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Improving Commissioning and Qualification Delivery Using Last Planner System®

William Power[1], Derek Sinnott[2], and Aidan Mullin[3]

Abstract

Question: Can the Last Planner System® enhance the Commissioning and Qualification phase of project delivery?

Purpose: Evaluation of Last Planner System in the Commissioning and Qualification phase of project execution; identifies challenges; proposes mitigations and opportunities for enhancing future implementations.

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

Findings: Last Planner System offers distinct value-add to Commissioning and Qualification. However, there is need for increased involvement of upstream and downstream players in planning construction production processes.

Limitations: Conducted on a single project with limited sample size.

Implications: Paper offers value for clients and practitioners as Last Planner System in the Commissioning and Qualification phase of project execution facilitates greater collaboration, increased visibility of workflow, and resulting productivity, schedule alignment, safety, cost, and client value-add benefits.

Keywords: Lean Construction; Last Planner System®; collaboration; workflow; lookahead planning; handoff.

Paper type: Case Study

Introduction

Construction still struggles to meet customer expectations relating to schedule, cost, safety, and quality value demands. Recent publications (Flyvberg, 2009; Farmer, 2016; Barbosa *et al.*, 2017; Oakland and Marosszeky, 2017) indicate core issues remain

1 Productivity & Performance Manager, DPS Group, 4 Eastgate Avenue, Eastgate Business Park, Little Island, Co. Cork, Ireland, +353 21 7305000willie.power@dpsgroupglobal.com
2 Senior Lecturer, Waterford Institute of Technology, Waterford, Ireland, dsinnott@wit.ie
3 Senior Project Manager, DPS Group, 4 Eastgate Avenue, Eastgate Business Park, Little Island, Co. Cork, Ireland, +353 21 7305000, aidan.mullin@dpsgroupglobal.com

(adversarial relationships, poor productivity, and substantial inefficiency and rework) despite almost 25 years passing since the publication of Latham's (1994) and Egan's (1998) reports. Elements of the sector has looked to Lean Construction (LC) as an antidote to its problems (Koskela, 1999) and as a means of delivering the requisite value that clients have been long-demanding (Koskela, 1992; Ballard, 2000; Hamzeh *et al.*, 2009). This study evaluates the implementation of Last Planner System (LPS) in the Commissioning and Qualification (C&Q) phase of project execution; identifies challenges; and proposes mitigations and opportunities for improvement to future implementations.

Lean and Lean Construction

While early lean literature focused primarily on the reduction of waste (Womack *et al.*, 1990; Liker, 2004), contemporary literature identifies the softer aspects of respect for people and continuous improvement as necessary for the creation of a culture of excellence (Bhasin 2012, 2013; Hines *et al.*, 2018; Hines and Butterworth, 2019). A shared theme across lean literature is the emphasis on customer value, flow, people empowerment and continuous improvement (Womack *et al.*, 1990, Koskela, 1992, Hines *et al.*, 2008; Liker and Hoseus, 2010; Hines and Butterworth, 2019). In a production context, Lean is an operations strategy that focuses primarily on the creation of efficient flow and this concept has been replicated across numerous economic sectors (Simu and Lidelöw, 2019). Koskela's empirical work (Koskela, 1992) redefined the original principles of lean and sought to apply the new production philosophy to construction (Bertelsen and Koskela, 2004). Lean Construction is conceived as '… a temporary production system dedicated to the three goals of delivering the product while maximising value and minimising waste' (Ballard and Howell 2003, pp.44). Thus, in construction, Lean thinking concentrates on how value is generated (Koskela, 2000; Bertelsen and Emmitt, 2005; Salvatierra-Garrido and Pasquire, 2011) and how customer needs are captured and expanded (Abdelhamid, 2004; Ballard, 2008), rather than how any single activity is managed (Howell and Ballard, 1998; Ballard, 2000).

Early proponents of LC recognised the necessity to link and supplement Traditional Construction Project Management (TCPM) with construction production operations; specific tools were therefore conceived for LC, namely LPS, Target Value Design (TVD), and the Lean Project Delivery System (LPDS) (Abdelhamid, 2004). Project Managers who rely on traditional tools of sequencing and planning struggle with uncertainty and variability (Howell *et al*. 1993); their focus is entirely on the single objective of project delivery (that is, fulfilling contractual obligations) (Koskela, 2000; Darrington, 2011) and they rarely see on-site operational issues arising from their TCPM view of operations (Howell *et al.*, 1993; Tommelein *et al.*, 1999; Mossman, 2009).

