Power, W., and Taylor, D. (2019) Last Planner® System and Percent Plan Complete: An Examination of Trade Contractor Performance. *Lean Construction Journal* 2019 pp 131-146 (submitted 04Nov2019; Accepted 25Nov2019) www.leanconstructionjournal.org

Last Planner® System and Percent Plan Complete: An Examination of Trade Contractor Performance

William Power[1] and Darrin Taylor[2]

Abstract

Research Question: What are the project performance differences between Irish construction firms that have adopted Lean thinking and practices and those that have not?

Purpose: This study explores Percent Plan Complete (PPC) as part of the application of Last Planner® System (LPS) across two concurrent capital projects in Ireland. It examines commonalities and differences between trade contractors' PPC, and it identifies areas of improvement for implementation on future projects.

Research Method: Mixed-methods approach encompassing critical literature review, site documentation data-analysis, focus groups, and semi-structured purposeful interviews.

Findings: Lean Construction-oriented contractor selection, early engagement of trades in the design process, implementation of all functions of LPS, education and training in Lean, increased modularization and prefabrication, and embracing technological advances are posited as areas for focused improvement.

Limitations: This study is limited to examination of PPC data from two concurrent Engineering, Procurement, Construction Management, Validation (EPCMV) Projects.

Implications: Irish construction firms should adopt Lean thinking and practices to provide added value on capital projects. There is a need for further studies on the PPC performances and reasons for non-completion (RNC) of trade contractors across multiple projects.

Keywords: Lean Construction, Percent Plan Complete, Last Planner System, Reasons for Non-Completion, Ireland.

Paper type: Case Study.

1 Productivity & Performance Manager, DPS Group, 4 Eastgate Avenue, Eastgate Business Park, Little Island, Co. Cork, Ireland, +353 21 7305000, willie.power@dpsgroupglobal.com

2 Principal Lead, Academy of Lean Enterprise Excellence, RIKON Centre, School of Business, Waterford Institute of Technology, Waterford, Ireland, +353 51 834129, dtaylor@wit.ie

Introduction

A key concept in Lean Construction (LC) is the provision of reliable workflow to the teams to reduce uncertainty in the delivery process (Ballard 2000). Last Planner® System (LPS) is a key waste elimination and variability reduction technique that addresses that uncertainty (Hamzeh *et al.*, 2009, 2016; Abdelhamid 2004). Whilst much has been written on LPS over the past 25 or more years, there appears to be a dearth of research that investigates the performance of individual trade contractors and their respective and collective contributions to a project's weekly and overall Percent Plan Complete (PPC).

Research problem and context

LC is recommended as an antidote to productivity issues encountered on capital project delivery. LPS is a key tool of LC and high PPC achievement is positively correlated to increased productivity (Liu *et al.*, 2010).

There is a dearth of research on the application of LC thinking and practices in the Irish construction sector generally, and in particular on live capital projects. This study examines the PPC performance of several trade contractors across two concurrent capital projects; it considers commonalities and differences between relevant trade contractors' PPC; and it identifies areas for improvement to enhance PPC on future capital projects.

Literature review

Lean construction

Koskela (1992, p.64) challenged the construction sector to apply extant Lean production thinking and practices, positing that Lean '… contains a promise of tremendous possibilities for improvement and of a solution of the chronic problems of construction'. Ballard was at the same time developing what became known as the "Last Planner System of Production Control" (Ballard, 2000). Koskela's development of the theory and more holistic approach, alongside Ballard and Howell's tools, extended Lean into construction (Ballard *et al.*, 2007).

Early LC researchers recognized that Traditional Construction Project Management (TCPM) was unable to cope with the increasingly more complex and dynamic projects that clients were demanding (Howell and Koskela, 2000; Howell *et al.*, 2010). Construction needed to adopt a productivity mindset, and Koskela's Transformation-Flow-Value (TFV) theory integrated the successful qualities of Craft, Mass, and Lean Production concepts (Abdelhamid and Salem, 2005), thus creating a comprehensive theory of production management for construction.

