001).Table II-1 lists the challenges and their occurrences in the literature. AEC professionals face challenges at two stages. First is the implementation stage, when the project team is introduced to LPS and pilot projects are in progress. These are organizational challenges faced by senior and mid-level management in the initial stages. During the second stage, LPS is used by an experienced team and technical challenges associated with skill building and human capital needed for using LPS are introduced.

2.2.2.1 Leadership and Management Commitment

The internal organization for a company implementation requires the active presence and involvement of upper management in some of the key activities (Alarcón et al. 2002). Application of LPS at Advanced Communication and Information Technology Center (ACITC) building construction at Virginia Tech Campus confirmed that in order to implement a new concept, support and commitment from management is essential (Garza and Leong 2000).

2.2.2.2 Training

Training last planners is critical to the implementation of LPS. Lack of understanding of conceptual aspects (lean principles) and perceiving LPS as a "micro-planning-system" hinders the successful implementation (Alarcón et al. 2002). An empirical study on LPS implementation concluded that training will be a key aspect of implementation and its success at the site. The staff and workers will need to be trained to use this tool effectively (Salem et al. 2005).

2.2.2.3 Partial Implementation

Not implementing all the components of LPS is a challenge, i.e. missing out one or more of 1) phase scheduling 2) look ahead planning 3) weekly work planning 4) constraint analysis 5) PPC 6) Reasons Charting 7) First run studies 8) Daily huddle meetings 9) Five Whys' analysis 10) Learning process. An analysis of a database of 77 Chilean projects, where LPS was implemented, revealed that the projects with a more complete implementation had a higher PPC than projects with basic implementation

Table II-1 Challenges faced by AEC professional during the implementation and use of LPS

	Challenges	Ballard (2000)	Garza and Leong (2000)	Alarcón et al. (2001)	Alarcón et al. (2002)	Fiallo and Revelo (2002)	Kim and Jang (2005)	Koskenvesa and Koskela (2005)	Salem et al. (2005)	Arbulu and Soto (2006)	Ansell et al. (2007)	Ballard et al. (2007)	Jang et al. (2007)	Kemmer et al. (2007)	Kim et al. (2007)	Sterzi et al. (2007)	Alarcón et al. (2008)	AlSehaimi et al. (2009)	Hamzeh (2009)	Jara et al. (2009)	Liu and Ballard (2009)
1	Organizational inertia or Resistance to change or "This is how I always done it" attitude		✔		✔	✔		✔	✔		✔	✔	✔			✔		✔			
2	Lack of commitment to LPS implementation or Attitude towards new systems	✔	✔	✔					✔	✔		✔	✔					✔			✔
3	Lack of human capital - Lack of understanding of new system or difficulty to make quality assignments or Lack of skills and experience	✔					✔			✔			✔	✔	✔				✔	✔	✔
4	Lack of training	✔			✔		✔	✔	✔			✔							✔	✔	
5	Lack of leadership or Failure of management commitment or Organizational climate	✔	✔	✔	✔					✔		✔									✔
6	Lack of stakeholder support	✔	✔						✔					✔							
7	Partial or late implementation of LPS			✔	✔													✔			✔
8	Poor use of information generated during implementation of LPS	✔											✔				✔				
9	Lack of empowerment of field management or Lengthy approval procedure from client and top management												✔					✔			✔
10	Extra resources or More paper work or Extra staff or More meetings or Additional time				✔				✔	✔											
11	Lack of physical integration of all the stakeholders									✔											✔
12	Short term vision				✔													✔			
13	Inadequate administration				✔													✔			
14	Misinterpretation of PPC indicator		✔		✔																
15	Contracting and legal issues or Contractual structure	✔	✔																		
16	Bad team chemistry or Lack of collaboration											✔									
17	Bad work ethics and cultural issues																	✔			
18	Parallel implementation with other improvement programs				✔																

(Alarcón et al. 2008). The results of a research effort to study the critical factors in the implementation LPS in 12 Chilean construction companies show that the partial implementation, intermittent implementation and insufficient preparation of the planning meetings were barriers to its implementation. This situation had an impact on the effectiveness of the system and increased the need for more time for implementation (Alarcón et al. 2002).

LPS is identified as the leading lean construction concept in German construction industry. Although it may be possible to employ some of LPS techniques (weekly work plan, look-ahead plan etc.) separately, it has been recognized that they are most effective when applied together. This includes the techniques of constraints analysis and the Activity Definition Model (ADM), which usually come into play during the preparation of look-ahead schedules (Johnsen et al. 2007).

2.2.2.4 Late Implementation

Implementing LPS after the project has been started and partially completed - for example using LPS after the project is 25% complete - is reported as an obstacle in successful LPS implementation. Introducing a new practice on a project where different trades are working at the same time and many activities going on simultaneously is an obstacle (AlSehaimi et al. 2009).

2.2.2.5 Bad Work Ethics

Bad attitude towards time affected the LPS implementation in Saudi Arabian construction project this includes arriving one hour late in a meeting etc. (AlSehaimi et al. 2009).

2.2.2.6 Short Term Vision

Short term vision doesn't allow people to visualize problems with enough time to make the right decisions (Alarcón et al. 2002).

2.2.2.7 Lack of Collaboration

A Danish study (Nielsen and Thomassen 2004) suggests that reduction in building time (and batch-size) should not only go hand in hand with the LPS but also with partnering between client, designers and the main contractor and long term collaboration relationships between the main contractors and the subcontractors.

2.2.2.8 Time

Meetings, training activities, preparation of forms, etc., were not usual activities and surpassed the capacity of the project personnel in a Chilean (LPS) implementation experiment. This condition became more critical in the extent that these activities were relayed exclusively to the field administrator (Alarcón et al. 2002).

2.2.2.9 Adequate Administration

An adequate administration at the project level is a must to undertake the challenge of performing planning meetings in large projects, where a meeting that

gathers project managers, foremen, subcontractor, and other participants, can become not viable due to the high number of participants (Alarcón et al. 2002).

2.2.2.10 Parallel Implementation with Other Improvement Programs

The results of a research effort to study the critical factors in the implementation of LPS in 12 Chilean construction companies revealed that the LPS implementation was mainly affected in companies that were making parallel efforts to implement LPS and quality. However, companies where other improvement systems functioned, or those that had participated in similar programs before, were better able to deal with the implementation by doing an integration effort of both programs (Alarcón et al. 2002).

2.2.2.11 Resistance to Change

Human factor is critical to LPS implementation. Resistance to change, for example the refusal to assume commitments, refusal to include subcontractors in planning meetings or negative reactions to the theoretical concepts of LPS and to its application in the project are evident (Alarcón et al. 2002). Considering the implementation of LPS from a sociological viewpoint Johansen et al. (2004) conclude that cultural barriers are inherent in construction industry.

2.2.2.12 Commitment to LPS Implementation

Commitment to implementing all components of LPS and learning from own mistakes are important factors to the successful implementation. Lack of self-criticism of last planners may hamper the successful implementation efforts (Alarcón et al. 2002, AlSehaimi et al. 2009).

2.2.2.13 Misinterpretation of PPC Indicator

The use of PPC indicator as a form of controlling and evaluating the individual completion of tasks affected seriously the implementation and generated barriers at every level of the organization of some projects in Chilean experiments with LPS implementation (Alarcón et al 2002).

2.2.2.14 Human Capital – Lack of Understanding of New System

The unfamiliarity with or misunderstanding of lean concepts and implementation may become the greatest barriers at the beginning of the project (Salem et. al 2005).

2.2.2.15 Contractual and Legal Issues

Traditionally, facility owners have been presented with a standard set of project delivery options: design-bid-build, construction management (agency or at-risk), or design-build. Despite this range of options, many owners remain dissatisfied: projects take too long, they cost too much, and the work fails to meet quality expectations. Integrated form of Agreement (IFOA) is new form of contract. It binds all the parties — client/owner, designers, constructor and trade partners — into a single agreement which requires them to share risks and rewards. This encourages everyone in the team to think of the project first as their commercial interests are clearly bound up with the overall success of the project. In turn this means that leadership and decision making is both more inclusive and distributed. The integrated agreement for lean project delivery offers improved project performance both from the owner's perspective (reduced cost and time, improved quality and safety) and from the viewpoint of the designers and

contractors (increased profit and profit velocity, improved safety, and employee satisfaction) (Lichtig, 2006).

CHAPTER III

RESEARCH METHODS

The aim of the research presented in this thesis is to identify areas of application of LPS and the challenges faced by AEC professionals during implementation and use of LPS at organizational and project levels and then to assess the challenges faced by senior and mid level management during the implementation of LPS. The scope of this research effort is limited to the identification of LPS implementation and user challenges and to assess the LPS implementation challenges at organizational level based on the perception of senior and mid level management. This research does not assess the user challenges at project level based on perception of field management.

To achieve this objective, the research is divided into two phases, due to dependency of second phase on the results from first phase. The first phase includes the identification of the areas of application of LPS and challenges faced by AEC professionals in LPS use and implementation. Literature review instrument is being used for this purpose. The second phase includes the assessment of challenges faced by senior and mid level management during the implementation of LPS. Questionnaire survey tool is being used for this purpose. The rationale used to select the LPS for study was related to the overall literature available on LPS implementation in different countries. Figure III-1 shows the research design used for this study.

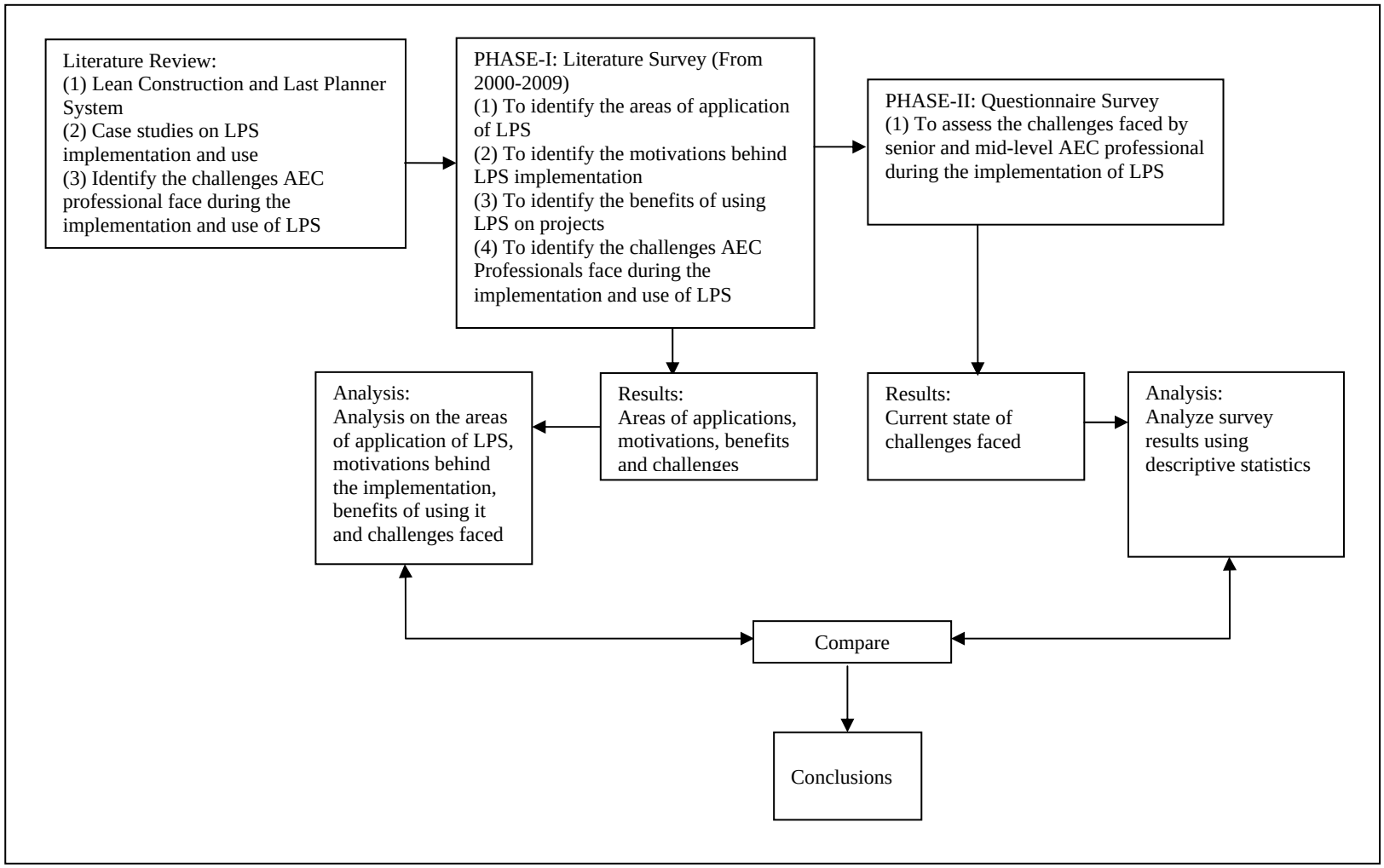

Figure III-1 Research design

3.1 PHASE I: LPS – AREAS OF APPLICATION AND IDENTIFICATION OF CHALLENGES FACED BY AEC PROFESSIONALS DURING THE IMPLEMENTATION AND USE OF LPS

To identify areas of application of LPS and the challenges faced by AEC professionals during implementation and use of LPS at organizational and project levels author carried out a systematic review of literature in this field. The scope was limited to publications dealing with LPS implementation as well as use at organizational and project levels. This means only descriptive articles reporting on real examples and cases were considered; purely theoretical, conceptual, and abstract works were excluded.

The literature survey strategy was developed by first identifying relevant data sources, time frame, and key words. Initially, a very broad selection of databases was identified, covering journals, conference proceedings, books, and articles from trade journals. This included Compendex, Emerald, Elsevier, Construction Industry Institute (CII), and Center for Integrated Facility Engineering (CIFE). These databases provide access to a wide variety of publications such as the Journal of Construction Engineering and Management, Lean Construction Journal, Conference Proceedings of the Annual Conferences of the International Group of Lean Construction (IGLC), and Conference Proceedings of the Construction Congress of the American Society of Civil Engineering (ASCE).

In order to restrict the search to more recent publications, the time frame for this study was chosen initially to include only literature published between 2005 and 2009.

However, as the research progressed this was extended by widening the search criteria to include publications from 2000.

Single case studies are extremely valuable to research typical cases that serve a demonstrative purpose (Yin, 2009). Therefore, each of the results from the case studies that IGLC and LCI researchers conducted on the implementations of LPS can give valuable insights about best practice and lessons learned on a specific construction project. Unfortunately, it is not easy for researchers and construction or design professionals to generalize the results of a single case study for their project and their specific application of LPS. This study, therefore, aggregates the results of a number of different case studies showing how practitioners on these LPS implementations have applied LPS methods. This aggregation method is contrary to the multiple case study design described in Yin 2009 as this study do not try to replicate findings on multiple cases, but try to summarize findings from different cases to offer a broad overview about the actual state of LPS implementation and how they apply to the construction sector. This study did not use a random sampling logic to choose the cases, but sampled specific cases that provide the best possible overview about the LPS applications.

3. 2 PHASE II: ASSESSMENT OF CHALLENGES FACED BY SENIOR AND MID LEVEL MANAGEMENT DURING THE IMPLEMENTATION OF LPS

In the second phase author designed a questionnaire survey to assess the challenges faced by senior and mid-level managers during the implementation of LPS in their organizations. The questionnaire was designed based on the LPS implementation challenges identified in Phase I and with the help of LPS experts' feedbacks.

Phase I identified the following LPS implementation challenges:

1. Organizational inertia or resistance to change or “This is how I always done it” attitude
2. Lack of commitment to LPS implementation or attitude towards new systems
3. Lack of human capital - lack of understanding of new system or difficulty to make quality assignments or lack of skills and experience
4. Lack of training
5. Lack of leadership or failure of management commitment or organizational climate
6. Lack of stakeholder support
7. Contracting and legal issues or contractual structure
8. Partial or late implementation of LPS
9. Bad team chemistry or lack of collaboration

Table III-1 describes the distribution of questions in the survey questionnaire based on the above mentioned LPS implementation challenges. The number of questions for each challenge was based on the frequency of challenge in the literature during the Phase I study, which included 26 case projects from year 2000 to 2009. The survey was sent out to industry practitioners through several venues, including an open invitation through the European Group of Lean Construction (EGLC) newsletter and a direct request to a network of practitioners recommended by Jose Fernández-Solís at Texas A&M University. Members of Lean Construction Institute (LCI), International Group of

Lean Construction (IGLC) and European Group of Lean Construction (EGLC) constitute the sample group for the survey. The requirement for the selection of the organizations is based on the experience of members and their respective companies with LPS implementation. Survey was sent to 56 Lean Construction Institute (LCI) corporate member companies, 9 LCI approved consultants and 131 LCI members, making a sample size of 196. Questionnaire included questions on implementation challenges at organizational level. Each respondent answered a set of 51 questions.