Noting other economic sectors (production, manufacturing, services) have increased their productivity output per worker year on year over the past 20 years, construction's output has stagnated and at times regressed (Barbosa *et al.*, 2017). Therefore, numerous researchers assert construction needs to follow production and manufacturing and reconceptualise itself (Koskela, 1992; Ballard, 2000), as improvement will only come from changing the way of thinking rather than just solving problems as they arise (Koskela, 2000; Abdelhamid, 2004). Building on principles introduced by Ballard (2016), Oakland and Marosszeky (2017, pp. 49) state it is imperative to '…involve upstream players in downstream processes to realise innovative and efficient design and construction

solutions.' Forbes (2013, pp. 492) called for application of Lean methodology to commissioning procedures and for examination of how LPS could assist critical handoffs.

Commissioning and Qualification

The primary objective of the C&Q phase is to provide documented evidence which demonstrates that the building systems have been commissioned in accordance with Good Engineering Practice (GEP) expectations and User Requirements, and that the installation and operation is fit for purpose (Sohmen, 1992; Lawry and Pons, 2013). Comprehensive documentation details the pre-commissioning, installation, and functional testing required to provide assurance that the system conforms to installation requirements, operates across intended design ranges, approved design specifications, regulatory codes, and is commissioned as per current GEP. The C&Q stage therefore is an essential execution process which consists of many activities that are focused primarily at the construction handover to pre-commissioning phase and ensures that the needs of the 'Owner's Project Requirements' are met (Forbes, 2013).

On many large capital projects, high levels of complexity create productivity bottlenecks that can slow handovers between phases, thus leading to further downstream schedule impact (O Connor and Mock, 2019). Lawry and Pons (2013, pp.2) assert: 'It is widely recognised in the literature that commissioning requires deliberate planning, as opposed to ad-hoc treatment. … it needs appropriate consideration in the work breakdown structure and project planning' and proceed to suggest '…a clear refrain in the literature is that commissioning (i) needs deliberate project management, but (ii) is too often not given the attention it deserves'. At the later stages of a project, both construction and commissioning teams are actively involved with scope and schedule overlaps. Therefore, a common theme on projects is looming commissioning handover dates with teams already behind schedule and over budget. These activities are often challenging and can have adverse consequences which may significantly impact overall project success (Lawry and Pons, 2013; O Connor and Mock, 2019). Horsley (1998, pp. 7) suggests:

> *'…it is too often the case that when slippage occurs in design or construction, commissioning time is arbitrarily reduced to hold the programme end date. Commissioning teams are accustomed to challenging targets, but the timescale and budget within which they are expected to complete their work must at least be realistic if they are expected to commit to it'.*

Therefore, it is critical that the commissioning team doesn't become overwhelmed with the scale of the handover process; late and incomplete handoffs from upstream providers are a common source of project stress.

TCPM struggles with schedule adherence at the latter stages of projects as departmentalisation of phases (design, construction, commissioning) leads to differing priorities within the project team. Lawry and Pons (2013) posit that existing project management frameworks (PMBOK) '…treat commissioning very lightly and rely on the practitioner to identify whether or not commissioning is an important part of the project'. Broader literature suggests commissioning is not treated with the importance it requires resulting in incomplete or insufficient planning (Horsley, 1998; Kirsilä *et al.*, 2007; Peachey *et al.*, 2007). The proposal to incorporate other stakeholders 'voice' is proposed by Kirsilä *et al.* (2007, pp.720) '…project schedules must not only include the vital stages for a

specific company's ''own'' activities – it should also incorporate activities of the other stakeholders in the network, which affect or are affected during the project delivery.' It is therefore critical that effective management and coordination of the C&Q phase is essential for overall success of the project (Sohmen 1992; Horsley, 1998; Lawry and Pons, 2013).