TFV focuses on reducing lead times and minimizing variability, whilst simplifying on-site and off-site processes (Koskela, 1992). TFV also promotes pull concepts and continuous improvement of the delivery process (Koskela, 1999). The value view of TFV theory considers voice of customer (VOC) by emphasising delivery of what is considered valuable from the customer's - and most importantly the next customer's – viewpoint (Koskela, 2000; Ballard *et al.*, 2007).

Accordingly, specific tools were developed for LC, namely Target Value Design (TVD), the Lean Project Delivery System (LPDS), and LPS (Howell and Koskela, 2000; Abdelhamid, 2004).

Last Planner® System

LPS is central to the implementation of LC, and it requires continuous and collaborative effort from all stakeholders in a production planning and control system to reduce variability whilst enhancing reliability and predictability in construction workflows (Hamzeh and Bergstrom, 2010; Howell *et al.*, 2010). This is fundamentally different to the TCPM approach of directing and adjusting after the occurrence (Koskela and Howell, 2002) and the assumption that variability in workflow lies outside the control of management (Ballard and Howell, 2003).

LPS was developed from research into productivity improvement, with Ballard and Tommelein (2016, p.59) positing that 'the inspiration for LPS was the discovery of chronically low *workflow reliability* in construction projects.' Ballard *et al.* (2009) summarize the 'principles' underlying LPS as follows:

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

There is a dearth of research on LPS vis-à-vis how each trade contributes towards the overall PPC, which measures the percentage of tasks completed relative to those planned. However, Ballard and Tommelein (2016, p.60) assert that '… from the perspective of continuous improvement, LPS's job is to stabilize operations so they can be further improved, both individually and in the processes which they comprise, but it also improves productivity. Many, perhaps most, people are satisfied with that and don't exploit the opportunity for more fundamental improvement in performance'.

PPC is a key metric of LPS and measures workflow reliability. A high PPC indicates a well-planned production process with tasks screened in advance, ensuring high workflow reliability between teams (Ballard, 2000). However, Ballard and Tommelein (2016, p.59) warn against placing too much focus on PPC figures, stating that '… PPC could be 100%, productivity excellent, and a project still be falling behind schedule'. This emphasizes the importance of using all functions of LPS to ensure that PPC and productivity are linked to the overall milestone schedule (Ballard and Howell, 2004; Hamzeh *et al.*, 2009). As PPC is positively linked to productivity (Liu *et al.*, 2010), it is critical for LPS users to ensure that the trade contractors' teams executing the work are afforded the greatest opportunity of achieving high PPC.

Howell and Ballard (1994) recommend reducing workflow variation by stabilizing all functions through which work flows, from concept through to completion, whilst Hamzeh *et al.* (2009) posit formalizing the planning and production operations process on the construction project. Ensuring consideration of the eight prerequisite flows (Koskela, 2000; Pasquire and Court, 2013) to make the right tasks sound is an essential element of LPS: 'Progress rises and falls with PPC to the extent that tasks are made ready in the right sequence and rate' (Ballard and Tommelein, 2016 p.60).

Understanding the Reasons for Non-Completion (RNC) of tasks will enable future improvement of the planning process (Liu *et al.*, 2010) as it provides teams with trends that can be used to develop strategies to prevent re-occurrence of the same failures in the future (Ballard and Tommelein, 2016).

Research methodology

A mixed-methods approach was adopted (Creswell, 2013) encompassing a critical literature review, site documentation data-analysis, focus groups, and semi-structured purposeful interviews. This approach helped minimize bias as both the quantitative and qualitative models have individual weaknesses that can be compensated by the comparative strengths of the other methods (Steckler *et al.*, 1992; Glaser, 2008; Creswell, 2013) and such triangulation enhances the depth, quality, and validity of the research findings (Bouma and Kamp-Roelands, 2000; Bogdan and Biklen, 2006).