The questionnaire consisted of three main sections: (1) respondent's perception survey to assess the challenges (2) multiple choice and open ended questions to assess the respondent's LPS practices and (3) respondent's profile. A seven point Likert scale was used for the perception survey. Where level of agreement increased towards the higher value. A value of 1 represented strong disagreement with a given statement, while 7 represented strong agreement. Often five ordered response levels are used, although psychometricians advocate using seven or nine levels; a recent empirical study (Dawes 2008) found that a 5- or 7- point scale may produce slightly higher mean scores relative to the highest possible attainable score, compared to those produced from a 10-point scale, and this difference was statistically significant. The survey questionnaire has been included in Appendix-B. The survey was confidential and an Institutional Review Board (IRB) approval was obtained for the survey. It is included in Appendix-C.

The survey was posted online using Google Documents and survey link was sent out through emails. The first question on the survey questionnaire was "Do you use Last Planner System for planning and control purposes?" Only respondents with the answer

"Yes" were qualified to answer the further questions. Descriptive statistics was used to analyze the survey data.

Table III-1 Distribution of questions based on implementation challenges identified in Phase I

No.	Challenge	No. of Questions
C01	Lack of human capital - lack of understanding of new system or difficulty to make quality assignments or lack of skills and experience	8
C02	Lack of leadership or failure of management commitment or organizational climate	8
C03	Lack of stakeholder support	5
C04	Organizational inertia or resistance to change or "This is how I always done it" attitude	3
C05	Contracting and legal issues or contractual structure	3
C06	Lack of commitment to LPS implementation or attitude towards new systems	2
C07	Bad team chemistry or lack of collaboration	1
C08	Lack of training	2
C09	Partial or late implementation of LPS	3

Although there are limitations to the study, set by the small sample size, a quantitative approach with statistically significant sample would not shed light on the phenomenon under investigation as there are only small pockets of AEC professional using LPS within the sector.

CHAPTER IV

DATA ANALYSIS

4.1 PHASE I: RESULTS FROM LITERATURE SURVEY

The International Group of Lean Construction (IGLC) and Lean Construction Institute (LCI) has a long history of conducting pilot implementations for Last Planner system on variety of different construction projects. Published examples of some of these case studies can be found in (Khanzode et al. 2008); (Ballard et al. 2007); (Lane and Woodman 2000); (Mikati et al. 2007); (Tsao and Tommelein 2004). Overall, IGLC and LCI researchers together have collected and published case study data from more than 200 projects since 1996. Table IV-1 shows a summary of the characteristics of the test case projects that the author has selected for this study. A set of 26 projects, where LPS was implemented, provide the best possible overview about the LPS applications from the LPS case studies reported from 2000 to 2009. Altogether, the author selected three commercial, six institutional, six industrial, seven transportation and three residential projects. Five of the 26 test cases are non-U.S. projects, based in Europe, Asia and South America.

4.1.1 Motivations behind LPS Implementation and Benefits Realized

The test case projects report a range of different motivations behind LPS implementation. Table-IV-2 summarizes the motivations behind LPS implementation as reported in these test case projects. The top three motivations behind LPS

implementation in these 26 test case projects were as follows: 1. Increase work plan reliability, 2. Reduce uncertainties, 3. Integrating supply chain management functions, 4. Improve work flow reliability. LPS was implemented at twelve test case projects with these motivations. These results create a clear picture of “why” LPS was implemented at test case projects.

LPS was implemented in construction and design phases and for supply chain management as a tool to streamline work flow, and improve plan reliability and productivity among the other motivations as listed in Table IV-2. However, the benefits realized by LPS implementation on 26 test case projects are listed in Table IV-3. Results shown in Table IV-3 about benefits of using LPS on projects indicate that LPS was successfully used for the purpose it was intended to be used for. For example, Table IV-2 shows that LPS was implemented with a motivation of improving plan and workflow reliabilities and these purposes were fulfilled as reported in terms of benefits of using LPS in Table IV-3. It can be inferred from these results that LPS implementers were able to improve plan and workflow reliabilities by implementing LPS at test case projects. Results in Tables IV-2 and IV-3 are useful in understanding the answers to the two compelling questions: first “why use LPS?” and second “what benefits could be realized by LPS implementation at a project?

These questions may be of interest to the organizations that are new to LPS and willing to implement LPS at their projects.

Table IV-1 Characteristics of test case projects

Case	Year	Country	Reference	Project	Type of Project						LPS Implementation Phase		
					Commercial	Institutional	Indus-trial	Transportation	Residential	Health Care	Construction	Design	SCM*
C1	2000	USA	Garza and Leong 2000	Advanced Communication and Information Technology Center (ACITC) at Virginia Tech Campus		✔					✔		
C2	2000	USA	Ballard 2000	Center for Clinical Services Research, Stanford University		✔					✔		
C3	2000	USA	Ballard 2000	Texas Showplace Project	✔						✔		
C4	2002	Ecuador	Fiallo and Revelo 2002	102 one family units- housing project					✔		✔		
C5	2004	Denmark	Nielsen and Thomassen 2004	3 schools in Skelskor – refurbishment and new build		✔					✔		
C6	2005	South Korea	Kim et al. 2007, Kim and Jang 2005	Seoul Subway project				✔			✔		
C7	2005	South Korea	Kim et al. 2007, Kim and Jang 2005	Busan Subway project				✔			✔		
C8	2006	Peru	Arbulu et al. 2006	Central Bus Station project		✔						✔	
C9	2006	USA	Salem el al. 2005, Salem and Solomon. 2006	Four floor University parking garage	✔						✔		
C10	2007	UK	Ansell et al. 2007	3 miles of carriageway renewal				✔			✔		
C11	2007	South Korea	Jang et al. 2007	Nam Chun Highway project				✔			✔		
C12	2007	South Korea	Jang et al. 2007	Seoul Ring Road project				✔			✔		
C13	2007	Brazil	Kemmer et al. 2007	17-storey residential building					✔		✔		
C14	2007	Sweden	Simonsson and Emborg 2007	Industrial bridge construction			✔				✔		
C15	2007	Brazil	Sterzi et al. 2007	Construction and refurbishment of an industrial building for a steel manufacturer			✔				✔		✔
C16	2007	Brazil	Sterzi et al. 2007	Construction of an industrial building for a car manufacturer			✔				✔		✔
C17	2007	Brazil	Sterzi et al. 2007	Construction and refurbishment of an industrial building for a car manufacturer			✔				✔		✔
C18	2007	USA	Ballard et al. 2007	Air Products - Large chemical plant			✔				✔		
C19	2007	UK	Ballard et al. 2007	Heathrow Terminal 5 building- civil phase –British Airport Authority	✔								✔
C20	2009	Saudi Arabia	AlSehaimi et al. 2009	Faculty of Business and Administration building		✔					✔		
C21	2009	Saudi Arabia	AlSehaimi et al. 2009	General classrooms and laboratories		✔					✔		
C22	2009	USA	Ballard et al. 2009	New town development					✔			✔	
C23	2009	USA	Hamzeh et al. 2009, Hamzeh 2009	Cathedral Hill Hospital project						✔		✔	
C24	2009	USA	Liu and Ballard 2009	Pipeline construction for an oil refinery plant			✔				✔		
C25	2009	Peru	Olano et al. 2009	Leaching pad construction				✔			✔		
C26	2009	Peru	Olano et al. 2009	7.1 KM highway construction				✔			✔		
Summary					3	6	6	7	3	1	23	3	4

*Supply chain management

Table IV-2 Summaries of motivations behind LPS implementation

#	Motivations	LPS Implementation Phase		
		Construction	Design	SCM*
1	Increase work plan reliability	C1, C2, C3, C6, C7, C24	C22, C23	
2	Reduce uncertainty	C15, C16, C17		C15, C16, C17
3	Integrating supply chain management functions	C15, C16, C17		C15, C16, C17
4	Improve work flow reliability	C24, C6, C7, C4		
5	Reducing production time	C14, C5		C19
6	Find relationship between plan reliability and schedule performance index	C25, C26		
7	Improve construction planning practices	C20, C21		
8	Team building to improve lean construction	C11, C12		
9	Improve processes in construction phase	C10		
10	Shielding production, integration between long- and short term planning, controlling and learning, management of physical flows, cost control and safety planning and control	C13		
11	Reducing number of workers	C14		
12	Developing an integrated approach for product and progress design		C8	
13	Improving productivity	C4		
14	Make timely decisions	C4		
15	Learning from failures	C4		
16	Continuous improvement	C18		
17	Reduce cost of construction			C19
18	Sustainable competitive advantage	C6, C7		
19	Eliminate waste	C9		
20	Increase profit	C9		
21	Reducing batch-size	C5		

*Supply chain management

Table IV-3 Benefits realized by LPS implementation

#	Benefits	LPS Implementation Phase		
		Construction	Design	SCM*
1	Increased workflow reliability	C25, C26, C15, C16, C17		C15, C16, C17
2	Improved supply chain integration	C15, C16, C17		C15, C16, C17
3	Reduced project delivery time or reduced production time	C10, C14, C18	C8, C22	
4	Increased work plan reliability	C4, C6, C7	C8	
5	Improved communication among project participants	C6, C7	C23	
6	Less firefighting or fewer problems in day-to-day running of project	C6, C7, C10		
7	Improvement in quality of work practice	C20, C21		
8	Enhancement of managerial practices	C20, C21		
9	Knowledge expansion and learning	C20, C21		
10	Reduced stress levels	C14	C22	
11	Improved work planning ability		C22, C23	
12	Improved informational transparency	C6, C7		
13	Reduced procurement cost	C6, C7		
14	Reduced cost	C14		C19
15	Better resource leveling		C22	
16	Better control over assignments		C22	
17	Improved safety	C14		
18	Improved medium-term (look-ahead) planning	C13		
19	Improved resource utilization	C14		
20	Reduced physical loads	C14		
21	Reduced batch-size	C5		
22	Improved project performance	C4		

*Supply chain management

4.1.2 Challenges Faced By Senior and Mid-Level AEC Professionals during the Implementation and Use of LPS

AEC professionals face challenges at two stages. First is the implementation stage, when the project team is introduced to LPS and pilot projects are in progress. These are organizational challenges faced by senior and mid-level management in the initial stages. During the second stage, LPS is used by an experienced team and technical challenges associated with skill building and human capital needed for using LPS are introduced. Table IV-4 lists the challenges faced by AEC professionals during the selected 26 test case projects. The challenges faced by AEC professionals first during implementation stage and second during the use by experienced team are listed in the following sections.

4.1.2.1 LPS Implementation Challenges

Phase I identified the following LPS implementation challenges:

1. Organizational inertia or resistance to change or “This is how I always done it” attitude
2. Lack of commitment to LPS implementation or attitude towards new systems
3. Lack of human capital - lack of understanding of new system or difficulty to make quality assignments or lack of skills and experience
4. Lack of training

5. Lack of leadership or failure of management commitment or organizational climate
6. Lack of stakeholder support
7. Contracting and legal issues or contractual structure
8. Partial or late implementation of LPS
9. Bad team chemistry or lack of collaboration

4.1.2.2 LPS User Challenges

Following is the list of LPS user challenges identified in the Phase I study:

1. Lack of commitment to LPS implementation or attitude towards new systems
2. Lack of human capital - lack of understanding of new system or difficulty to make quality assignments or lack of skills and experience
3. Lack of leadership or failure of management commitment or organizational climate
4. Lack of stakeholder support
5. Bad team chemistry or lack of collaboration
6. Lack of empowerment of field management or lengthy approval procedure from client and top management
7. Poor use of information generated during implementation of LPS
8. Bad work ethics and cultural issues
9. Short term vision
10. Inadequate administration

11. Extra resources or more paper work or extra staff or more meetings or additional time
12. Misinterpretation of PPC indicator

Table IV-4 Challenges faced by AEC professionals during the implementation and use of LPS

#	Challenges	LPS Implementation Phase		
		Construction	Design	SCM*
1	Organizational inertia or resistance to change or "This is how I always done it" attitude	C1, C4, C9, C10, C11, C12, C15, C16, C17, C18, C20, C21		C15, C16, C17, C19
2	Lack of commitment to LPS implementation or attitude towards new systems	C1, C2, C3, C9, C11, C12, C18, C20, C21, C24	C8	C19
3	Lack of human capital - lack of understanding of new system or difficulty to make quality assignments or lack of skills and experience	C2, C3, C6, C7, C11, C12, C13, C24	C8, C23	
4	Lack of training	C2, C3, C6, C7, C9, C18	C23	C19
5	Lack of leadership or failure of management commitment or organizational climate	C1, C2, C3, C18, C24	C8	C19
6	Lack of stakeholder support	C1, C2, C3, C9, C13		
7	Lack of empowerment of field management or lengthy approval procedure from client and top management	C11, C12, C20, C21, C24		
8	Poor use of information generated during implementation of LPS	C2, C3, C11, C12		
9	Contracting and legal issues or contractual structure	C1, C2, C3		
10	Partial or late implementation of LPS	C20, C21, C24		
11	Bad team chemistry or lack of collaboration	C18		C19
12	Bad work ethics and cultural issues	C20, C21		
13	Short term vision	C20, C21		
14	Inadequate administration	C20, C21		
15	Extra resources or more paper work or extra staff or more meetings or Additional time		C8	
16	Misinterpretation of PPC indicator	C1		

*SCM = Supply chain management

Some challenges are common in both the stages. For example, lack of stakeholder support is a challenge for the organizations in both the stages. During the initial kick off meetings and during the pilot projects some stakeholders resist to change their current practices and they do not support later on during the LPS use on projects by not committing through weekly work plans (WWP) and not participating in reverse phase scheduling and look-ahead planning.

4.2 PHASE II: RESULTS FROM THE SURVEY ASSESSING THE CHALLENGES FACED BY SENIOR AND MID-LEVEL MANAGERS DURING LPS IMPLEMENTATION

A questionnaire survey was conducted to assess the challenges faced by AEC professionals in LPS implementation stage. This survey was designed based on challenges reported in 26 test case projects and identified in Phase I of the study. The online survey questionnaire was available from April 22nd 2010 to July 2nd 2010. Survey link was sent to 56 Lean Construction Institute (LCI) corporate member companies, 9 LCI approved consultants and 131 LCI members, making a sample size of 196. A request was also sent through European Group of Lean Construction (EGLC) newsletter. A total of 40 returned surveys were analyzed using descriptive statistics and results were compared with the literature survey results from Phase I study.

The survey was answered by architects, engineers, general contractors, subcontractors, and management professional as shown in Figure IV-1. Fifty percent of

respondent organizations are general contracting (GCs) firms. Other functions mentioned are facilitators or coach.

Figure IV-2 shows the respondents' job positions. Ten percent of other respondents are continuous improvement managers, researchers and lean construction managers. Fifty five percent respondents are senior managers and other respondents are counted as middle management, including architects, construction managers, and schedulers.

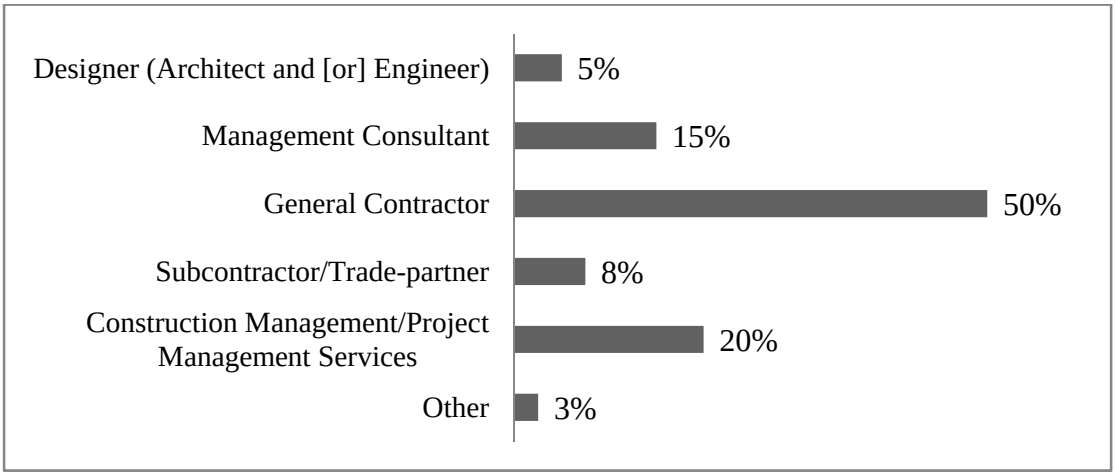

Figure IV-1 Functions of respondents' organizations

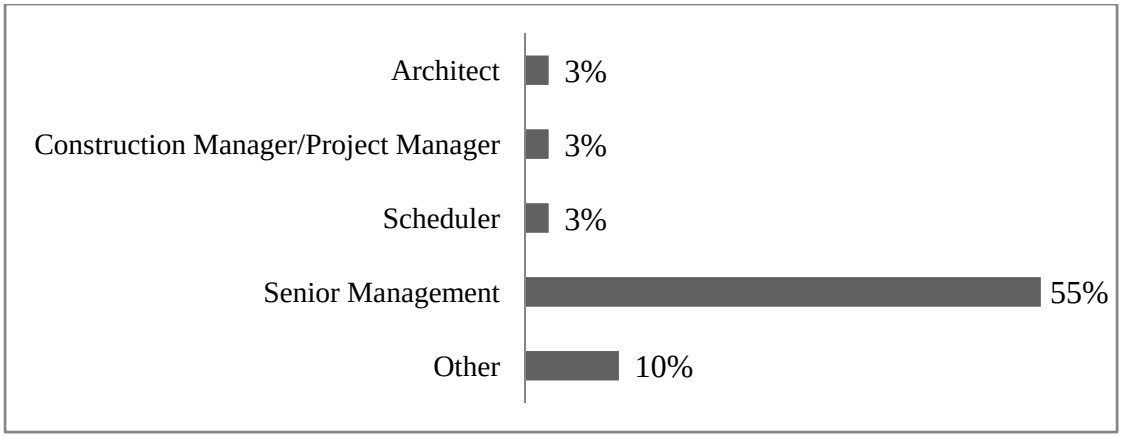

Figure IV-2 Respondents' job positions

Respondents' average industry experience is 22 years and they are working on their current positions on an average of past 9 years. To capture the wider LPS user perceptions the online survey link was sent to worldwide IGLC and LCI members, however 35 out of 40 (87%) respondents are from USA and their organizations are headquartered in USA. Moreover, they used LPS on projects based in USA only. All other respondents also implemented LPS in the same countries where their organizations are headquartered. Figure IV-3 shows the countries where respondents' organizations are headquartered.