Last Planner System®

'Unreliable planning is the Achilles' heel of the construction sector the world over' (Oakland and Marosszeky, 2017, pp. 55) and research indicates that often only half of planned construction tasks are executed on a weekly basis (Ballard, 2000). A key concept in LC is the provision of reliable workflow to the teams; LPS® is a key waste elimination and variability reduction technique that achieves this while reducing uncertainty in the delivery process (Hamzeh *et al.*, 2009, 2016; Abdelhamid, 2004). Ballard *et al.* (2009) summarise the 'principles' underlying LPS as follows:

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

LPS® requires continuous and collaborative effort from all stakeholders to reduce variability whilst enhancing reliability and predictability in construction workflows (Howell *et al.*, 2010). A more complete introduction of LPS® on construction projects could bring about a change in mind-set and ultimately assist overcome the cultural barriers to the new approaches to collaboration, efficiency, and production (Pasquire *et al.*, 2015; Power and Taylor, 2019). Whilst much has been written on LPS® over the past 25 or more years, there is a dearth of research that examines the outcomes of LPS® in the C&Q phase of project execution.

Research Design

Data for the research was gathered through the C&Q phase of a pharmaceutical plant construction. The project encompasses design, construction, and commissioning and qualification of a new facility, utilities, and equipment for manufacture of a new product.

Overall project governance was administered by the Director and Senior Managers of the Engineering, Procurement, Construction Management, Validation (EPCMV) provider and the client project delivery arm. This team was known as the Senior Leadership Team (SLT). LPS® had been successfully implemented in design and construction phases but C&Q had not previously used LPS®. Due to schedule slippage SLT mandated LPS® be introduced in the C&Q phase.

The study adopted a mixed-methods approach (Creswell, 2013). Triangulation is achieved by contrasting and comparing the documentation analysis data and the direct observation diary notes with the interview, focus group, and literature review themes (Figure 1). Such triangulation enhances the depth, quality, and validity of the research findings (Richie and Lewis, 2003).

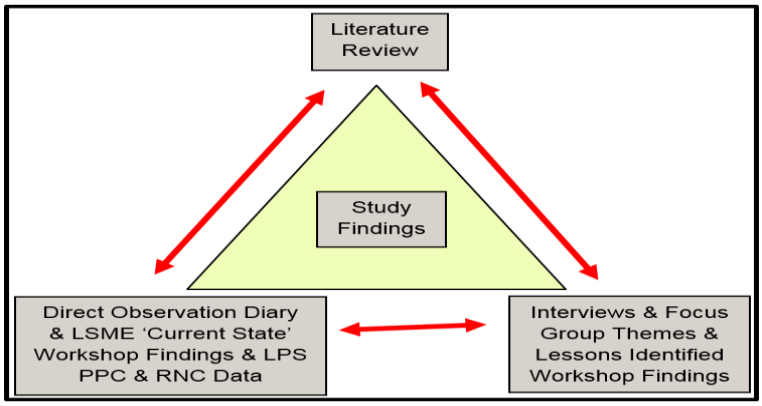

Figure 1: Triangulation of Research Sources

Case study is a very popular and widely used research design in business research (Bryman and Bell, 2015) and is useful for theory building (Eisenhardt and Braebner, 2007) This study is conducted on a single project and literature suggests once the study goal parameters are established then it should be applicable to all research (Yin, 1993, 1994; Tellis, 1997). Principles of action research and learning were applied (Eden and Huxham, 1996) and this enabled one of the researchers and the case organisation to 'collaborate in the diagnosis of a problem and in the development of a solution based on the diagnosis' (Bryman & Bell, 2015, pp. 418-419). Numerous interventions and augmentations were applied, based on Lean theory, Lean Construction principles, and knowledge gleaned from the weekly LPS® data and direct observation diary notes. Table 1 provides an overview of the sources of information for the study.

Table 1: Research Sources

Source	Project and Participants
Project Documentation	LPS® data in the form of Percent Planned Complete (PPC) and Reasons for Non-Completion (RNC) for 40 weeks. Project Lessons Identified output 'Current State' Workshop output
Purposeful interviews	Client Project Manager, Delivery Project Manager, Commissioning Team Lead, Construction Manager, Engineering Project Manager.
Focus Group	Facilitated workshop with six Delivery Team Leads
Direct Observation	Action Research Diary

Unique sources were sought to increase validity and to provide a wider perspective. LPS® data was recorded weekly; an external Lean Subject Matter Expert (LSME) was engaged to facilitate a 'current state workshop'; purposeful interviews were conducted with the C&Q leadership team (interviewees were selected as they were members of both client and delivery team management who were closest to and most knowledgeable on the LPS® implementation); a focus group workshop was conducted with the Delivery Team leads to understand the challenges being encountered by team members; an action research diary was recorded daily by the lead researcher; and, at project completion, a lessons identified workshop facilitated by an external expert was attended by 18 members of the project delivery team.