A sequential explanatory approach (Creswell, 2009) was utilized, with the quantitative data being collected weekly as the Projects proceeded and the qualitative data being gathered after the Projects were completed. As per Creswell *et al.* (2003), priority was given to the quantitative data as this was analyzed and then connected to the next stage by selection of methods and participants best suited to the follow-up qualitative data collection phase (Creswell, 2009). The analysis of the data informed the secondary data collection process (Creswell, 2009) which is useful when unexpected results arise from a quantitative study (Morse, 2003).

The first author acted as lead researcher in his capacity as the assigned "LPS Facilitator" on both Projects.

Table 1 provides an overview of the three focus groups which comprised each Project's construction management team (CMT), the respective trade contractors' Last Planners, and the senior operations management; along with details of the purposeful sample of seven interviewees representing senior management of the key trade contractors.

Unique sources were sought to increase validity and to provide a wider perspective (Yin, 1994; Stake, 1995). Focus group sessions were conducted on both Projects to gather the opinions of the trade contractors' Last Planners on the challenges and opportunities for improvement in LPS implementation. The qualitative findings were transcribed and then analyzed using a thematic analysis approach and organized into different themes (Braun and Clarke, 2006). Inferences drawn from the emerging themes were checked by triangulation against the literature review findings to check their reliability and integrity (Steckler *et al.*, 1992; Richie and Lewis, 2003).

In accordance with Creswell (2009), the research is presented as two distinct findings sets, with the quantitative findings directing the subsequent qualitative research.

The following questions were posed:

- What differences exist between individual trade contractors' PPC?
- How can those differences be explained?
- What areas of improvement can be implemented on future projects to enhance PPC?

Table 1: Qualitative Research Sources

Source	Project & Participants
Focus Group 1	Project A (n6) – CMT (2); Trades Last Planners (3); Director Steel/Roofing/Cladding (1)
Focus Group 2	Project B (n7) – CMT (4); Trades Last Planners (3)
Interviewee A	Project A – Mechanical (M) & Electrical (E) Project Manager
Interviewee B	Project A – Civil, Structural & Architectural Project Manager
Interviewee C	Project A – Cleanroom Project Manager
Interviewee D	Project B – Mechanical Project Manager
Interviewee E	Project B – Electrical Project Manager
Interviewee F	Project B – Civil, Structural, & Architectural Director
Interviewee G	Project B – Cleanroom Project Manager
Focus Group 3	Projects A & B (n7) – Senior Operations Management

Findings

In summary, data in the form of PPC and RNC was collected weekly on both Projects, accumulating to 69 weeks of data for Project A and 58 weeks of data for Project B.

Question 1: What differences exist between individual trade contractors' PPC?

To address question 1, we examined the quantitative PPC data that was retained on both Projects for the duration of each trade's presence, and their average PPC is presented in Table 2.

On Project A, there was a noticeable gap in the average PPC between the CSA, Steel/Roofing/Cladding, and Cleanroom trades on one end, and the M&E and Sprinkler trades on the other end. CSA were on site for almost twice the duration of other trades and they committed 43% of the work tasks to the weekly work plan (WWP). The Steel/Roofing/Cladding, despite completing only 15% of the work tasks, achieved 80% PPC. M&E and Sprinkler achieved 91-92% PPC each on a combined 40% of the work tasks. It is noteworthy that the M&E company and Sprinkler company on Project A were knowledgeable and practiced in LC.

Similar gaps were evident on Project B. CSA were longest on site, completing 29% of tasks and achieving 80% PPC. Mechanical (90%) and Electrical (89%) were the highest PPC achievers with 23% and 22%, respectively of total tasks committed to the work plan. The M&E companies on Project B (different to that on Project A) were also knowledgeable and practiced in LC. However, the Sprinkler company on Project B – a locally-based incumbent contractor – had a poorer PPC performance, and it is noteworthy that it was neither knowledgeable nor practiced in LC.