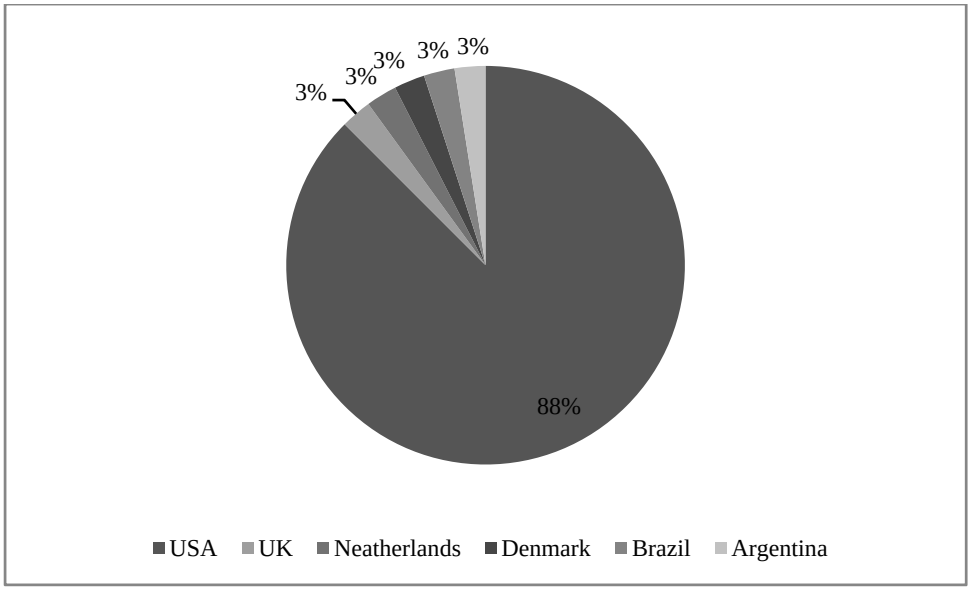

Figure IV-3 Countries where respondents' organizations are headquartered

Respondents' organizations work in diverse construction sectors namely commercial, industrial, health care, higher education, residential, heavy civil, and public & community building. Figure IV-4 shows the construction sectors in which respondents' organizations work and Figure IV-5 shows the project phase when LPS is used in their organizations. Twenty three percent of respondents' mentioned their organizations work in health care or labs and data centre building sectors. Eight percent respondents said they use LPS in commissioning phase too.

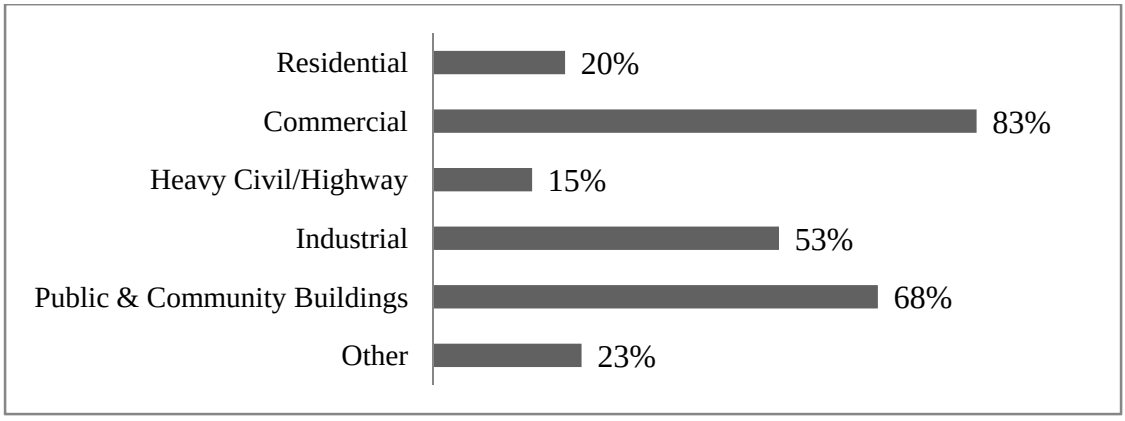

Figure IV-4 Construction sectors in which respondents' organizations work

Literature survey conducted in Phase-I revealed that LPS was implemented in construction phase, design phase and for supply chain management. Phase I study also revealed that 23 out of 26 test case projects used LPS during the construction phase. In Phase-II study 50% of survey respondents are general contractors.

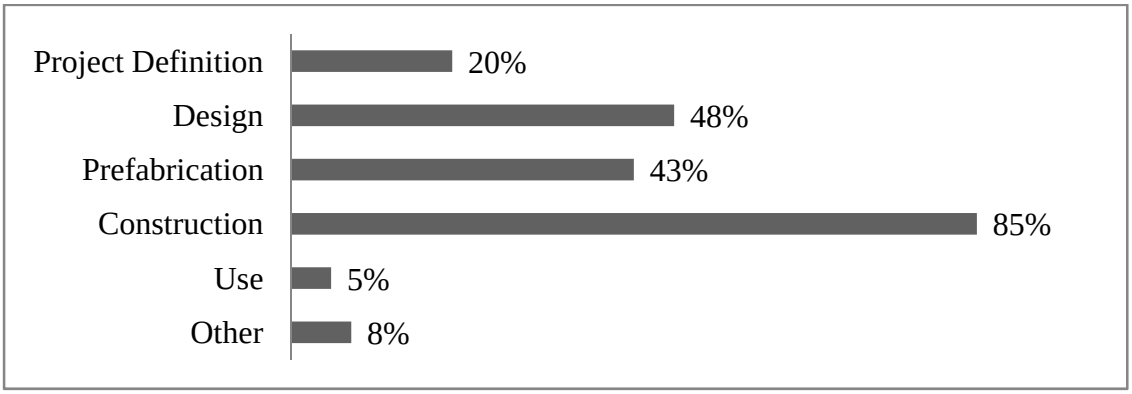

Figure IV-5 Phase for which LPS was implemented

Table IV-5 Respondents' experience profiles

#	Construction industry experience (years)	Number of years on current job position	Experience on LPS (years)	Number of projects done using LPS
R1	36	6	3	3
R2	35	6	3	3
R3	35	2	2	2
R4	34	34	9	8
R5	32	0	1	
R6	31	12	1	1
R7	30	5	11	
R8	30	19	1	2
R9	30	5	5	50
R10	30	10	1	2
R11	30	5	2	3
R12	30	15	2	
R13	30	26	5	
R14	26	12	10	8
R15	25	10	5	25
R16	25	20	6	3
R17	25	25	8	20
R18	25	4		30
R19	25	6	10	2
R20	24	2	4	55
R21	22	18	3	16
R22	21	5	7	10
R23	20	1	2	1
R24	18	9	5	5
R25	17	5	3	1
R26	17	3	2	3
R27	15	3	5	5
R28	15	7	10	2
R29	14	12	5	2
R30	13	8	1	2
R31	13	2	6	12
R32	13	1	9	
R33	13	6	4	30
R34	13	10	3	5
R35	12	1	4	10
R36	11	5	2	35
R37	6	4	1	1
R38	4	4	1	3
R39	0	0	0	0

The primary condition for filling out the survey was respondent's experience with LPS. Only people answering YES to the first question "Do you use Last Planner System for planning and control purposes?" were directed to the survey questionnaire (Appendix-B). Thirty four respondents said they have experience with LPS implementation on 360 projects that makes an average experience of 11 projects each respondent. Three respondents said they did several projects where LPS was implemented. Table IV-5 lists the respondents' construction industry experience and their experience with LPS.

Table IV-6 shows the 20 statements (S01-S20) that were used to assess the perceptions of senior and mid level AEC professionals about the challenge categories (C02-C07) during the implementation of LPS. In the survey questionnaire five statements are positive that are reiterated in negative statements. For example, the positive statement "There is a strong leadership in my organization for implementing LPS" in the survey questionnaire is reiterated to form a negative statement S05 "There is no strong leadership in my organization for implementing LPS." Statements S05, S06, S08, S11 and S12 are reiterated and included in Table IV-5.That way all the statements (S05-S09) under challenge category C02 "Lack of leadership or failure of management commitment or organizational climate" become negative and endorsement of any of these statements by respondents would mean the endorsement to challenge category C02. This is done to analyze survey data based on the respective challenge category. Answers to these questions are inverted that is a response of 7 becomes 1, 6 becomes 2, and 5 becomes 3 on a seven point Likert scale question for the analysis part.

Table IV-6 Statements included in the survey questionnaire based on LPS implementation challenge categories

C01: Lack of human capital - lack of understanding of new system or difficulty to make quality assignments or lack of skills and experience
S01: In my organization people are not skilled at using LPS
S02: In my organization people do not have enough knowledge in using LPS for planning and control purposes
S03: In my organization people do not have enough experience in using LPS for planning and control purposes
S04: In my organization people find it hard to use the LPS
C02: Lack of leadership or failure of management commitment or organizational climate
S05: There is no strong leadership in my organization for implementing LPS
S06: Management in my organization is not committed to the implementation and use of LPS
S07: My organization does not provide a positive climate for implementing LPS
S08: My organization does not offer incentives to last planners (example: foreman, supervisor, project engineer) who support implementing and using LPS
S09: My organization faces internal conflicts (example: resistance to change, lack of training) in implementing and using LPS
C03: Lack of stakeholder support
S10: My organization faces external conflicts (example: lack of client support or subcontractor support) and challenges in implementing and using LPS
S11: My organization does not get good support from the owner (client) for using lean principles and techniques such as LPS
S12: My organization does not get encouragement from the owner (client) for using lean principles and techniques such as LPS
S13: In my organization people refuse to include subcontractors in planning
C04: Organizational inertia or resistance to change or "This is how I always done it" attitude
S14: In my organization people are reluctant to implement and use LPS for planning and control purposes
S15: In my organization people are unwilling to change, when new systems are introduced
S16: Standard procedures of my organization make it difficult to implement and use a new system such as LPS
C05: Contracting and legal issues or contractual structure
S17: My organization faces contractual issues when implementing and using LPS
S18: My organization faces legal issues when implementing and using LPS
C06: Lack of commitment to LPS implementation or Attitude towards new systems
S19: In my organization people refuse to assume commitments themselves
C07: Bad team chemistry or lack of collaboration
S20: In my organization people find it difficult to collaborate with the teams from other organizations during the weekly-work-plan meetings

Table IV-7 Results of calculating the median, quartiles, minimum, maximums, and ranges response for each statement

Statement	N	N*	Minimum	Q1	Median	Q3	Maximum	Range
S01	40	0	1	2	4	6	7	6
S02	40	0	1	2	4	5	7	6
S03	40	0	1	3	4	6	7	6
S04	40	0	1	2	3	5	7	6
S05	40	0	1	1	3	3	7	6
S06	40	0	1	1	2	4	7	6
S07	38	2	1	1	2	3	7	6
S08	40	0	2	4	6	7	7	5
S09	40	0	1	3	4	6	7	6
S10	39	1	1	2	5	5	7	6
S11	40	0	1	2	4	5	7	6
S12	38	2	1	2	3	5	6	5
S13	40	0	1	1	2	3	6	5
S14	40	0	1	2	4	5	7	6
S15	40	0	1	2	3	5	6	5
S16	39	1	1	1	2	3	7	6
S17	39	1	1	1	2	4	6	5
S18	40	0	1	1	1	3	6	5
S19	40	0	1	2	3	5	7	6
S20	40	0	1	2	2	4	7	6
N=Total number of responses, N*= Missing responses								

Author used a seven-point Likert scale for the perception survey, which is an ordinal scale. The statistic most appropriate for describing the central tendency of scores in an ordinal scale is the median, since the median is not affected by changes of any scores which are above or below it as long as the number of scores above and below remains the same (Siegal and Castellan1988). The results of medians, quartiles, minimums, maximums, and ranges for each of the statement are shown in Table IV-7.

Figure IV-6 shows the graphing of the median response for each of the statement from the perception survey of AEC professionals.

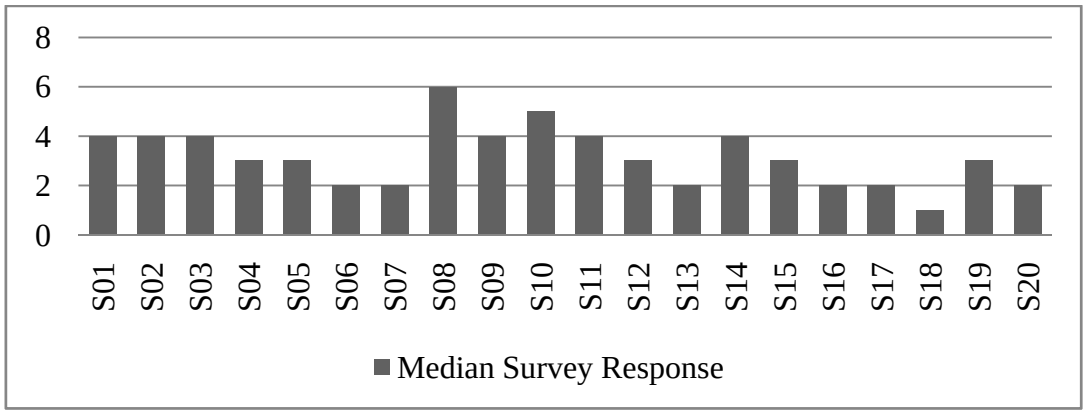

Figure IV-6 Median survey response

The major feature of the AEC professionals' responses missing from the median approach is any indication of the distribution of the responses.

The second alternative for reporting these data, the proportion of responses in each category for every statement, appears in Table IV-8 and Figure IV-7, where the AEC professional perceptions survey statements are presented in the same order as in the median report in Figure IV-6.

Table IV-8 Results from the perceptions survey

	1=Strongly Disagree		2=Moderately Disagree		3=Slightly Disagree		4=No Feeling		5=Slightly Agree		6=Moderately Agree		7=Strongly Agree		Total Cnt
	Cnt	%	Cnt	%	Cnt	%	Cnt	%	Cnt	%	Cnt	%	Cnt	%	
S01	1	3%	10	25%	7	18%	6	15%	6	15%	6	15%	4	10%	40
S02	3	8%	10	25%	6	15%	7	18%	8	20%	4	10%	2	5%	40
S03	1	3%	7	18%	6	15%	6	15%	7	18%	8	20%	5	13%	40
S04	5	13%	9	23%	7	18%	5	13%	9	23%	4	10%	1	3%	40
S05	11	28%	8	20%	12	30%	5	13%	1	3%	2	5%	1	3%	40
S06	14	35%	7	18%	9	23%	6	15%	1	3%	2	5%	1	3%	40
S07	15	39%	9	24%	6	16%	3	8%	2	5%	2	5%	1	3%	38
S08	0	0%	1	3%	5	13%	6	15%	2	5%	10	25%	16	40%	40
S09	1	3%	8	20%	7	18%	5	13%	9	23%	7	18%	3	8%	40
S10	3	8%	9	23%	3	8%	4	10%	12	31%	5	13%	3	8%	39
S11	4	10%	10	25%	6	15%	9	23%	5	13%	4	10%	2	5%	40
S12	5	13%	5	13%	11	29%	7	18%	4	11%	6	16%	0	0%	38
S13	11	28%	15	38%	5	13%	2	5%	5	13%	2	5%	0	0%	40
S14	2	5%	9	23%	6	15%	7	18%	8	20%	7	18%	1	3%	40
S15	5	13%	12	30%	5	13%	3	8%	6	15%	9	23%	0	0%	40
S16	11	28%	9	23%	10	26%	4	10%	3	8%	1	3%	1	3%	39
S17	15	38%	5	13%	2	5%	9	23%	5	13%	3	8%	0	0%	39
S18	21	53%	7	18%	3	8%	7	18%	1	3%	1	3%	0	0%	40
S19	7	18%	12	30%	7	18%	4	10%	7	18%	2	5%	1	3%	40
S20	8	20%	13	33%	7	18%	3	8%	6	15%	2	5%	1	3%	40

Table IV-9 summarizes the results from the perception survey for each challenge category, where overall rejection percentage is calculated by averaging the rejection percentages (response = 1 or 2 or 3) of supporting statements and overall endorsement is calculated by averaging the endorsement percentages (response = 5 or 6 or 7) of supporting statements. For example, overall rejection percentage for category C01 is calculated by averaging the percentages of rejections (response = 1 or 2 or 3) for statements S01, S02, S03 and S04.