Qualitative findings were transcribed, then analysed using a thematic analysis approach, and organised into different themes. 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). A sequential explanatory approach (Creswell, 2009) was utilised, with the quantitative data (PPC and RNC) and the action research diary being recorded weekly (for 40 weeks of the LPS® implementation). The qualitative data was gathered on project completion. The analysis of the primary data informed the secondary data collection process which is useful when unexpected results arise from a quantitative study (Creswell, 2009). The LPS® implementation was evaluated by vigilant examination of the merged quantitative and qualitative findings. Limitations exist around the single case example and limited sample size.

Findings

Delivery Team Approach

The C&Q team was established with six individual Delivery Teams, defined as: '*a fully resourced team aligned to deliver a collection of common equipment / systems scope per overall execution strategy and boundaries set by the client'*. The Delivery Team's key principles are presented in Table 2.

Table 2: Principles of Delivery Team Approach

Principle	Description
Integrated	Consistent, co-located, full cross functional representation and required resources (people, material, etc.) to self-execute assigned scope within schedule and cost targets
Empowered	Granted the authority to make decisions and perform their responsibilities within sponsored boundaries
End to End	Focused on overall program success (design – construction management - C&Q - client operations)
Tier Approach	Utilise Tier structure for coordinating activities, cross delivery coordination, and escalation as required

Due to missing some key early milestone dates early in the commissioning phase, the client and delivery management team engaged an external Lean Subject Matter Expert to facilitate a 'current state workshop' by examining the daily management and handover process between construction and C&Q. The findings are summarised in Table 3.

Table 3: Review of Construction handoff to C&Q

Summary of review of Construction handoff to C&Q
Too much late, ad hoc, reactionary planning
A need for C&Q to join the dots with Construction (and other units)
A need to have and honour the "next customer mindset"
A requirement to have "value" discussions, engagement, and transactions
Teams should work from a shared "meta" board and plan

Table 3 presents issues occurring early in the project; the primary area of concern being an absence of integration of construction and C&Q in the handoff of systems. Construction were focusing on achieving client signoff of completed systems. However, the next customer in line was C&Q and their request was neither made explicit nor considered.

Table 4 reflects on issues in the entire C&Q process. The interviews and focus group workshop were conducted after project completion.

Table 4: Issues in the C&Q Process

Issue theme	Detail of the problem
Incomplete handoff from construction	Systems were being split and partially handed over necessitating C&Q engineers to engage with craft personnel to complete systems
Continuing change	Change was still being introduced rendering it impossible for construction to handover a completed system on schedule
Incomplete design	Due to the extent of change, design was still taking place while C&Q were waiting for the system to be completed
Documentation review issues	Issues were being noted in approval cycles that were not picked up in client review phase; this resulted in multiple documentation cycles
Absence of next-customer awareness	Accruing from late design changes, C&Q were now uncertain of what the completed handoff from construction would look like
Teams resourcing	Designers had transitioned from design to the Delivery Teams resulting in inadequate design resourcing to respond to new change

The primary issue in C&Q (Table 4) was incomplete and untimely system completion handoffs from construction. These handoffs were further delayed due to the amount of change so late in the construction phase. This issue was further exacerbated by insufficient design resources to accommodate the extra unexpected scope of work; design had been complete, and members of the design team had joined the C&Q Delivery Teams or were working on other projects. A secondary issue was the impact of late reviews and approvals on the documentation handover schedule.

Traditional CPM planning methodologies were being utilised to coordinate and manage workflow; the lack of look ahead planning was hindering predictability of workload and workflow. There was an absence of next-customer awareness; an example being equipment vendors booked to come to site with no preplanning or path-clearing in place to ensure all prerequisite tasks were identified and completed. A key finding, therefore, was the absence of clarity and communication between upstream and downstream players in the production process.

Challenges introducing LPS® in C&Q

Changes were implemented to alleviate the challenges and achieve better team alignment. All C&Q Delivery Team members received training on the functions of LPS®, why is was being introduced, and the expectations regarding work planning, constraint identification, huddle attendance, behaviours, and norms were communicated. Emphasis was placed on using all functions of LPS® as weekly work planning and measuring its success would provide an accurate reflection of the work that is being completed, thus leading to a precise indication of the status of each system regarding its completion and outstanding scope.