Table 2: Individual Trade Contractors' Duration on Projects and Average PPC

Trades	Project A			Project B		
	Weeks on Project	Average PPC	Percent of Total Project Tasks	Weeks on Project	Average PPC	Percent of Total Project Tasks
CSA	69	84%	43%	58	80%	29%
Cleanroom	27	86%	2%	54	84%	22%
Steel/Roofing/Cladding	54	80%	15%	45	72%	2%
Mechanical	34	92%	15%	54	90%	23%
Electrical	34	92%	21%	50	89%	22%
Sprinkler	40	91%	4%	46	79%	2%

Data on the RNC of tasks was gathered from both Projects and is presented in Figure 1. The top three RNC on both Projects were 'Schedule/Coordination', followed by 'Staff Availability', and then 'Pre-requisite Work Others'. Other RNC categories that impacted PPC on both Projects included 'Weather', 'Materials/Supplies', and 'Design'. Additionally, 'Pre-Requisite Work Self' was a factor on Project A but not on Project B; and 'Incorrect Time Estimate' was a factor on Project B but not on Project A.

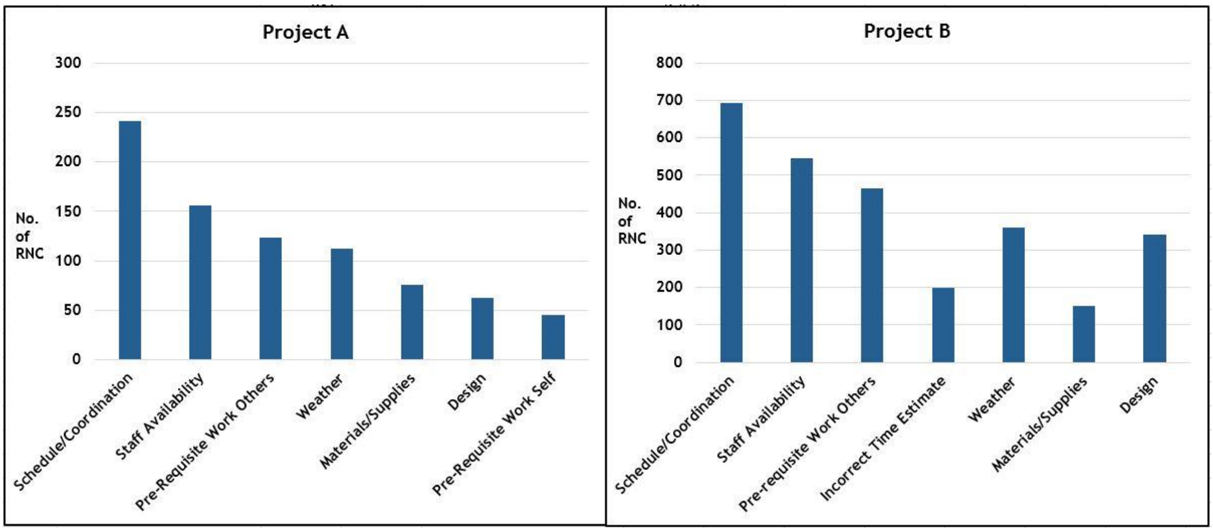

Figure 1. RNC of Tasks on Project A & Project B

The RNC categories are described in Table 3.

Table 3: Categories of Reasons for Non-Completion

RNC Category	Description
Schedule/Coordination	The planned task could not proceed due to insufficient planning or coordination of multiple trade contractor requirements.
Staff Availability	Insufficient resources available to execute the planned tasks.
Pre-Requisite Work Others	Other trade contractors not completing their tasks prior to handoff to the next trade.
Weather	Adverse weather affecting task execution (high winds, heavy rainfall, temperature extremes, snow/ice).
Materials/Supplies	Insufficient supply of materials; delayed delivery of materials.
Design	Missing or incomplete information regarding design drawings.
Incorrect Time Estimate	Inaccurate estimation of time allowed to complete the task.
Pre-Requisite Work Self	Trade contractors own incomplete task handoff preventing commencement of next task.

By examining the top three RNC only, Figure 2 illustrates how they are apportioned amongst the trade contractors.

The largest quantity of 'Schedule/Coordination, 'Staff Availability', and 'Pre-Requisite Work Others' was attributed to CSA on both Projects A and B, Steel/Roofing/Cladding on Project A, and Cleanroom on Project B. Sprinkler, Electrical, and Cleanroom were most impacted by incomplete or late work handoffs from other trades. It should be noted that CSA had 43% of the work tasks on Project A WWP and 29% of the work tasks on Project B WWP.