Table IV-9 Summaries of perceptions of AEC professionals about the challenge categories C01 to C07

	Challenge Categories	Overall Rejection	Overall Endorsement
C01	Lack of human capital - lack of understanding of new system or difficulty to make quality assignments or lack of skills and experience	45%	40%
C02	Lack of leadership or failure of management commitment or organizational climate	57%	30%
C03	Lack of stakeholder support	55%	31%
C04	Organizational inertia or resistance to change or "This is how I always done it" attitude	58%	30%
C05	Contracting and legal issues or contractual structure	67%	13%
C06	Lack of commitment to LPS implementation or attitude towards new systems	65%	25%
C07	Bad team chemistry or lack of collaboration	70%	23%

The display of proportion of responses in each category, from strongly disagree on the left side to strongly agree on the right side of each column in Figure IV-7, provides a clear picture of the patterns of endorsement of the survey statements. For example, it appears that the statement S06 "Management in my organization is not committed to the implementation and use of LPS" is strongly rejected by the AEC professionals with thirty five percent of AEC professionals responding that they *strongly disagree* and rejected by further forty one percent of AEC professionals. This statement is closely followed by the statement S07 "My organization does not provide a positive climate for implementing LPS" with thirty nine percent of AEC professionals responding that they *strongly disagree*.

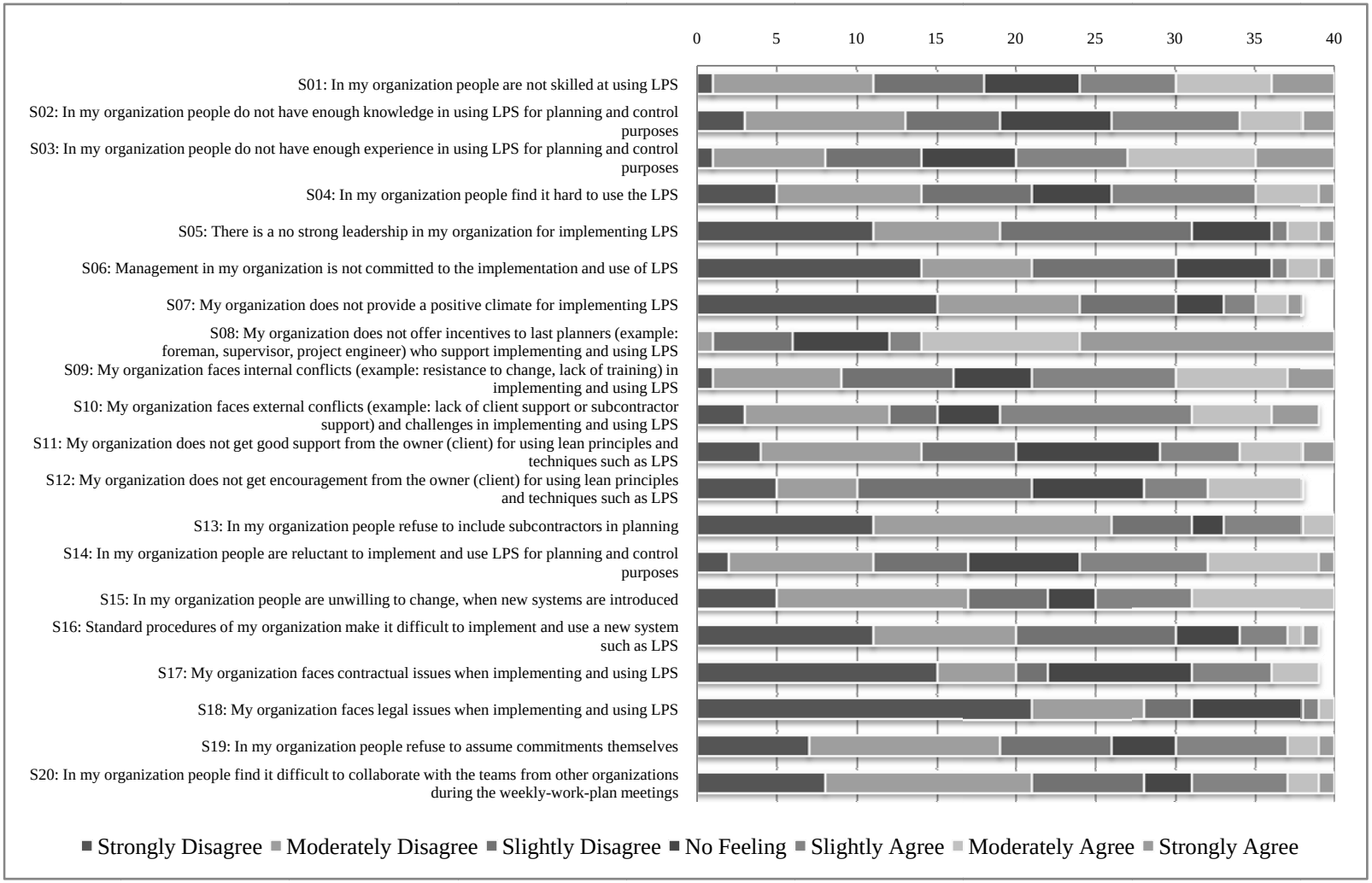

Figure IV-7 Proportion of responses in each response category

At the other end of the scale, the statement S09 “My organization faces internal conflicts (example: resistance to change, lack of training) in implementing and using LPS” is endorsed with forty nine percent of AEC professionals. Thus, from the graph of response proportions, we can see that about half of the AEC professionals believe that their organizations face internal conflicts during the implementation of LPS.

Other inferences can be drawn from the graph of the proportions of responses since the survey statements have been grouped in such a way that those which address the same LPS implementation challenge are together. In the following sections the challenge categories C01-C07 as mentioned in Table IV-6 and C08 –“Partial or late implementation of LPS” and C09-“Lack of training” are discussed in detail.

4.2.1 Lack of Human Capital - Lack of Understanding of New System or Difficulty to Make Quality Assignments or Lack of Skills and Experience

Challenge category C01, "Lack of human capital - lack of understanding of new system or difficulty to make quality assignments or lack of skills and experience", is addressed by the following AEC professional perceptions survey statements:

1. S01: In my organization people are not skilled at using LPS
2. S02: In my organization people do not have enough knowledge in using LPS for planning and control purposes
3. S03: In my organization people do not have enough experience in using LPS for planning and control purposes
4. S04: In my organization people find it hard to use the LPS

The bar graph in Figure IV-7 shows that responses to statements S02 and S04 are negative with about forty eight percent of AEC professionals rejecting the statement S02 against thirty five percent endorsing it, and fifty three percent rejecting the statement S04 against thirty five percent endorsing it. However the response to statement S03 is positive with about half of the AEC professionals endorsing the statement against thirty five percent rejecting it. This indicates that AEC professionals perceive that people in their organizations have enough knowledge about using LPS and they do not find it hard to use LPS; however there is a lack of experience in using LPS in their organizations.

AEC professionals do not appear to either reject or endorse statement S01 with forty five percent of respondents rejecting and forty percent of endorsing it. It is also important that the 'last planners' – one who instructs people to execute the work, generally foreman – prepare the weekly work plans (WWP) and commit to the work (Ballard 2000). Therefore, to understand the level of understanding of new system (LPS), AEC professionals were asked as to who is responsible for making commitments in weekly work plan meetings in their organizations. Fifty five percent AEC professionals said foreman or superintendent or both prepare the WWP, thirty three percent respondents said that subcontractors' (or trade-partners') superintendents or foremen or both prepare the WWP. These responses show that in majority of AEC professionals' organizations last planners are making promises. However, twenty five respondents said project managers make the commitments in WWP meetings. This indicates that in a quarter of AEC professionals' organizations middle management makes commitments in WWP meetings and not the 'last planners'.

Table IV-10 There is an agreement among project team on what makes a 'sound' commitment

	Response Percent	Response Count
Yes	55%	22
No	42%	17
No Response	2%	1
Total	100%	40

The results from the Spearman's Rank-Order Correlation test between statements S01 and S03 are shown in Table IV-11.

Table IV-11 Results from Spearman's Rank-Order Correlation test (S01-S03)

Spearman Rank-Order Correlation Coefficient (S01-S03)	
n	40
Spearman's rho (r_s)	0.7586
t	7.18
df	38
p-one tailed	<.000001
p-two tailed	<.000001
r_s^2	0.575474

Agreement among project stakeholders on what makes a sound commitment (and thus quality assignments) is crucial to the successful LPS implementation (Ballard and Howell 1997). Table IV-10 shows that in fifty five percent of AEC professionals' organizations there is an understanding, an agreement, on what makes a sound commitment, a reliable promise. However, in forty two percent of AEC professionals' organizations there is no understanding among project stakeholders on what makes a

sound commitment. These results indicate that there is lack of understanding of the new system (LPS) in forty two percent of AEC professionals' organizations.

r_s^2=0.57 means that the covariance between the statements S01 and S03 rankings is 57% as strong as it possibly could be, and the positive sign of r_s =+0.7586 signals that this co-variation occurs along the upward slant, with higher values of responses to statement S01 tending to be associated with higher values of responses to statement S03, and vice versa. This could be inferred from these results that respondents tend to either agree or disagree on both questions S01 and S03. These statements are made with a higher than 99% confidence level (p-values lower than 0.01). This in turn implies that organizations where AEC professionals perceive that people in their organizations do not have enough experience in using LPS for planning and control purposes also believe that people in their organizations are not skilled at using LPS and vice versa. These results indicate that people's skills in using LPS for planning and control purposes depend on the experience with LPS in respondents' organizations. This is a commonly seen phenomenon that skill set on any new system improves with experience with the system and this is also true with LPS.

Moreover, the results from the Spearman's Rank-Order Correlation test between statements S01 and S04 are shown in Table IV-12.

Table IV-12 Results from Spearman's Rank-Order Correlation test (S01-S04)

Spearman Rank-Order Correlation Coefficient (S01-S04)	
n	40
Spearman's rho (r_s)	0.6652
t	5.49
df	38
p-one tailed	0.000002
p-two tailed	0.000003
r_s^2	0.442491

r_s^2=0.44 means that the covariance between the statements S01 and S04 rankings is 44% as strong as it possibly could be, and the positive sign of r_s =+0.6652 signals that this co-variation occurs along the upward slant, with higher values of response to statement S01 tending to be associated with higher values of response to statement S04, and vice versa. This could be inferred from these results that respondents tend to either agree or disagree on both questions S01 and S04. These statements are made with a higher than 99% confidence level (p-values lower than 0.01). This in turn implies that organizations where AEC professionals perceive that people in their organizations are not skilled at using LPS also believe that people in their organizations find it hard to use LPS and vice versa. These results highlight the importance of skill development and human capital in using LPS.

4.2.2 Lack of Leadership or Failure of Management Commitment or Unfavorable Organizational Climate

Challenge category C02, "Lack of leadership or failure of management commitment or unfavorable organizational climate", is addressed by the following AEC professional perceptions survey statements:

1. S05: There is no strong leadership in my organization for implementing LPS
2. S06: Management in my organization is not committed to the implementation and use of LPS
3. S07: My organization does not provide a positive climate for implementing LPS
4. S08: My organization does not offer incentives to last planners (example: foreman, supervisor, project engineer) who support implementing and using LPS
5. S09: My organization faces internal conflicts (example: resistance to change, lack of training) in implementing and using LPS

The bar graph in Figure IV-7 shows that responses to statements S05, S06 and S07 are negative with more than three quarters of AEC professionals rejecting these statements. These results indicate that AEC professionals perceive that their organizations have a strong leadership and management commitment to the implementation of LPS and there is a positive climate in their organizations for LPS implementation.

However, AEC professionals do not appear to either reject or endorse statement S09 with forty eight percent respondents endorsing it against forty percent rejecting it. This indicates that about half of the AEC professionals perceive that they face internal conflicts such as resistance to change in their organizations.

Response to statement S08 is positive with seventy percent of the AEC professionals endorsing the statement S08. This indicates that AEC professionals perceive that their organizations do not offer any incentives to people who support the LPS implementation. However, less stress levels and getting home on time everyday have been pointed out as indirect incentives from LPS implementation. One respondent said that "*Pride in contributing to improving a service or industry in the community, securing a repeat client, and job satisfaction from working on large complex high profile projects are main incentives. Employees who really go way above and beyond expectations, like working hard to learn and teach LPS, are singled out in several levels of bonus programs depending on contribution of effort / measurable client satisfaction and / or earnings results.*"

Organizational climate also decides how well LPS will be accommodated with the day-to-day life of the project. Seventy eight percent of AEC professionals said they do not feel blamed when there is a mistake while using LPS, as shown in Table IV-13. This shows positive implementation environments in respondents' organizations.

Table IV-13 People feel blamed when there is a mistake while using LPS

	Response Percent	Response Count
Yes	20%	8
No	78%	31
No Response	2%	1
Total	100%	40

The results from the Spearman's Rank-Order Correlation test between statements S05 and S06 are shown in Table IV-14.

Table IV-14 Results from Spearman's Rank-Order Correlation test (S05-06)

Spearman Rank-Order Correlation Coefficient (S05-S06)	
n	40
Spearman's rho (r_s)	0.7154
t	6.31
df	38
p-one tailed	<.000001
p-two tailed	<.000001
r_s^2	0.511797

r_s^2=0.51 means that the covariance between the statements S05 and S06 rankings is 51% as strong as it possibly could be, and the positive sign of r_s =+0.7154 signals that this co-variation occurs along the upward slant, with higher values of response to statement S05 tending to be associated with higher values of response to statement S06, and vice versa. This could be inferred from these results that respondents tend to either agree or disagree on both questions S05 and S06. These statements are made with a higher than 99% confidence level (p-values lower than 0.01). This in turn implies AEC professionals who perceive that their organizations have strong leadership for LPS

implementation also believe that management in their organizations is committed to LPS implementation and vice versa.

4.2.3 Lack of Stakeholder Support

Challenge category C03, "Lack of stakeholder support", is addressed by the following AEC professional perceptions survey statements:

- S10: My organization faces external conflicts (example: lack of client support or subcontractor support) and challenges in implementing and using LPS
- S11: My organization does not get good support from the owner (client) for using lean principles and techniques such as LPS
- S12: My organization does not get encouragement from the owner (client) for using lean principles and techniques such as LPS
- S13: In my organization people refuse to include subcontractors in planning

The bar graph in Figure IV-7 shows that responses to statements S11, S12 and S13 are negative with half of the AEC professionals rejecting statement S11 against twenty eight percent endorsing it, fifty five percent of respondents rejected the statement S12 against twenty six percent endorsing it, and seventy eight percent respondents rejecting statement S13. This indicates that AEC professionals perceive that their organizations get good support and encouragement from owner (client) for using LPS and people in their organizations do not refuse to include subcontractors. These results

imply that AEC professionals get good support and encouragement from the owner (client) during the LPS implementation and their organizations include subcontractors in the meetings. However, fifty one percent of AEC professionals endorsed statement S11 against thirty eight percent rejected it. This indicates that fifty one percent of AEC professionals perceive that their organizations face external conflicts during the LPS implementation and thirty eight percent do not believe so.

To further investigate perceptions of AEC professionals about stakeholder support they were asked to name the organizations they find most difficult to deal with during the LPS implementation. To understand the perceptions of AEC professionals, from the organizations with different functions, about the other stakeholders a proportional response graph is drawn as shown in Figure IV-8. Figure IV-8 provides a clear picture of the pattern of responses by one stakeholder about the support in LPS implementation from the other project stakeholders.

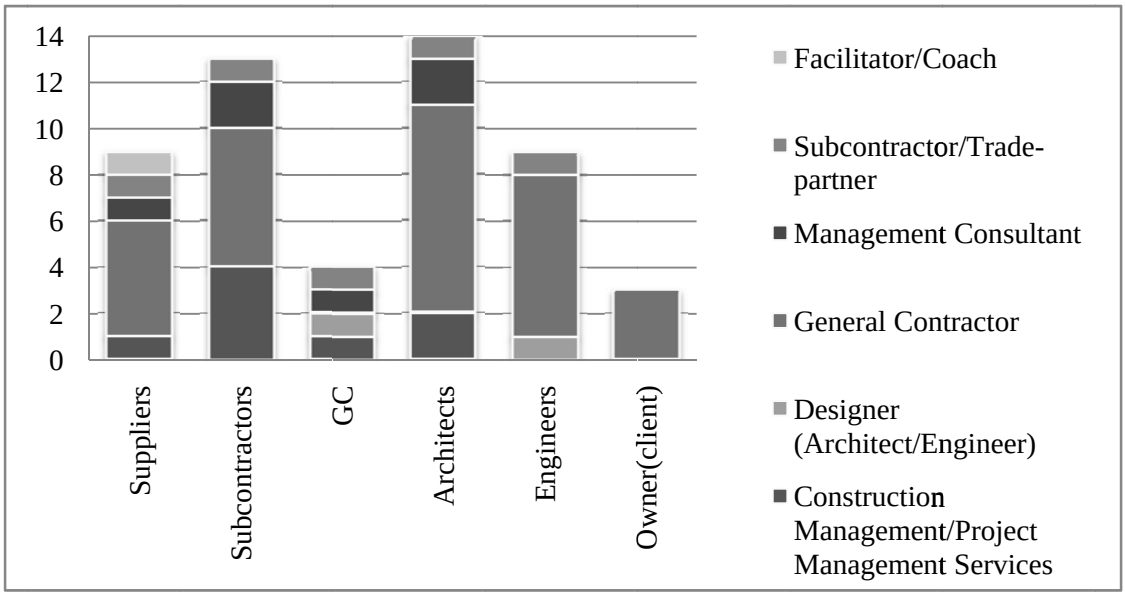

Figure IV-8 Organizations most difficult to deal with during LPS implementation

4.2.4 Organizational Inertia or Resistance To Change or "This Is How I Always Done It" Attitude

Challenge category C04, " Organizational inertia or resistance to change or "This is how I always done it" attitude", is addressed by the following AEC professional perceptions survey statements:

- S14: In my organization people are reluctant to implement and use LPS for planning and control purposes
- S15: In my organization people are unwilling to change, when new systems are introduced
- S16: Standard procedures of my organization make it difficult to implement and use a new system such as LPS

The bar graph in Figure IV-7 shows that responses to statements S15 and S16 are negative with fifty five percent of the AEC professionals rejecting statement S15 against thirty eight percent endorsing it and seventy seven percent of respondents rejected the statement S16. This indicates that fifty five percent of AEC professionals believe that people in their organizations are willing to change and more than three quarter of respondents believe that standard procedures of their organizations do not hamper the LPS implementation.

However, AEC professionals do not seem to either endorse or reject statement S14 with forty three percent rejecting it and forty percent endorsing it.

To further investigate the relationship between organizational climate and organizational inertia the responses to statement S07 “My organization does not provide a positive climate for implementing LPS” and statement S14 “In my organization people are reluctant to implement and use LPS for planning and control purposes” were compared. Forty three percent of AEC professionals rejecting statement S07 endorsed statement S14. This indicates that forty three percent of AEC professionals perceive that their organizations provide positive climate for LPS implementation but people in their organizations are reluctant to implement and use LPS.

The results from the Spearman’s Rank-Order Correlation test between statements S14 and S15 are shown in Table IV-15.

Table IV-15 Results from Spearman's Rank-Order Correlation test (S14-S15)

Spearman Rank-Order Correlation Coefficient (S14-S15)	
n	40
Spearman's rho (r_s)	0.7026
t	6.09
df	38
p-one tailed	<.000001
p-two tailed	<.000001
r_s^2	0.493647

r_s^2=0.49 means that the covariance between the statements S14 and S15 rankings is 49% as strong as it possibly could be, and the positive sign of r_s =+0.7026 signals that this co-variation occurs along the upward slant, with higher values of response to statement S14 tending to be associated with higher values of response to statement S15, and vice versa. This could be inferred from these results that respondents tend to either agree or disagree on both questions S14 and S15. These statements are made with a higher than 99% confidence level (p-values lower than 0.01). From these results it could be inferred that organizations where AEC professionals perceive that people in their organizations are unwilling to change whenever new systems are introduced also believe that people in their organizations are reluctant to implement and use LPS and vice versa.

4.2.5 Contracting and Legal Issues or Contractual Structure

Challenge category C05, " Contracting and legal issues or contractual structure", is addressed by the following AEC professional perceptions survey statements:

- S17: My organization faces contractual issues when implementing and using LPS

- S18: My organization faces legal issues when implementing and using LPS

The bar graph in Figure IV-7 shows that responses to statements S17and S18 are negative. Thirty eight percent AEC professionals responded that they *strongly disagree* with statement S17 with further eighteen percent rejecting it. Statement S18 is strongly rejected by AEC professionals with fifty three percent responding that they *strongly disagree* with further twenty five percent respondents rejecting it. This indicates that AEC professionals perceive that their organizations do not face any contractual or legal issues when implementing and using LPS.

Traditionally, facility owners have been presented with a standard set of project delivery options: design-bid-build, construction management (agency or at-risk), or design-build. Despite this range of options, many owners remain dissatisfied: projects take too long, they cost too much, and the work fails to meet quality expectations (Lichtig 2006). Figure IV-9 shows the type of project delivery methods used in AEC professionals' organizations when LPS was implemented. The top four in order are: design-build (53%), integrated project delivery (43%), construction management at risk (38%) and design-bid-build (35%). Two respondents reported they use design-assist as a project delivery method when LPS is implemented. These results indicate that LPS was implemented on projects irrespective of project delivery method. However, respondents implied that owner (client) needs a detailed CPM schedule at the beginning of the project and so owner's buy into LPS is necessary to avoid contractual and legal issues.

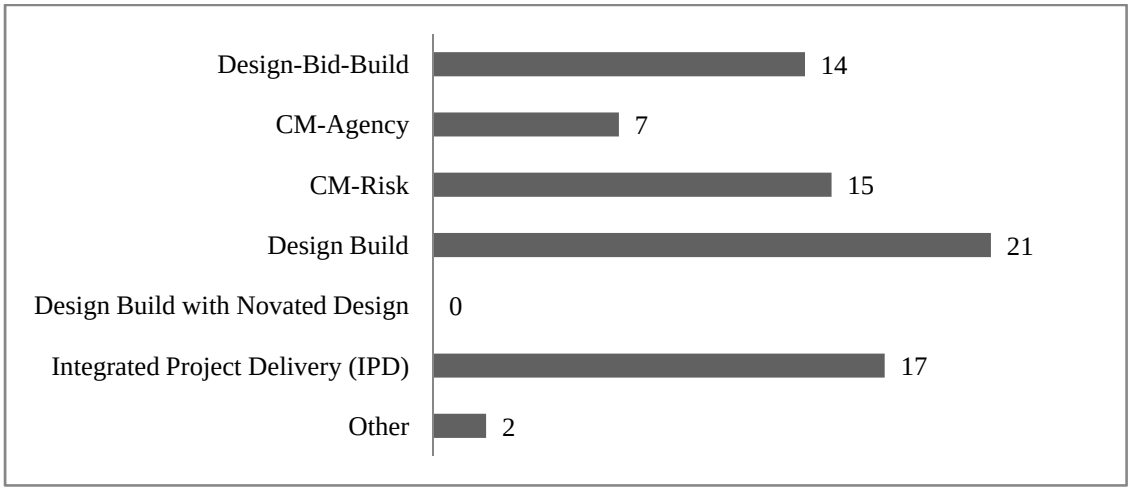

Figure IV-9 Project delivery methods used when LPS was implemented

Eighty three percent of AEC professionals (who have done 360 projects using LPS altogether) indicated that they either use design-build, integrated project delivery (IPD) or CM-risk project delivery method on the projects where LPS is implemented. These results indicate that majority of projects where LPS is implemented in respondents' organizations do not choose design-bid-build project delivery method.

4.2.6 Lack of Commitment to LPS Implementation or Attitude towards New Systems

Challenge category C06, "Lack of commitment to LPS implementation or attitude towards new system", is addressed by the following AEC professional perceptions survey statement:

- S19: In my organization people refuse to assume commitments themselves

The bar graph in Figure IV-7 shows that response to statement S19 is negative with sixty five percent of AEC professionals rejecting it. This indicates that AEC professionals perceive that people in their organizations do not refuse to assume commitments while implementing and using LPS.

Statement S15 “In my organization people are unwilling to change, when new systems are introduced” could also be used to analyze AEC professionals’ perceptions about challenge category C06, "Lack of commitment to LPS implementation or attitude towards new system." Fifty five percent of AEC professionals rejected statement S15 and thirty eight percent respondents endorsed it. This indicates that majority of AEC professionals believe that people in their organizations are willing to change when new systems such as LPS are introduced.

4.2.7 Bad Team Chemistry or Lack of Collaboration

Challenge category C07, "Bad team chemistry or lack of collaboration", is addressed by the following AEC professional perceptions survey statement:

- S20: In my organization people find it difficult to collaborate with the teams from other organizations during the weekly-work-plan meetings

The bar graph in Figure IV-7 shows that response to statement S20 is negative with seventy percent of AEC professionals rejecting it. This indicates that AEC professionals perceive that in their organizations people find it easy to collaborate with the teams from other organizations during the weekly work plan meetings.

4.2.8 Lack of Training

Sixty five percentage of respondents said that there is a formal training program to implement LPS in their organizations as shown in Table IV-16.

Table IV-16 Organization has formal training program to implement LPS

	Response Percent	Response Count
Yes	65%	26
No	35%	14
Total	100%	40

Majority of these organizations developed an LPS implementation plan and they run LPS training sessions on regular basis. One respondent said "*We have developed a training curriculum and maintain an implementation plan that tracks who has received training, participated in activities, reached skill levels, etc.*" Some respondents said their organizations have a continuous improvement program in place and LPS implementation is a part of this program. Respondents also reported that their organizations run LPS training in the beginning of each project and some said their organizations do not always implement LPS but it is a preferred method.

The lean construction department and LCI approved consultants provide workshops on lean principles and LPS implementation in some organizations. Study Action Team™ (SAT)[5], LPS boot camps, and LCI meetings are also mentioned as preferred LPS training methods.

[5] Study Action Team is a trademark of Lean Project Consulting, California, USA

Sixty two percent of AEC professionals whose organizations do not have formal training program for LPS implementation endorse the statement S01 “In my organization people are not skilled at using LPS” with only fifteen percent rejecting it. It can be inferred from these result that AEC professionals whose organizations do not have formal training programs for LPS implementation also believe that people in their organizations are not skilled at using LPS.

To investigate if size of the company affects the presence of formal training programs for LPS implementation in the organizations the companies with size greater than US $ 1 Billion and companies with size less than US $ 300 Million are compared. It appears that seventy five percent of organizations with size greater than US $ 1 Billion and sixty two percent of organizations with size less than US $ 300 Million have formal training programs for LPS implementation. These results indicate that organizations have training programs for LPS implementation irrespective their sizes.

To evaluate the effect of organizational strategies on LPS implementation and training AEC professionals were asked whether their organizations have a strategy to implement LPS. Forty two percentage of respondents said that their organizations have a strategy for LPS implementation. Table IV-17 shows the survey results. These results indicate that majority of AEC professionals’ organizations do not have LPS implementation strategies.

Table IV-17 Organization has a Strategy for Implementing LPS

	Response Percent	Response Count
Yes	42%	16
No	58%	24
Total	100%	40

The strategy for LPS implementation in majority of organizations is to train the entire project team on LPS. One respondent said that their strategy is to "*educate entire staff in culture and guiding principles of lean production as it specifically relates to construction*". On respondent pointed out that his organization is running LPS pilot projects and planning to take the continuous improvement path based on the lessons learned on this project. One other respondent said that his organization decides LPS implementation strategy based on project duration "*The mix of our projects includes some that are fewer than 8 weeks in length. We find the LPS to be a little bit more work than we derive value out of using it on such short term projects. For any medium to large projects, we believe that the LPS should always be used in construction. We are trying to find a way to make it work in the design phase. Possibly implementing something like QFD (quality function deployment) or Outcome Driven Innovation for scope development would eliminate some of the 'elasticity' or dynamic nature of design (and making it more conducive to a production environment where LPS would be appropriate).*" In other instance respondent said that his organization aim at changing foreman's role from fire-fighter to planner and reviewer.

These results imply that strategies for LPS implementation in the organizations are designed by keeping LPS training requirements and project durations in mind.

4.2.9 Partial or Late Implementation of LPS

An analysis of a database of 77 Chilean projects, where LPS was implemented, revealed that the projects with a more complete implementation had a higher plan reliability rates (percentage plan complete) than projects with basic implementation (Alarcón et al. 2008). Figure IV-10 shows the LPS components used by AEC professionals' organizations as a part of planning process. As shown in the Figure IV-10 majority of organizations use master schedule (85%), phase planning (88%), look-ahead planning (93%), weekly work planning (90%), and percentage plan complete (PPC) (73%). Thirteen percent others mentioned location based scheduling (line-of-balance method) and value stream mapping and 4D BIM visualization as the part of their planning process. These results indicate that there is a minimal use of other LPS components such as constraint analysis, reason charting, first run studies, and root cause analysis.

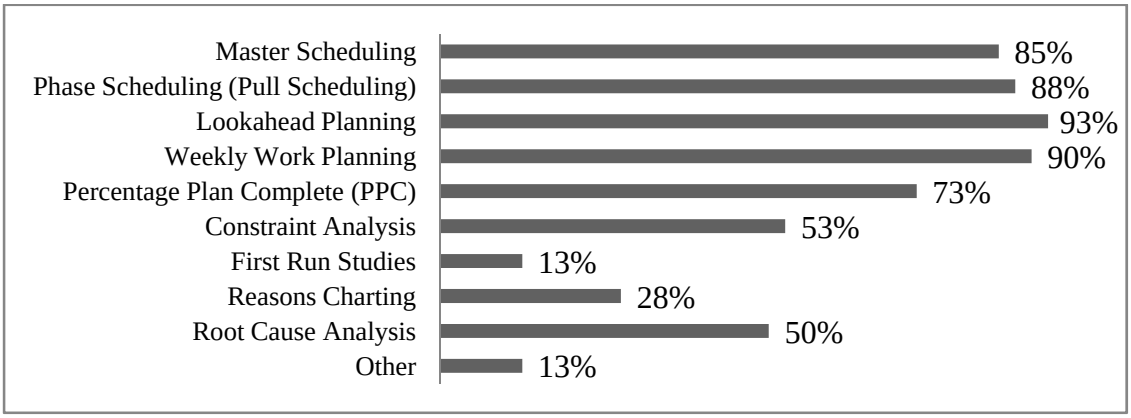

Figure IV-10 LPS components used as a part of planning process in the organizations

As shown in Table IV-18 sixty percent of respondents said their organizations do not implement LPS from the beginning of the project. However, forty three percent of AEC professionals said their organizations implemented LPS in most of the projects when the project was 0% to 25% complete, as shown in Table IV-19.

Table IV-18 Number of organizations implementing LPS from the beginning of the project

	Response Percent	Response Count
Yes	40%	16
No	60%	24
Total	100%	40

Table IV-19 Project phase when LPS was implemented in most of the projects in the organizations

	Response Percent	Response Count
When project was 0% to 25% complete	43%	17
When project was 25% to 50% complete	13%	5
When project was 50% to 75% complete	3%	1
No Response	43%	17
Total	100%	40

Forty percent of AEC professionals whose organizations implement LPS from the beginning of the project have experience on 234 projects altogether where LPS was used as compared to 217 projects done by the sixty percent of AEC professionals whose organizations do not implement LPS from the beginning of the project. These results

indicate that organizations with more experience on LPS projects tend to implement LPS from the beginning of the project.

4.3 BENEFITS OF USING LPS

The benefits realized by LPS implementation in the 26 test case projects are discussed in the earlier sections of this chapter. Survey respondents also reported the similar benefits in their organizations by LPS implementation. The benefits realized by survey respondents are listed below:

- Improved individual reliability
- Significant decrease in fire fighting and reduce chaos
- Improved Sub involvement in developing work plan
- Predicable workflow and improved trust among project participants
- Reliable and smoother work flow
- LPS helps flexibility in the event that work sequences change
- Reduced variability in plans
- Better working relationships with subcontractors - more trust leads to faster completion of work and less surprises.
- More coordination completed during design - Less changes in the field.
- Better relationships with architect & owner - more willing to listen to contractor and make design decisions based on impact to schedule and budget.
- Stabilizing the project (less unexpected issues)

- Shorter production time
- Lower costs and higher profitability
- Lower number of construction quality issues
- Lower number of complaints
- Better knowledge of possible upcoming constraints.
- Better cash flow predictability
- Improved safety Performance, less accidents
- Higher productivity
- Higher worker satisfaction and improved quality of life for staff and key business partners
- Just-in-Time (JIT) delivery of material and information
- Reduced batch size
- Help ensure the right personnel, material, equipment, tools, safety plan, and quality plan in place ahead of executing the work
- Winning new projects with repeat customers
- Better informed owner and design team
- Better overall understanding of the plan
- Better daily communication between trades
- Lower hidden contingency (hidden float), more reliable promising

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This thesis identified the challenges of applying LPS found in the literature. The expressed challenges were used to formulate a survey questionnaire to the industry. A perceptions survey was conducted to assess the challenges of implementing LPS by senior and mid-level AEC professionals by first users and experienced users.
A criterion was created to select twenty six test case projects from the larger set of available literature (as described in Chapter IV). LPS was implemented in the construction phase at 23 out of 26 test case projects and at 3 and 4 test case projects for design phase and supply chain management respectively.

The prime reasons behind the application of LPS on test case projects were (1) shielding production, (2) making plans and work flow more reliable, (3) improving the management practices, (4) improving productivity, (5) improving safety, and (6) improving quality. Reported benefits attributed to LPS implementation were (a) smooth work flow, (b) predictable work plans, (c) reduced cost, (d) reduced time of project delivery, (e) improved productivity, and (e) greater collaboration with field personnel and sub contractors.