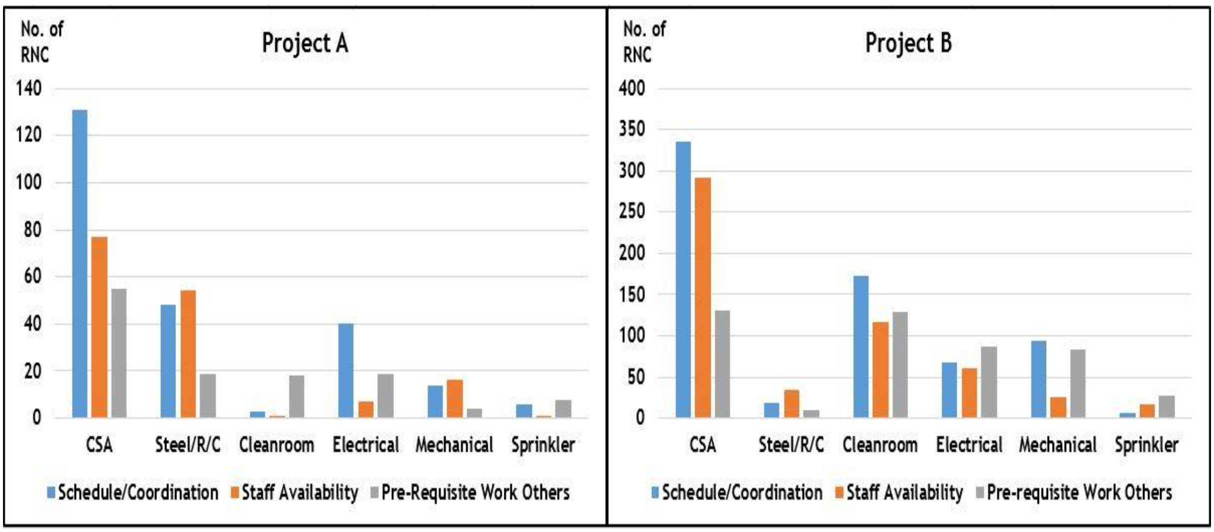

Figure 2. Breakdown of top three RNC

In accordance with the sequential explanatory design strategy (Creswell, 2009), the key findings arising from the quantitative research are presented in Table 4.

Table 4: Summary of Key Quantitative Findings

Themes	Findings
Trade Contractor PPC	M&E (different contractors on both Projects) achieved the higher PPC on Project A and on Project B.
	Sprinkler (different contractors on both Projects) achieved a high PPC on Project A and a lower PPC on Project B.
	CSA (different contractors on both Projects) achieved a lower PPC than M&E on each Project.
	Cleanroom (different contractors on both Projects) achieved a lower PPC than M&E on each Project.
	Steel/Roofing/Cladding (different contractors on both Projects) achieved the lowest PPC on each Project.
PPC ranges	M&E ranged between 92% and 89%.
	CSA ranged from 84% to 80%.
	Cleanroom ranged from 86% to 84%.
	Steel/Roofing/Cladding ranged more widely from 80% to 72%.
	Sprinkler had the greatest range from 91% to 79%.
RNC	On both Projects, “schedule/coordination”, “resource availability”, and “prerequisite work by others” were the top three RNC.

An analysis of the findings from the quantitative element of the study generated key points to take forward to the focus groups and semi-structured purposeful interviews.

Question 2: How can these differences be explained?

As the quantitative research analysis determined a gap existed between individual trade contractors’ PPC, we proceeded to conduct focus groups and interviews as we sought to address this question. Two focus group sessions were conducted with the Last Planners and members of the CMT from both Project A and Project B, and the key findings from those focus groups are presented in Table 5. We next combined the findings from those focus group sessions with the quantitative data findings and our analysis of pertinent literature, and this provided the basis for a deeper and more nuanced assessment to bring forward into the interviews (Table 6).