Test case projects also reported certain challenges faced by project participants while applying LPS such as: (i) lack of leadership, (ii) organizational inertia, (iii) resistance to change, (iv) lack of training, (v) contractual issues and (vi) lack of experience and knowledge are the major challenges reported among others.

Senior and mid-level AEC professionals' perceptions survey produced interesting results. They do not confirm the claim of previous research that lack of leadership, failure of management commitment or contractual issues are hindrance to LPS implementation. Most organizations have developed training programs to train their people in LPS and they run training sessions and workshops on a regular basis. Also, LCI regional, state and area chapters are filling the training void. Organizations have also reported that strategies have been implemented for the systematic LPS training throughout the organizations. These efforts for successful LPS implementation are resulting into new contractual agreements such as Integrated Form of Agreement (IFOA). Survey respondents reported that they use LPS with integrated project delivery (IPD), CM at risk, and design build project delivery methods on the projects.
This is evident from these results that implementation practices are improving relative to past LPS applications and there is a scope for improvement. Following is the summary of conclusions drawn from the AEC professionals' perceptions survey:

- AEC professionals perceive that people in their organizations have enough knowledge about using LPS and they do not find it hard to use LPS; however there is a lack of experience in using LPS in their organizations.
- In a quarter of respondents' organizations middle management makes commitments in WWP meetings and not the 'last planners'.
- There is lack of understanding of the new system (LPS) in forty two percent of AEC professionals' organizations.

- People's skills in using LPS for planning and control purposes depend on the experience with LPS in respondents' organizations.
- Organizations where AEC professionals perceive that people in their organizations are not skilled at using LPS also believe that people in their organizations find it hard to use LPS and vice versa. These results highlight the importance of skill development and human capital in using LPS.
- AEC professionals perceive that their organizations have a strong leadership and management commitment to the implementation of LPS and there is a positive climate in their organizations for LPS implementation.
- AEC professionals perceive that they face internal conflicts such as resistance to change in their organizations.
- There is a positive implementation environment in respondents' organizations.
- AEC professionals who perceive that their organizations have strong leadership for LPS implementation also believe that management in their organizations is committed to LPS implementation and vice versa.
- AEC professionals get good support and encouragement from the owner (client) during the LPS implementation and their organizations include subcontractors in the meetings.

- Fifty one percent of respondent AEC professionals perceive that their organizations face external conflicts during the LPS implementation but thirty eight percent do not believe so.
- Fifty five percent of respondent AEC professionals believe that people in their organizations are willing to change and more than three quarter of respondents believe that standard procedures of their organizations do not hamper the LPS implementation.
- Forty three percent of AEC professionals perceive that their organizations provide positive climate for LPS implementation but people in their organizations are reluctant to implement and use LPS.
- Organizations where AEC professionals perceive that people in their organizations are unwilling to change when new systems are introduced also believe that people in their organizations are reluctant to implement and use LPS and vice versa.
- AEC professionals perceive that their organizations do not face any contractual or legal issues when implementing and using LPS.
- LPS was implemented on projects irrespective of project delivery method.
- Majority of projects where LPS is implemented in respondents' organizations do not choose design-bid-build project delivery method.
- Majority of AEC professionals believe that people in their organizations are willing to change when new systems such as LPS are introduced.

- AEC professionals perceive that in their organizations people find it easy to collaborate with the teams from other organizations during the weekly work plan meetings.
- AEC professionals whose organizations do not have formal training programs for LPS implementation also believe that people in their organizations are not skilled at using LPS.
- Organizations have training programs for LPS implementation irrespective their sizes.
- Majority of AEC professionals' organizations do not have LPS implementation strategies.
- Strategies for LPS implementation in the organizations are designed by keeping LPS training requirements and project durations in mind.
- There is a minimal use of LPS components such as constraint analysis, reason charting, first run studies, and root cause analysis.
- Organizations with more experience on LPS projects tend to implement LPS from the beginning of the project.

The method used in this research effort could be used to evaluate the level of maturity of LPS implementation in the organizations using LPS with a goal of improving the implementation techniques.

Future research should investigate an experienced team's use of LPS where technical challenges related to skill building and human capital is further needed for a greater increase in production performance by surveying and interviewing the people

who execute the work at field, the front end managers, specially superintendents and foremen. The current study attempted to reach this level but did not attract sufficient responses to create a database with statistical significance. It is also important to know the implications of LPS implementation efforts for an owner (client). Therefore owners' perceptions about LPS implementation should be studied to identify the challenges they face and benefits they realize from its implementation.

It is also recommended that expert opinions and industry best practices be studied (such as in focus groups or by using the Delphi method) to address the challenges identified in this research and further the propagation of LPS in the industry. Learning from field and owner will help round out this study.

REFERENCES

Alarcón, L. F., and Diethelm, S. (2001). "Organizing to introduce lean practices in construction companies." *Proc., 9th Annual Conf. of the Int. Group for Lean Construction (IGLC-9)*, International Group of Lean Construction, Singapore.

Alarcón, L. F., Diethelm, S., and Rojo, O. (2002). "Collaborative implementation of lean planning system in Chilean construction companies." *Proc., 10th Annual Conf. of the Int. Group for Lean Construction (IGLC-10)*, International Group of Lean Construction, Granmado, Brazil.

Alarcón, L. F., Diethelm, S., Rojo, O., and Calderon, R. (2008). "Assessing the impact of implementing lean construction." *Abril de 2008, Revista Ingeniería de Construcción* (J. Constr. Eng.), 23 (1), <http://www.scielo.cl/pdf/ric/v23n1/art03.pdf> (July 5th 2010).

AlSehaimi, A., Tzortzopoulos, P., and Koskela, L. (2009). "Last Planner System: Experiences from pilot implementation in the Middle East." *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17)*, International Group of Lean Construction, Taipei, Taiwan.

Alves, T. C. L., and Formoso, C. T. (2000). "Guidelines for managing physical flows in construction sites." *Proc., 8th Annual Conf. of the Int. Group for Lean Construction (IGLC-8)*, International Group of Lean Construction, Brighton, UK.

Ansell, M., Holmes, M., Evans, R., Pasquire, C., and Price, A. (2007). "Lean construction trial on a highway maintenance project." *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Arbulu, R., and Soto, J. (2006). "A design case study: Integrated product and process management." *Proc., 14th Annual Conf. of the Int. Group for Lean Construction (IGLC-14)*, International Group of Lean Construction, Santiago, Chile.

Azambuja, M. M. B., Isatto, E. L., Marder, T. S., and Formoso, C. T. (2006). "The importance of commitments management to the integration of make-to-order supply chains in construction industry." *Proc., 14th Annual Conf. of the Int. Group for Lean Construction (IGLC-14)*, International Group of Lean Construction, Santiago, Chile.

Ballard, G. (2000). "The Last Planner System of production control." Ph.D. Diss., Faculty of Engineering, University of Birmingham, U.K.

Ballard, G., Hammond, J., and Nickerson, R. (2009). "Production control principles." *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17)*, International Group of Lean Construction, Taipei, Taiwan.

Ballard, G. and Howell, G. A. (1997). "Shielding production: An essential step in production control." *J. of Constr. Eng. and Manage*., 124(1), 11-17.

Ballard, G., and Howell, G. A. (2003). "Lean project management." *Building Research and Information*, 31(2), 119-133.

Ballard, G., Liu, M., Kim, Y. W., and Jang, J. W. (2007). “Roadmap to lean implementation at the project level.” *Construction Industry Institute (CII)*, Austin, TX.

Bertelsen, S. (2004). "Lean construction: Where are we and how to proceed?" *Lean Construction Journal*, 1 (1), 46-69.

Choo, H. J. (2003). “Distributed planning and coordination to support lean construction.” Ph.D. Diss., University of Berkley, CA.

Conte, A. S. I. (2002). “Lean construction: From theory to practice.” *Proc., 10th Annual Conf. of the Int. Group for Lean Construction (IGLC-10)*, International Group of Lean Construction, Gramado, Brazil.

Court, P. F., Pasquire, C., and Gibb, A. (2009). “A lean and agile construction system as a set of countermeasures to improve health, safety and productivity in mechanical and electrical construction.” *Lean Construction Journal*, November 2009, 61-76.

Dawes, J. (2008). "Do data characteristics change according to the number of scale points used? - An experiment using 5-point, 7-point and 10-point scales." *Int. J. of Market Research*, 50 (1), 61–77.

Denning, P. J., and Medina-Mora, R. (1995). “Completing the loops.” *Interfaces*, 25(3), 42-57.

Egan, J. (1998). “Rethinking construction”, *Construction Task Force,* <http://www.strategicprojectsolutions.com/docs/Rethinking_Construction_Report.pdf>, (June 2010).

Fernández- Solis, J. F. (2007). “The systemic nature of the construction industry.” *Proc., CIB World Building Congress-2007*, International Council for Research and Innovation in Building and Construction, 1598-1625, Cape Town, South Africa, <http://www.irbnet.de/daten/iconda/CIB5266.pdf> (June 2010).

Fernando, L. B., Alvarez, and Eugenia, M. (2005). “Last Planner: An advance in planning and controlling construction projects - Case study in the city of Medellin.” *Proc. IV Sibragec I Elagec*, Porto Alegre, Brazil, http://bdigital.eafit.edu.co/Libreria/PonenciaIVSibragec.pdf (June 2010)

Fiallo, C. M., and Revelo, P. V. H. (2002). “Applying the Last Planner System to a construction project- Case study in Quito Ecuador.” *Proc., 10th Annual Conf. of the Int. Group for Lean Construction (IGLC-10),* International Group of Lean Construction, Granmado, Brazil.

Formoso, C. T., and Moura, C. B. (2009). "Evaluation of the impacts of the Last Planner System on the performance of construction projects." *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17)*, International Group of Lean Construction, Taipei, Taiwan.

Friblick, F., Olsson V., and Reslow J. (2009). "Prospects for implementing Last Planner in the construction industry." *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17)*, International Group of Lean Construction, Taipei, Taiwan.

Garza, J. M., and Leong, M. W. (2000). "Last Planner technique: A case study." *Proc., Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World*, American Society of Civil Engineers, Orlando, FL.

Green, S. D. (2000). "The future of lean construction: A brave new world." *Proc., 8th Annual Conf. of the Int. Group for Lean Construction (IGLC-8)*, International Group of Lean Construction, Brighton, U.K., 1-11.

Hamzeh, F. R. (2009). "Improving construction workflow- The role of production planning and control." Ph.D. Diss., University of Berkley, CA.

Hamzeh, F. R., Ballard, G., and Tommelein, I. D. (2009). "Is the Last Planner System applicable to design? - A case study." *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17)*, International Group of Lean Construction, Taipei, Taiwan.

Hill, K., Slivon, C., and Draper, J. (2007). “Another approach to transforming project delivery: Creating a shared mind.” *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Howell, G. A., and Ballard, G. (1994). "Lean production theory: Moving beyond ‘can-do’." *Proc., 2nd Annual Conf. on Lean Construction at Catolica Universidad de Chile, Santiago,* Chile, <http://www.leanconstruction.org/pdf/beyond-can-do.pdf>, (June 5th 2010).

Huovila, P., and Koskela L. (1998). "Contribution of the principles of lean construction to meet the challanges of sustainable development." *Proc., 6th Annual Conf. of the Int. Group for Lean Construction (IGLC-6)*, International Group of Lean Construction. Guarujá, Brazil.

Jang, J. W., Kim, Y. W., Park, C. J., and Jang W. S. (2007). “Importance of partners in a challenging lean journey.” *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Jara, C., Alarcón, L. F., and Mourgues, C. (2009). “Accelerating interactions in project design through extreme collaboration and commitment management – A case study.” *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17)*, International Group of Lean Construction, Taipei, Taiwan.

Johansen, E., Porter, G., and Greenwood, D. (2004). "Implementing change: UK culture and system change." *Proc., 12th Annual Conf. of the Int. Group for Lean Construction (IGLC-12)*, International Group of Lean Construction, Copenhagen, Denmark, 3-5.

Johansen, E., and Walter, L. (2007). "Lean construction - Prospects for the German construction industry." *Lean Construction Journal*, 3(1), 19-32.

Jorgensen, B., Emmitt, S. and Bonke, S. (2004). "Revealing cultures and sub-cultures during the implementation of lean construction." *Proc., 14th Annual Conf. of the Int. Group for Lean Construction (IGLC-14)*, International Group of Lean Construction, Santiago, Chile, 1-13.

Kemmer, S. L., Heineck, L. F. M., Novaes, M. V., Alexandre, C., Mourão, M. A., and Alves T. C. L. (2007). “Medium term planning- Contribution based on field application.” *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Khanzode, A., Fischer, M., and Reed, D. (2008). “Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing (MEP) systems on a large healthcare project.” *ITcon*, 13, 324-342.

Kim, Y. W., and Jang, J. W. (2005). “Case study - An application of Last Planner to heavy civil construction in Korea.” *Proc., 13th Annual Conf. of the Int. Group for Lean Construction (IGLC-13)*, International Group of Lean Construction, Sydney, Australia.

Kim, Y. W., Park, C., and Ballard, G. (2007). “A case study on rebar supply chain management by GS E&C.” *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Koskela, L. (1992). “Application of the new production philosophy to construction.” *Center for Integrated Facility Engineering (CIFE)*, Stanford <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.15.9598&rep=rep1&type=pdf> (June 2010)

Koskela, L. (2000). "An exploration towards a production philosophy to construction." Ph.D. Diss., VTT Building Technology, Tampere, Finland.

Koskenvesa, A. and Koskela, L. (2005). “Introducing Last Planner- Finnish experience.” Proc., *CIB Conference*, Helsinki, < http://usir.salford.ac.uk/9380/1/2005_Introducing_Last_Planner_Finnish_Experiences.pdf> (June 2010)

Lane, R., and Woodman, G. (2000). “Wicked problems, righteous solutions back to the future on large complex projects.” *Proc., 8th Annual Conf. of the Int. Group for Lean Construction (IGLC-8)*, International Group of Lean Construction, Brighton, UK.

Lean Construction Institute White Paper (2009). "Learning Last Planner on a project." *Lean Construction Institute website*, <http://www.leanconstruction.org/pdf/LearningLPS.pdf> (July 2010).

Lean Construction Institute White Paper #7 (2000). “Phase scheduling.” *Lean Construction Institute website*, < http://www.leanconstruction.org/pdf/WP7-PhaseScheduling.PDF> (July, 2010).

Lichtig, W. A. (2006). “The integrated agreement for lean project delivery.” *Construction Lawyer*, 26(3), <http://www.mhalaw.com/mha/newsroom/articles/ABA_IntegratedAgmt.pdf> (June 2010).

Liu, M., and Ballard G. (2009). “Factors affecting work flow reliability - A case study.” *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17)*, International Group of Lean Construction, Taipei, Taiwan.

Mikati, S. O., Roller, T. G., Tommelein, I. D., and Khanzode, A. (2007). “Priority conversations: A case study on priority walls.” *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI, 431-441.

Mohan, S. B., and Iyer, S. (2005). “Effectiveness of lean principles in construction.” *Proc., 13th Annual Conf. of the Int. Group for Lean Construction (IGLC-13)*, International Group of Lean Construction, Sydney, Australia.

Mossman, A. (2009). "Why isn’t the UK construction industry going lean with gusto?" *Lean Construction Journal*, November 2009, 24-36.

National Academy of Sciences (2009). “Advancing the competitiveness and efficiency of the U.S. construction industry.” *National Research Council*, <http://www.nap.edu/catalog/12717.html> (June 2010).

Nielsen, A. S., and Thomassen, M. A. (2004). “How to reduce batch size.” *Proc., 12th Annual Conf. of the Int. Group for Lean Construction (IGLC-12)*, International Group of Lean Construction, Copenhagen, Denmark.

Olano, R. M, Alarcón, L. F., and Razuri, C. (2009). “Understanding the relationship between planning reliability and schedule performance - A case study.” *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17)*, International Group of Lean Construction, Taipei, Taiwan.

Picchi, F. A., and Granja, A. D. (2004). "Construction site- using lean principles to seek broader implementations." *Proc., 12th Annual Conf. of the Int. Group for Lean Construction (IGLC-12)*, International Group of Lean Construction, Copenhagen, Denmark, 1-12.

Sacks, R., and Harel, M. (2006). "How Last Planner motivates subcontractors to improve plan reliability - A Game Theory model." *Proc., 14th Annual Conf. of the Int. Group for Lean Construction (IGLC-14)*, International Group of Lean Construction, Santiago, Chile.

Salem, O., Genaidy, J. S. A., and Luegring, M. (2005). "Site implementation and assessment of lean construction techniques." *Lean Construction Journal*, 2(2), 1-21.

Salem, O., and Solomon, J. (2006). "Lean construction: From theory to implementation." *J. Manag. in Eng.*, 22(4), 168-175.

Schwaber, K. (2001). *Agile software development with Scrum*, Prentice Hall, Upper Saddle River, NJ.

Senaratne, S., and Wijesiri, D. (2008). "Lean construction as a strategic option: Testing its suitability and acceptability in Sri Lanka." *Lean Construction Journal*, 2008, 34-48.

Siegal, S., and Castellan, N. J. (1988). *Non-parametric statistics for the behavioral sciences*, McGraw-Hill, New York.