The M&E trades clearly performed the best on both Projects. Different companies provided the Mechanical and the Electrical services on each Project, and these companies were early adopters and practitioners of LC. Interestingly, the Electrical company on Project B also provided the Sprinkler services on Project A, which performed substantially better than the Sprinkler company on Project B which is not a practitioner of LC. It is therefore our assessment that embedded LC knowledge and proven LPDS and LPS practice is *the* primary explanation for the differences in PPC experienced on both Projects.

Table 5: Key Focus Group Findings

Themes	Findings
Time required for/commitment to LPS	Lack of adequate trade management time to adequately plan WWP. No dedicated and trained Last Planner management resource.
Late receipt of WWP from trades	Much greater coordination is needed where trades overlap and late receipt of WWPs left little time for CMT supervision to proof and coordinate the plan.
Specialist resource availability	The local region is currently experiencing a construction boom in the Pharma sector, and availability of specialist resources was a major challenge for clients and management teams.
Not using all functions of LPS	Inconsistency of implementation of all functions of LPS. Project A successfully implemented all functions of LPS, while Project B experienced implementation issues due to its size and complexity.
Design-related issues	Incomplete design led to delays in resolving design-related constraints. Delayed appointment of trades meant a lack of trade involvement in early planning, scheduling, and design coordination decisions.

The key interview findings are presented in Table 6.

Table 6: Key Interview Findings

Interviewees	Findings
A B C E F G	M&E adopt a productivity-based and metrics-focused approach and mindset to construction delivery. CSA approach is more reactionary, with an acceptance of the peculiarities and traditional problems associated with construction work execution.
A C E G	The LC-practiced M&E contractors have developed management systems and structures enabling them to set their own agenda on a project, and they lead out their own design, schedule, and workflows. CSA appear to be under-resourced at site management level with immediate problem-solving prioritised over short- to medium-term planning.
A B C D E F G	Late and incomplete design, as well as contractors commencing on site in advance of design being sufficiently developed, had an impact on the smooth flow of work tasks. Early engagement of the M&E contractors in the design development process was considered a key advantage in maintaining reliable flow and contributing to higher PPC.
A B C G	Engagement with, and preparation for the LPS process, as well as using all functions of the system, is critical for successful project delivery. Poor lookaheads lead to inadequate preparation of workplans, resulting in missed tasks being categorised as 'schedule/coordination' and 'prerequisite work by others', impacting on other trades' PPC.
A B D E G	Prefabrication and Modularisation offers distinct advantages by reducing onsite activities and the associated coordination issues.
A C D E G	The embracing of ICT advancements in construction software, allied to the utilisation of handheld applications and devices, enables more efficient solutions to data storage and acquisition.

Question 3: What areas of improvement can be implemented on future projects to enhance PPC?

A final focus group session involving EPCMV senior operations management was held to discuss and validate the research findings, and to identify areas for improvement that could be implemented on future projects to enhance individual trade contractors' PPC as well as the overall project PPC. Table 7 presents those identified areas for improvement.

Table 7: Areas of Improvement for Implementation on Future Projects

Areas	Findings
Procurement	Feature LC in prequalifications, tenders, and actual contracts. Contractor selection needs to be restricted to proven LC companies. Ongoing assessment systems should incentivise process excellence and continuous improvement.
Trades' Differences	Provide greater attention and involvement at design stage for CSA, Steel/Roofing/Cladding, and Cleanroom. Review contracting strategy to accommodate early appointment and involvement of these trades as early as possible and engage them across the design process. No contractor should be permitted to commence on site without a clearly defined and agreed design in place. Develop a trust-driven, transparent, collaborative relationship amongst parties at design stage.
LC Training & Education	Deliver LC training and education to the client, the EPCMV team, and contractors to ensure a productivity-based and metrics-focused mindset is embedded amongst the construction delivery partners.
LPS Training & Education	Schedule more detailed LPS training and refresher courses into the project duration and have these supported by the client. Focus to be placed on enabling flow with the Tasks Made Ready (TMR) metric and the creation of sound, constraint-free tasks ahead of committing them to the WWPs.
Off-Site	Demand more off-site fabrication and assembly processes. Contractors should propose a greater variety of options, and clients should ensure modularisation is respected to avoid requirement for bespoke solutions.
ICT	Adopt site-wide technological solutions across all contractors to improve visualisation (BIM), process improvement (RFIs, punch-lists, submittals), planning and coordination (LPS software), and the efficient accessibility of project documentation (cloud-based platforms).