Simonsson, P., and Emborg, M. (2007). "Industrialization in Swedish bridge engineering: A case study of lean construction." *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Song, L., Liang, D., and Javkhedkar, A. (2008). “A case study on applying lean construction to concrete construction projects.” <http://ascpro0.ascweb.org/archives/cd/2008/paper/CPGT201002008.pdf> (June 2010).

Sterzi, M. P., Isatto, E. L., and Formoso, C. T. (2007). “Integrating strategic project supply chain members in production planning and control.” *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Teicholz, P. (2004). “Labor productivity declines in the construction industry: causes and remedies.” *AECbytes Viewpoints*, <http://www.aecbytes.com/viewpoint/2004/issue_4.html> (June 2010).

Tommelein, I. D. (1999). “Parade game: Impact of work flow variability on trade performance.” *J. of Constr. Eng. and Manage.*, 304- 310.

Tsao, C. C. Y., and Tommelein, I. D., (2004). "Work structuring to achieve integrated product-process design." *J. of Constr. Eng. and Manage.*, 130(6), 780-789.

Tzortzopoulos, P., Formoso, C. T., and Betts, M. (2001). “Planning the product development process in construction: An exploratory case study.” <http://cic.vtt.fi/lean/singapore/Tzortzopoulosetal.pdf> (June 2010).

Vrijhoef, R., and Koskela, L. (2005). “Revisiting the three peculiarities of production in construction.” *Proc., 13th Annual Conf. of the Int. Group for Lean Construction (IGLC-13)*, International Group of Lean Construction, Sydney, Australia.

Yin, R. K. (2009). *Case study research design methods - Volume-5*, Sage, Los Angeles.

SUPPLEMENTAL SOURCES

Alarcón, L. F., and Calderon, R. (2003). “Implementing lean production strategies in construction companies.” *Proc., Construction Research Congress - Wind of Change: Integration and Innovation*, Honolulu, HI.

Alarcón, L. F., Diethelm, S., Rojo, O., and Calderon, R. (2005). “Assesing the impact of implementing lean construction.” *Proc., 13th Annual Conf. of the Int. Group for Lean Construction (IGLC-13)*, International Group of Lean Construction, Sydney, Australia, 387-393.

Alves, T. d., and Tsao, C. C. (2007). “Lean construction 2000-2006.” *Lean Construction Journal*, 3(1), 46-70.

Arbulu, R. J., Tommelein, I. D., Walsh, K., and Hershauerd, J. (2003). "Value stream analysis of a re-engineered construction supply chain." *Building Research and Information*, 31(2), 161-171.

Ballard, G., and Howell, G. A. (1995). “Toward construction JIT.” *Proc., The 1995 Association of Researchers in Construction Management (ARCOM) Conf.*, Association of Researchers in Construction Management, Sheffield, England.

Ballard, G., Koskela, L., Howell, G. A., and Zabelle, T. (2001). “Production system design in construction.” *Proc., 9th Annual Conf. of the Int. Group for Lean Construction (IGLC-9),* International Group of Lean Construction, Singapore.

Ballard, G. (1998). "What kind of production is construction?” *Proc., 6th Annual Conf. of the Int. Group for Lean Construction (IGLC-6),* International Group of Lean Construction, Guarujá, Brazil.

Ballard, G. (2002). "Descriptive design study: A building-facility renewal planning study." *J. of Constr. Research*, 3(1), 17-33.

Ballard, G., and Howell, G. A. (2003). "Competing construction management paradigms." *Lean Construction Journal*, 1(1), 38-45.

Ballard, G., Koskela, L., Howell, G. A., and Tommelein, I. D. (2002). “Lean construction tools and techniques.” *Design and Construction- Building in Value,* R. Best and G. De Valence, eds., Butterworth Heinemann, New York, 227-254.

Ballard, G., Koskela, L., Howell, G. A., Tommelein, I. D. (2005). "Discussion of "improving labor flow reliability for better productivity as lean construction principle" by H. Randolph Thomas, Michael J. Horman, R. Edward Minchin Jr., and Dong Chen." *J. of Constr. Eng. and Manage.*, 131(5), 615-617.

Ballard, G., Harper, N., and Zabelle, T. (2003). "Learning to see work flow: an application of lean concepts to precast concrete fabrication." *Eng. Constr. and Arch. Manage.*, 10(1), 6-14.

Ballard, G., Arbulu, R., and Elfving, J. (2006). "Assignment set up: Building block for agility in project production systems." *Int. J. of Agile Manufacturing*, 9(1), 99-107.

Ballard, G. (2001). “Malling Precast Products Ltd.: A case study in the application of lean production concepts.” *Technical Report 2001-1*, Lean Construction Institute (LCI), Ketchum, ID.

Barlow, J. (1996). “Partnering-lean production and the high performance workplace.” *Proc., 4th Annual Conf. of the Int. Group for Lean Construction (IGLC-4)*, International Group of Lean Construction, Birmingham, U.K.

Bertelsen, S. (2002). “Bridging the gap – Towards a comprehensive understanding of lean construction.” *Proc., 10th Annual Conf. of the Int. Group for Lean Construction (IGLC-10)*, International Group of Lean Construction, Gramado, Brazil.

Bertelsen, S., and Koskela, L. (2004). "Construction beyond lean: A new understanding of construction management." *Proc., 12th Annual Conf. of the Int. Group for Lean Construction (IGLC-12)*, International Group of Lean Construction, Copenhagen, Denmark.

Blanco, J. M. (2004). “Lean enterprise in the construction industry.” M.S. Thesis, The Department of Civil and Environmental Engineering, Massachsetts Institute of Technology, Boston.

Bortolazza, R. C., Costa, D. B., and Formoso, C. T. (2005). “A quantitative analysis of the implementation of the Last Planner system in Brazil.” *Proc., 13th Annual Conf. of the Int. Group for Lean Construction (IGLC-13),* International Group of Lean Construction, Sydney, Australia.

Brink, T. and Ballard, G. (2005). “Slam - A case study in applying lean to job shops.” *Proc., Construction Research Congress 2005: Broadening Perspectives*, Reston, VA, 20191-4400.

Choo, H. J., Tommelein, I. D., Ballard, G., and Zabelle, T. R. (1999). "WorkPlan: Constraint-based database for work package scheduling." *J. of Constr. Eng. and Manage.*, 125(3), 151-160.

Choo, H. J., Hammond, J., Tommelein, I. D., Austin, S. A. and Ballard, G. (2004). "DePlan: A tool for integrated design management." *Automation in Construction*, Elsevier Group, 13(3), 313-326.

Fernández-Solís, J. L., (2009). “An application of Poppeer's method of conjectures and refutations to the critique of emerging construction theories.” *Lean Construction Journal*, November 2009, 37-60.

Freire, J. and Alarcón, L F. (2002). “Achieving lean design process: Improvement methodology.” *J. of Constr. Eng. and Manage*, 128(3), 248-256.

Gann, D. M. (1996). “Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan.” *Constr. Manage. and Economics*, 14(5), 437-450.

Garnett, N., Jones, D. T., and Murray, S. (1998). "Strategic application of lean thinking." *Proc., 6th Annual Conf. of the Int. Group for Lean Construction (IGLC-6)*, International Group of Lean Construction, Guarujá, Brazil.

Giandon, A. C., Junior, R. M., and Scheer, Sergio (2002). "Implementing electronic document management system for a lean design process." *Proc., 10th Annual Conf. of the Int. Group for Lean Construction (IGLC-10)*, International Group of Lean Construction, Gramado, Brazil.

Gil, N., Tommelein, I. D., Kirkendall, B., and Ballard, G. (2000). “Lean product-process development process to support contractor involvement during design.” *Proc., Computing in Civil and Building Engineering*, New York, 1086-1093.

Gonzalez, V., Alarcón L. F., and Mundaca, F. (2008). "Investigating the relationship between planning reliability and project performance." *Production Planning and Control*, 19(5), 461-474.

Gonzalez, V., Alarcón, L. F., and Molenaar, K. (2008). "Multiobjective design of Work-In-Process buffer for scheduling repetitive building projects." *Automation in Construction*, 18(2), 95-108.

Graham, M. W. (2006). "Towards a theory of construction as production by projects." *Building Research and Information*, 34(2), 154-163.

Green, S. D. (1994). "Beyond value engineering: Value management for building projects." *Int. J. of Project Manage.*, 12(1): 49-56.

Green, S. D. (1999). "Missing arguments of lean construction." *Constr. Manage. and Economics*, 17(2), 133-137.

Green, S. D. (1999). "The dark side of lean construction: Exploitation and ideology." *Proc., 7th Annual Conf. of the Int. Group for Lean Construction (IGLC-7)*, International Group of Lean Construction, Berkeley, CA.

Green, S. D. (2002). "The human resource management implications of lean construction: Critical perspectives and conceptual chasms." *J. of Constr. Research*, 3(1), 147-165.

Green, S. D. (2005). "Making sense of supply chain management: A comparative study of aerospace and construction." *Constr. Manage. and Economics*, 23(6), 579-593.

Green, S. D. and May, S. C. (2003). "Re-engineering construction: Going against the grain." *Building Research and Information*, 31(2), 97-106.

Green, S. D. and May, S. C. (2005). "Lean construction: Arenas of enactment, models of diffusion and the meaning of 'leanness'." *Building Research and Information,* 33(6), 498-511.

Green, S. D., C. Harty, et al. (2008). "On the discourse of construction competitiveness." *Building Research and Information,* 36(5), 426-435.

Horman, M. J. and Thomas, H. R. (2005). "Role of inventory buffers in construction labor performance." *J. of Constr. Eng. and Manage.*, 131(7), 834-843.

Howell, G. A., and Ballard, G. (2003). “An update on Last Planner.” *Lean Construction Institute website,* <http://www.leanconstruction.org/files/Mid_Feb_Updates/Introductory_Readings/2003_UpdateonLastPlanner.pdf> (December 2009)

Howell, G. A. (1999). “What is lean Construction-1999.” *Proc., 7th Annual Conf. of the Int. Group for Lean Construction (IGLC-7),* International Group of Lean Construction, Berkeley, CA.

Howell, G. A. (2003). "Discussion of ‘dynamic planning for fast-tracking building construction projects’ by Feniosky Pena-Mora and Moonseo Park." *J. of Constr. Eng. and Manage.*, 129(6), 706.

Howell, G. A. (2005). "Reform management model [1]." *Engineering News-Record (ENR)*, 254(11), 5.

Howell, G. A., Ballard, G., and Balkema, A. (1995). “Factors affecting project success in piping function.” *Proc., 3rd Annual Conf. of the Int. Group for Lean Construction (IGLC-3)*, International Group of Lean Construction, Rotterdam, Netherlands.

Howell, G. A., Ballard, G., Tommelein, I. D., and Koskela, L. (2004). "Discussion of "Reducing variability to improve performance as a lean construction principle" by H. Randolph Thomas, Michael J. Horman, Ubiraci Espinelli Lemes de Souza, and Ivica Zavrski." *J. of Constr. Eng. and Manage.*, 130(2), 299-301.

Howell, G. A., and Ballard, G. (1998). Implementing lean construction: Understanding and action.” *Proc., 6th Annual Conf. of the Int. Group for Lean Construction (IGLC-6)*, International Group of Lean Construction, Guarujá, Brazil.

Jang, J. W., and Kim, Y. W. (2007). “Using the Kanban for construction production and safety control.” *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Jorgensen, B., and Emmitt, S. (2008). "Lost in transition: the transfer of lean manufacturing to construction." *Eng., Constr. and Arch. Manage.*, 15(4), 383-398.

Koskela, L. (2002). "Design management in building construction: From theory to practice." *J. of Constr. Research*, 3(1), 1-16.

Koskela, L. and Ballard G. (2006). "Should project management be based on theories of economics or production?" *Building Research and Information*, 34(2), 154-63.

Koskela, L., Ballard. G., and Veli-Pekka, T. (1997). "Towards lean design management." *Proc., 5th Annual Conf. of the Int. Group for Lean Construction (IGLC-5)*, International Group of Lean Construction, Gold Coast, AU.

Koskela, L., and Howell, G. A. (2002). "The underlying theory of project management is obsolete." VTT Technical Technology, < http://usir.salford.ac.uk/9400/1/2002_The_underlying_theory_of_project_management_is_obsolete.pdf> (June 2010).

Koskela, L., Howell G. A., Ballard, G., and Tommelein, I. D. (2002). “The foundation of lean construction.” *Design and Construction: Building in Value*, R. Best and G. De Valence, eds., Butterworth Heinemann, New York, 211-226.

Koskela, L. and Vrijhoef, R. (2001). "Is the current theory of construction a hindrance to innovation?" *Building Research and Information*, 29(3), 197-207.

Lapinski, A. R., Horman M. J, and Riley, D. R. (2006). "Lean processes for sustainable project delivery." *J. of Constr. Eng. and Manage.*, 132(10), 1083-1091.

Maturana, S., Alarcón, L. F., Gazmuri, P., and Vrsalovic, M. (2007). "On-site subcontractor evaluation method based on lean principles and partnering practices." *J. of Manage. in Eng.*, 23(2), 67-74.

Mossman, A. (2008). “Last Planner – Five crucial conversions for reliable flow and project delivery.” *The Change Business Ltd. Website*, <http://www.thechangebusiness.co.uk/TCB/LPSBenefits_files/Last_Planner_5_crucial_conversations.pdf> (June 2010).

Mossman, A. (2007). “Lean logistics – Helping to create value by bringing people, information, plant, equipment, and material together at the workplace.” *Proc., 15th Annual Conf. of the Int. Group for Lean Construction (IGLC-15)*, International Group of Lean Construction, East Lansing, MI.

Ohno, T. (1988). *Toyota production system-beyond large scale production*, Productivity Press, New York.

Pheng, L. S., and Fang, T. H. (2005). "Modern-day lean construction principles: Some questions on their origin and similarities with Sun Tzu's Art of War." *Manage. Decision*, 43(4), 523-541.

Popper, K. (1972). *Objective knowledge: An evolutionary approach*, Oxford University Press, New York.

Rischmoller, L., Alarcón, L. F., and Koskela, L. (2006). "Improving value generation in the design process of industrial projects using CAVT." *J. of Manage. in Eng.*, 22(2), 52-60.

Rother, M. and Shook, J. (1998). *Learning to see-Version 1.2*, The Lean Enterprise Institute Inc, Brookline, MA.

Sacks, R. (2009). “Production system instability and subcontracted labor.” *Construction Supply Chain Management Handbook*, CRC Press, New York, 8.1-8.22.

Seppänen, O. and Aalto, E. (2005). “A case study of line-of-balance based schedule planning and control system.” *Proc., 13th Annual Conf. of the Int. Group for Lean Construction (IGLC-13)*, International Group of Lean Construction, Sydney, Australia.

Shingo, S. (1988). *Non-stock production: The Shingo system for continuous improvement*, Productivity Press, Cambridge, MA.

Shingo, S. (1989). *A study of the Toyota production system*, Productivity Press, Cambridge, MA.

Slaughter, E. S. (1998). “Models of construction innovation.” *J. of Constr. Eng. and Manage.*, 124(3), 226-231.

Thomas, H. R., and Horman, M. J. (2002). "Reducing variability to improve performance as a lean construction principle." *J. of Constr. Eng. and Manage.*, 128(2), 144-154.

Thomas, H. R., Horman, M. J., Minchin, R. E., and Chen D. (2003). "Improving labor flow reliability for better productivity as lean construction principle." *J. of Constr. Eng. and Manage.*, 129(3), 251-261.

Tommelein, I. D. (1997). "Models of lean construction processes: Example of pipe-spool materials management." *Proc., Construction Congress V: Managing Engineered Construction in Expanding Global Markets*, New York.

Womack, J. P., Jones, D. T., and Roos, D. (1990). *The machine that changed the world*, Harper Collins, New York.

Womack, J. P., and Jones, D. T. (2003). *Lean thinking: Banish waste and create wealth in your organization*, Free Press, New York.

APPENDIX A

A.1 LPS - THEORETICAL BACKGROUND

1973's oil crisis brought Toyota production system (TPS) into light. Toyota production system was created by Mr. Ohno of Toyota Motors. The basis of TPS is the absolute elimination of waste. The two pillars of TPS are just-in-time (JIT) and autonomation (or automation with human touch) (Ohno, 1988). Based upon the studies of the car manufacturing industry in Japan and other countries MIT researchers coined the term lean production to describe the implementation of the ideas inherent in the TPS. In Construction the application of the lean production model stems from a discussion of Koskela's work (1992), which emphasized the importance of the production process flow, as well as aspects related to converting inputs into finished products as an important element to the creation of value over the life of the project.

Lean construction principles and practice have been examined and developed in two interacting research streams. The theoretical stream started with Koskela's (1992) analysis of the application of the new philosophy of construction. The practical stream started with Howell and Ballard's (1995) observations that typically only half of the tasks in a weekly plan get realized as planned on site. In a series of experimental work, a new approach to production control, called the LPS, was developed (Ballard 2000). Whilst LPS covers production control and improvement during construction phase, methods for production system design has also been developed (Ballard et al. 2001).

Furthermore, various new practices for different aspects of design and construction management have been developed (Bertelsen et al. 2002a, Bertelsen 2002b).