Discussion

Lean Construction companies are top performers

The better performing trade contractors, namely the highest PPC achievers, are knowledgeable and practiced early adopters of LC. To assure high performance, the prequalification and selection processes should focus on a contractor's LPDS ability as opposed to lowest cost criteria which can promote loss of value (Sarhan *et al.*, 2017). Client alignment on this point is critical. In this study, the approach of M&E contractors was productivity-based, and founded on systems and processes that ensured resources and materials were matched with sound, constraint-free tasks prior to commitment to a WWP. That "productivity mindset" understands that creation of even and reliable workflow is critical to improving construction productivity (Ballard *et al.*, 2007; Liu *et al.*, 2010). Efficiency Ratio metrics are a key driver of forward planning, and a measurement of output and productivity at both task and project level within these M&E companies. However, Howell *et al.* (2010) assert that such traditional metrics reduce the reliability of workflow by creating a focus on local productivity and executing work out of sequence. It is therefore important that a contract that encourages the dissolution of traditional silos and promotes a more collaborative organizational structure be considered.

Management resourcing

The findings indicate sufficiently resourced site management teams and more clearly defined roles amongst the M&E companies. CSA appear to underestimate the level of management required to support both CMT and client reporting and supervisory requirements. With increasingly tighter margins due to more competitive tendering processes, CSA management and supervision staffing levels are minimized, thus contributing towards a cycle of insufficient planning and coordination and missed tasks (Howell *et al.*, 2010). M&E primarily have their own direct labor and very few subcontractors, whereas CSA differed in having minimal direct labor and many subcontractors, contributing to greater fragmentation and difficulty of communication on the Projects. The study contends that clients and EPCMV should recognize that CSA requires more attention at both the E and the CM stages.

Early contractor engagement

M&E were engaged early and involved in the design coordination and completion of the BIM model on each Project. However, the other trades were pressured to commence on site whilst the design was incomplete, which proved to be a constant constraint throughout the delivery phase of both Projects. Early engagement of key contractors is a critical enabler of LPDS (Ballard *et al.*, 2007; Do *et al.*, 2015) and this study suggests early engagement of all trades in the design process would contribute towards raising their respective PPC whilst lessening any negative impact on other trades and the project overall.

Lean education and training

This study earlier referred to the productivity-based mindset of M&E, and we suggest investment in education and training in Lean would contribute towards developing a value and next-customer awareness amongst the entire project team. M&E have supervision or charge-hands assigned to specific measurable tasks and are metrics-driven in their planning and setting of outputs and targets. By comparison, CSA appear to thrive on fire-fighting, reactionary problem-solving, and using their creativity to work around constant impending issues, like the improvisation referred to by Hamzeh *et al.* (2016). The introduction of standard work for trades' management, as well as incorporating the LPS weekly cycle into their working week, is considered a key step towards regularizing how trades should approach their work planning and coordination.

LPS alignment

M&E put more preparation into their weekly planning, and they arrived at the LPS coordination meetings fully prepared and familiar with their scope, whereas CSA were reluctant participants with the LPS process on both Projects. We suggest a more complete implementation of LPS is called for as there is evidence of each trade seeking to maximize their own weekly PPC figures with an absence of consideration for the whole project's gain. CSA's observed constant firefighting left inadequate time for organizing and coordinating the flow of work tasks, and that mindset allows little room for effective planning or improvement (Ballard, 2000).

Prefabrication and modularization

Because of early engagement, much of the mechanical work scope was prefabricated off-site, with site work primarily just an assembly process. Electrical switch-rooms and panels were also fabricated off-site, resulting in installation and connection tasks for the on-site crews. Cleanrooms work on a modular system and, to create the required efficiency, modularization must be respected and not turned into a bespoke-modular system. CSA work was exclusively site-based transformation of inputs. The amount of variability encountered from resource constraints, poor coordination, late materials ordering, and inadequately screened design, all gave little respite from resolving crises and issues – common problems accruing from inadequate lookahead planning (Hamzeh *et al.*, 2012).

Technology optimization

M&E embraced technological advances, and this contrasted with the CSA contractors on both Projects. M&E utilized iPads to view the BIM model and isometric drawings in the field, thus increasing visualization and understanding for the craft workers undertaking the installation. M&E also utilized cloud-based applications for punch-list identification, monitoring, and closeout. Cleanroom used similar technological aids; however, they highlighted issues relating to incomplete design as well as departures from modularization impacting on the benefits. CSA only minimally adopted available construction-based technological assistance. Barbosa *et al.* (2017, p. 10) suggest the '…biggest barriers to innovation by construction companies are underinvestment in IT and technology more broadly, and a lack of R&D processes'.

Reasons for non-completion

Analysis of RNC and implementation of countermeasures is a critical component of LC and LPS implementation. It is our assessment that the amount of RNC assigned to 'Schedule/Coordination', 'Staff Availability', and 'Pre-Requisite Work Others' variances, on both Projects points towards a deficiency in fundamental construction project management abilities allied to incomplete implementation of all functions of LPS.

Ballard and Tommelein (2016, p. 69) posit that 'Timely generation and implementation of countermeasures reduces accidents, rework, and plan failures. The return on investment makes this something everyone should do and allocating capacity for such analysis is a vital management act. Capturing reasons for breakdowns over time provides teams with trends, which can be used to develop strategies to prevent re-occurrence of the same failures in the future'. The data generated from LPS implementation (PPC and RNC) should be utilized to identify weaknesses in the delivery process, and, following detailed root-cause analysis, improvement projects should be implemented immediately to prevent reoccurrence of all high-impact RNC. Site management should become familiar with Lean quality tools like 5 Whys, Pareto analysis, A3 problem solving, and PDCA, and be competent in applying problem solving thinking in designing and implementing countermeasures.

Conclusion and recommendations

LC contractors deliver better PPC performances than non-LC contractors. Clients and EPCMV companies should select LC contractors and should use alternative contracting strategies like Integrated Project Delivery (IPD) and relational forms of contract like Integrated Form of Agreement (IFOA) to encourage more widespread use of collaborative working practices. This would help eliminate the siloed approach amongst project parties towards LPS implementation and embed a "project-first" mindset that aligns project team shared goals with the outcomes valued by the client.

Such strategies would also contribute towards resolving many of the issues raised in this study, in particular early appointment and engagement of all parties in the design process. Introducing LPDS requires cultural change (Ballard 2008) and the ensuing LC and LPS education and training would assist in embedding the "Lean mindset" across project participants (Pasquire *et al.*, 2015), allowing for more complete implementation of LC tools like LPS and TVD.

Clients and EPCMV companies should encourage the use of prefabrication and modularization while respecting the prerequisites required to achieve the efficiencies offered. Also, a more holistic adoption of advanced ICT-based applications and platforms should be utilized.

Regarding RNC, site management should become knowledgeable in applying Lean quality thinking and problem-solving techniques to prevent reoccurrence of plan failures, thus contributing to enabling smoother workflow.

Finally, future research is recommended to investigate the obstacles and barriers restricting a more complete adoption of LPS on projects, as well as the wider utilization of collaborative forms of contracting. Additionally, it is recommended that future research considers anticipation of and more agile responses to RNC and the application of a Lean quality mindset to construction site management.

Acknowledgments

The authors extend their gratitude to DPS Group Cork Operations, the Clients on whose projects this study was undertaken, and the trade contractor companies and individuals who participated in the study.

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[Republished, with modification, from Proc. 27th Ann. Conf. of the Int'l Group for Lean Construction. Dublin, Ireland, July 3-5, 2019 pp 1-12. Available at www.iglc.net]