A.1.1 JUST IN TIME (JIT)

The driving idea in the lean production approach was reduction or elimination of inventories (work in progress). This, in turn, led to other techniques that were forced responses to coping with fewer inventories: lot size reduction, layout reconfiguration, supplier co-operation, and set-up time reduction. The pull type production control method, where production is initiated by actual demand rather than by plans based on forecasts, was introduced. The concept of waste is one cornerstone of JIT. The following wastes were recognized by Shingo (1989): overproduction, waiting, transporting, too much machining (over-processing), inventories, moving, making defective parts and products. Elimination of waste through continuous improvement of operations, equipment and processes is another cornerstone of JIT.

A.1.2 TOTAL QUALITY CONTROL (TQC)

The starting point of the quality movement was the inspection of raw materials and products using statistical methods. The quality movement in Japan has evolved from mere inspection of products to total quality control. The term total refers to three extensions (Shingo 1988, Koskela 1992): (1) expanding quality control from production to all departments, (2) expanding quality control from workers to management, and (3) expanding the notion of quality to cover all operations in the company.

The quality methodologies have been developed in correspondence with the evolution of the concept of quality. The focus has changed from an inspection orientation, through process control, to continuous process improvement, and presently to designing quality into the product and process.

A.2.3 LEAN PRINCIPLES

The ideas of lean thinking were originally encapsulated within Toyota Production System and are well articulated by Womack et al. (1990). Lean thinking subsequently became the generic term to describe its universal application beyond manufacturing (Womack and Jones 1996). The idea of lean thinking comprise different ideas including continuous improvement, flattened organization structures, teamwork, elimination of waste, efficient use of resources and cooperative supply chain management (Green, 2000). In construction industry, the language of lean thinking has since become synonymous with best practice. The most frequently cited definition of lean principles found in the literature is that of Womack and Jones (1996);

(1) Specify value (2) Identify the value stream for each product (3) Make the product flow without interruptions (4) Let the customer pull value from the producer and (5) Pursue perfection. Application of lean principles in construction is under investigation and a number of case studies are published. One such case study reports that more reliable flows lead to a better labor performance (Thomas et. al, 2002).

A.2.4 KOSKELA'S TFV THEORY BASED ON LEAN PRINCIPLES

Research in lean construction is robustly shaped by the emergence of the Koskela's Transformation-Flow-Value (TFV) theory. Koskela described the traditional perception of construction production as a transformation of inputs into outputs. Complimenting the current transformation view with the value and flow concept, the TFV theory introduced a new paradigm of production centered on flow to reduce waste and maximize customer value. This theory advocates designing, operating and continuously improving production from the combined perspective of transformation, flow, and value (Koskela 1992). Detailed explanations on TFV theory could be found in Appendix A.

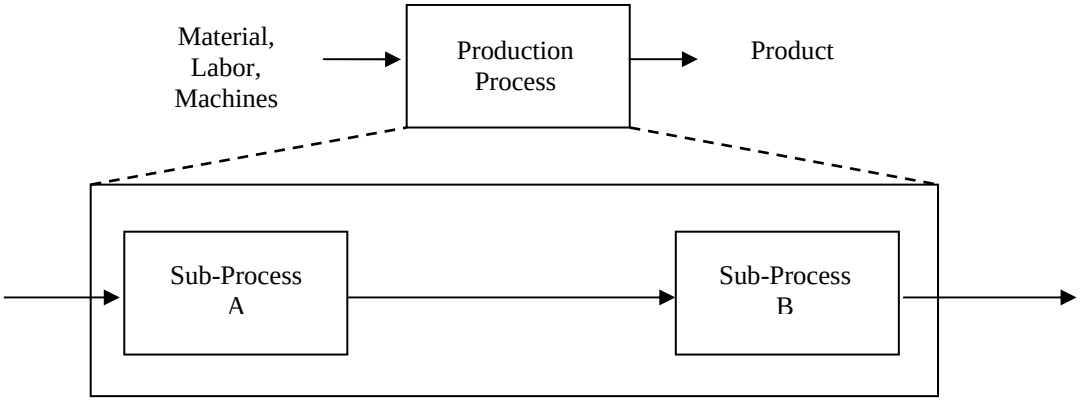

Figure A.1: The view of a production process as a transformation process that can be divided hierarchically into sub-processes

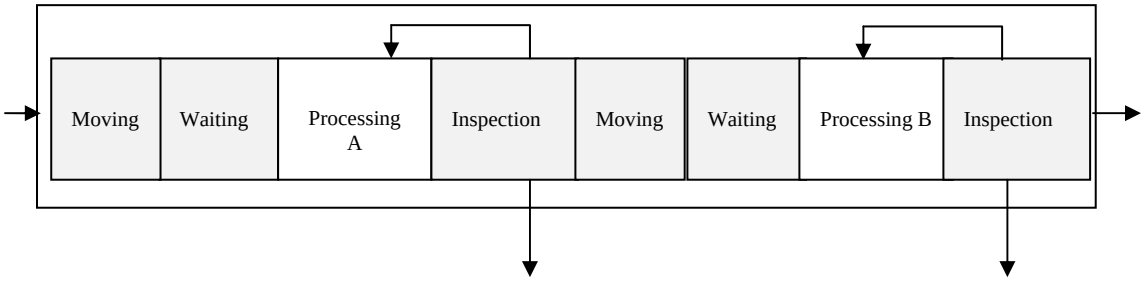

Figure A.2: Production as a flow process. The shaded boxed represent the non value

adding activities, in contrast to value adding processing activities (Koslela 2000)

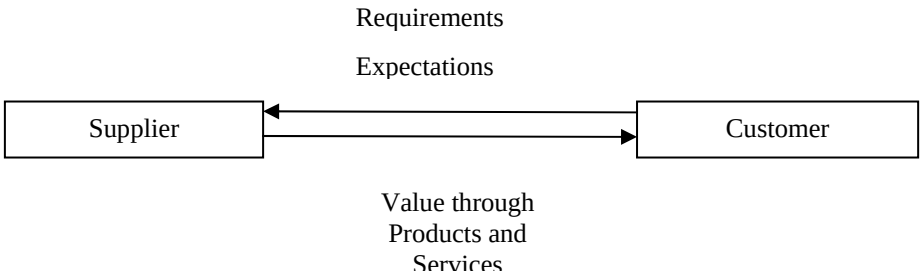

Figure A.3: The conceptual scheme of a supplier-customer pair (Koskela 2000)

A.2.5 LEAN PROJECT DELIVERY SYSTEM (LPDS)

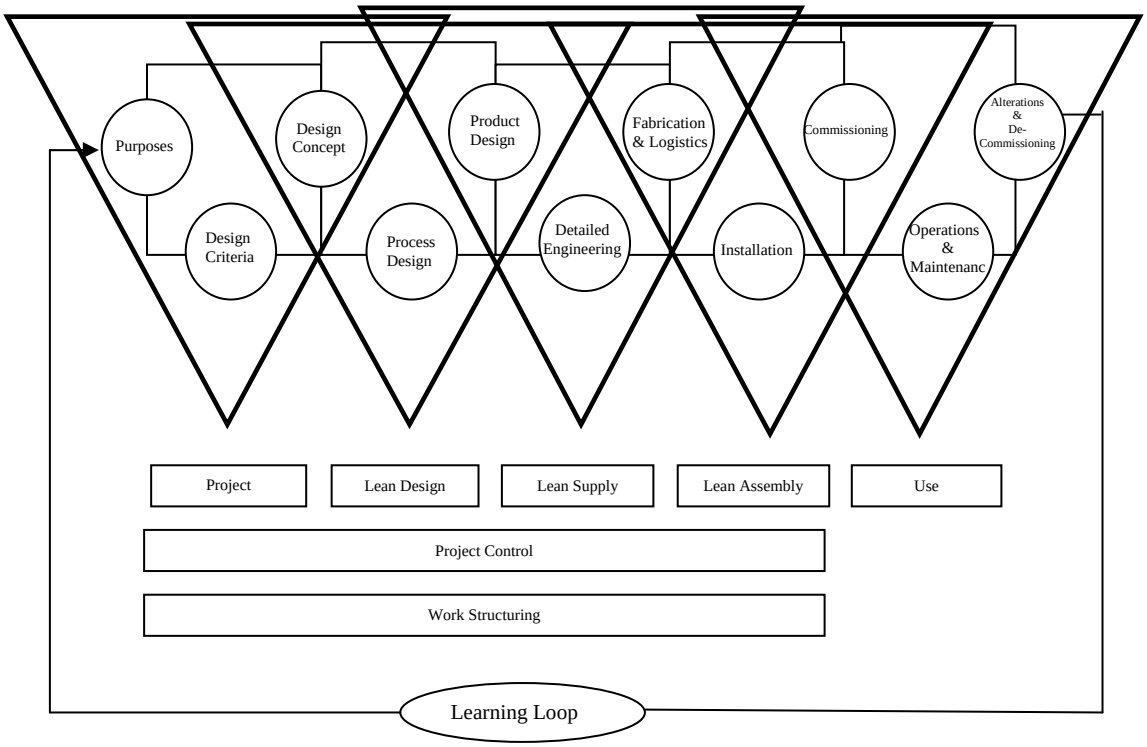

Figure A.4: Triads of lean Project Delivery System (LPDS)

A.2.6 LEAN THINKING

Lean production was coined by Womack et al. (1990) to describe the implementation of the ideas inherent in the Toyota Production System. It was based upon their studies of the car manufacturing industry in Japan and other countries.

Womack and Jones (2003) moved from the automotive industry to look at manufacturing in general and established five principles of lean production; this theoretical; this theoretical foundation is called Lean Thinking by them:

1. Precisely specify value by specific product.
2. Identify value stream for each product.
3. Make value flow without interruptions.
4. Let the customer pull value from the producer.
5. Pursue perfection

APPENDIX B

Survey Questionnaire

Assessment of Challenges Faced by AEC Professionals in Implementation of Last Planner System

Do you use Last Planner System for planning and control purposes? *

- Yes
- No

What is the function of your organization? *

- Designer (Architect/Engineer)
- Management Consultant
- General Contractor
- Subcontractor/Trade-partner
- Construction Management/Project Management Services
- Other: _____

How would you classify your current job position? *

- Construction Manager/Project Manager
- Scheduler
- Estimator
- Engineer
- Architect
- Procurement Manager

- Purchasing Manager
- Senior Management
- Other: _____

Section I: Implementation challenges at organizational level

Instructions: Below you will find a series of statements about your experiences with implementation and use of Last Planner System (LPS) - on all the projects that you have done using LPS. Some items may sound similar, but they address slightly different issues. Please respond to all items. Indicate your degree of agreement with each statement by placing the appropriate number in the box next to each item. Please use the following scale: 1-Strongly Disagree 2-Moderately Disagree 3-Slightly Disagree 4-No Feeling 5-Slightly Agree 6-Moderately Agree 7-Strongly Agree

Q1: There is a strong leadership in my organization for implementing LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q2: Management in my organization is committed to the implementation and use of LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q3: In my organization people are reluctant to implement and use LPS for planning and control purposes.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q4: In my organization people are unwilling to change, when new systems are introduced.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q5: In my organization people are not skilled at using LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q6: In my organization people do not have enough knowledge in using LPS for planning and control purposes.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q7: In my organization people do not have enough experience in using LPS for planning and control purposes.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q8: In my organization people find it hard to use the LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q9: My organization does not provide a positive climate for implementing LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q10: My organization offers incentives to last planners (example: foreman, supervisor, project engineer) who support implementing and using LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q11: In my organization people find it difficult to collaborate with the teams from other organizations during the weekly-work-plan meetings.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q12: My organization faces contractual issues when implementing and using LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q13: My organization faces legal issues when implementing and using LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q14: My organization faces internal conflicts (example: resistance to change, lack of training) in implementing and using LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q15: My organization faces external conflicts (example: lack of client support or subcontractor support) and challenges in implementing and using LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q16: My organization gets good support from the owner (client) for using lean principles and techniques such as LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q17: My organization gets encouragement from the owner (client) for using lean principles and techniques such as LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q18: Standard procedures of my organization make it difficult to implement and use a new system such as LPS.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q19: In my organization people refuse to assume commitments themselves.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Q20: In my organization people refuse to include subcontractors in planning.

1 2 3 4 5 6 7

Strongly Disagree Strongly Agree

Please answer the following questions

Is there any formal training or any specific plan in place (example: lean and LPS workshops) for teaching lean principles and implementing LPS in your organization?

- Yes
- No

If answer to the above question is YES, please specify _____

Does your organization always use LPS from the beginning of the project (example: construction, design, prefabrication etc.)

- Yes
- No

If answer to the above question is NO, when LPS was implemented in most of the projects in your organization?

- When project was 0% to 25% complete
- When project was 25% to 50% complete
- When project was 50% to 75% complete
- When project was complete more than 75%

Does your organization has a strategy for implementing LPS on a project?

- Yes
- No

If answer to the above question is YES, please describe briefly_____

Does your organization run LPS in parallel with other improvement programs? (Example: quality management, safety improvement)

- Yes
- No

If answer to the above question is YES, please check all that apply.

- CPM scheduling
- Quality management
- Risk prevention
- Safety improvement
- Reduction of environmental impact (Failure of Management Commitment)
- Other: _____

In your organization, in weekly or daily work planning meetings, who is responsible for proposing the work that will be done by each trade team/crew? _____

What benefits do you believe that your company already gets from using LPS? If any of these have been quantified please give describe briefly _____

Which of the following is (are) part of your planning process?

- Master Scheduling
- Phase Scheduling (Pull Scheduling)
- Look-ahead Planning
- Weekly Work Planning
- Percentage Plan Complete (PPC)
- Constraint Analysis
- First Run Studies
- Reasons Charting
- Root Cause Analysis
- Other: _____

What incentives does your organization provide to the employees who support the implementation and use of LPS? _____

Which of the following organization do you find most difficult to deal with during the weekly-work-plan meetings?

- Subcontractors (Trade-partners)
- General Contractors
- Suppliers
- Architects
- Engineers
- Other: _____

What contractual and legal issues does your organization face during the implementation and use of LPS? _____

Is there an agreement among project team on what makes a ‘sound’ commitment, a reliable promise?

- Yes
- No

When there is any mistake during the use of LPS, do you feel blamed for it?

- Yes
- No

How many projects are you doing [or have you done] using LPS? _____

What percentages of projects in your organization have been done using LPS in 2009?

_____

For what phase do you implement LPS? Please check all that apply

- Project Definition
- Design
- Prefabrication
- Construction
- Use
- Other: _____

Section II: The following questions are only asked for classification purposes

How long have you worked in the construction industry (years)? _____

How long have you worked at your current job position in this company (years)?

_____

How many years of experience do you have in using LPS? _____

Which construction sector(s) does your company work in? Please check all that apply

- Residential
- Commercial
- Heavy Civil/Highway
- Industrial
- Public & Community Buildings
- Other: _____

In your company's projects, where LPS is used, what type of project delivery method is generally adopted? Please check all that apply

- Design-Bid-Build
- CM-Agency
- CM-Risk
- Design Build
- Design Build with Novated Design
- Integrated Project Delivery (IPD)
- Other: _____

In which country (or countries) is your organization headquartered? _____

In which country (or countries) the most of the LPS projects you worked on are/were based? _____

How would you classify your company on the basis of revenue? *

- Greater than US $ 1 Billion (Greater than € 735 Million)
- US $ 301 Million to US $ 1 Billion (€ 222 Million to € 735 Million)
- Less than US $ 300 Million (Less than € 222 Million)

APPENDIX C

TEXAS A&M UNIVERSITY
DIVISION OF RESEARCH AND GRADUATE STUDIES - OFFICE OF RESEARCH COMPLIANCE

1186 TAMU, General Services Complex
College Station, TX 77843-1186
750 Agronomy Road, #3500

979.458.1467
FAX 979.862.3176
http://researchcompliance.tamu.edu

Human Subjects Protection Program — Institutional Review Board

DATE: 29-Apr-2010

MEMORANDUM

TO: PORWAL, VISHAL
77843-3578

FROM: Office of Research Compliance
Institutional Review Board

SUBJECT: Amendment

Protocol Number:	2010-0222
Title:	Application of Last Planner System in Construction Industry
Review Category:	Expedited
Approval Period:	29-Apr-2010 **To** 05-Apr-2011

Approval determination was based on the following Code of Federal Regulations:

45 CFR 46.110(b)(2) - Minor changes in previously approved research during the period of (one year or less) for which approval is authorized.

Provisions: Adding a survey to the study.

This research project has been approved for one (1) year. As principal investigator, you assume the following responsibilities

- **Continuing Review:** The protocol must be renewed each year in order to continue with the research project. A Continuing Review along with required documents must be submitted 30 days before the end of the approval period. Failure to do so may result in processing delays and/or non-renewal.
- **Completion Report:** Upon completion of the research project (including data analysis and final written papers), a Completion Report must be submitted to the IRB Office.
- **Adverse Events:** Adverse events must be reported to the IRB Office immediately.
- **Amendments:** Changes to the protocol must be requested by submitting an Amendment to the IRB Office for review. The Amendment must be approved by the IRB before being implemented.
- **Informed Consent:** Information must be presented to enable persons to voluntarily decide whether or not to participate in the research project.

This electronic document provides notification of the review results by the Institutional Review Board.

VITA

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