Table 5 presents the action research diary, interviews, and focus group discussions and highlights the challenges encountered and interventions applied.

Table 5: Challenges to LPS® Implementation and Interventions Applied

Challenge	Exhibited by	Intervention Applied
LPS® knowledge & awareness	Uncertainty of how to plan	LC education and Villego® Simulation Workshop conducted with teams
LPS® Facilitation & Behaviours	Poor facilitation skills & behaviours - fear at the tier morning huddles	Education & mentoring provided on best-practice huddle behaviours
Absence of Standard Work	Minimal ownership of actions allied to a willingness to be diverted onto other tasks	Creation of specific roles with escalation and support in place
Unwillingness to participate	Resistance to the change towards new work practices	Education provided and increased communication focus
Management Support	Unreliable & inconsistent support / leadership from management at early stages	LPS in C&Q was mandated from client & delivery management team directors & SLT
Firefighting to complete handoffs	Legacy issue of C&Q engineers going directly to construction craft persons to get tasks done. Much of this was unplanned reactive work leading to safety and quality risk	A resourced 'agile craft team' was created to remove the 'reactive tasks' from C&Q engineers. This mitigated safety and quality risk
Suitability of resource for roles	Poor organisation/structure of the team and allocation of work tasks.	By focusing on the process of LPS all were allowed prioritise value-adding work

Pull Plans were completed for all impending systems for each Delivery Team and were focused on aligning the WWP with the pull plan phase milestones. Workshops were held prior to each pull planning session to align the team with the reality of the documentation schedules; establishing the logic and sequencing of prerequisite activities was critical. The importance of clarifying the "Conditions of Satisfaction" (CoS) for each task in the milestone schedule was highlighted, as was getting each team member to contribute the constructing the WWP; the objective being to empower each member to take ownership of their own tasks. A critical intervention at this point was the weekly iterative cycle of providing live and accurate schedule updates to the scheduler and Project Manager. Table 6 presents the weekly calendar of events for aligning construction, C&Q, and client documentation team demands and deliverables.

Table 6: Weekly LPS® & Schedule Alignment

Construction & C&Q LPS Weekly Alignment					
Time	**Mon**	**Tue**	**Wed**	**Thur**	**Fri**
0830-0850	Construction Daily Huddle	Construction Daily Huddle	Construction Daily Huddle	Construction Daily Huddle	Construction Daily Huddle
0900-0920	C&Q Daily Huddle	C&Q Daily Huddle	C&Q Daily Huddle	C&Q Daily Huddle	C&Q Daily Huddle
0930-1000	Daily SLT Escalation	Daily SLT Escalation	Daily SLT Escalation	Daily SLT Escalation	Daily SLT Escalation
1130-1230	Constraints Analysis & Resolution Scrum	Constraints Analysis & Resolution Scrum	Constraints Analysis & Resolution Scrum	Constraints Analysis & Resolution Scrum	Constraints Analysis & Resolution Scrum
1400-1445	Documentation Alignment Scrum	Overall Schedule Phase Pull Plan Review– Construction / C&Q / Client Documentation	Documentation Alignment Scrum	C&Q Weekly Work Plan Coordination	Documentation Alignment Scrum
1500-1545	SLT Schedule update		Schedule 4 week lookahead	Construction Weekly Work Plan Coordination	P6 & LPS Alignment Session
1600-1645	Agile Craft Team Tomorrow Plan	Agile Craft Team Tomorrow Plan	Agile Craft Team Tomorrow Plan	Agile Craft Team Tomorrow Plan	Agile Craft Team Tomorrow Plan

The primary function of the schedule in table 6 was to create a routine by standardising the daily and weekly calendar of huddles, meets, and scrums. The schedule enabled flow and escalation by focusing attention on the most critical impending issues constraining workflow. The social interaction and verbalisation of 'asks' and 'gives' at the huddles and scrums was a critical enabler of change at this phase of the project.

Benefits of LPS® in the C&Q process

By measuring PPC alone, the weekly C&Q LPS® planning process brought increased stability over the 40-week LPS implementation time period, as indicated in Figure 2.

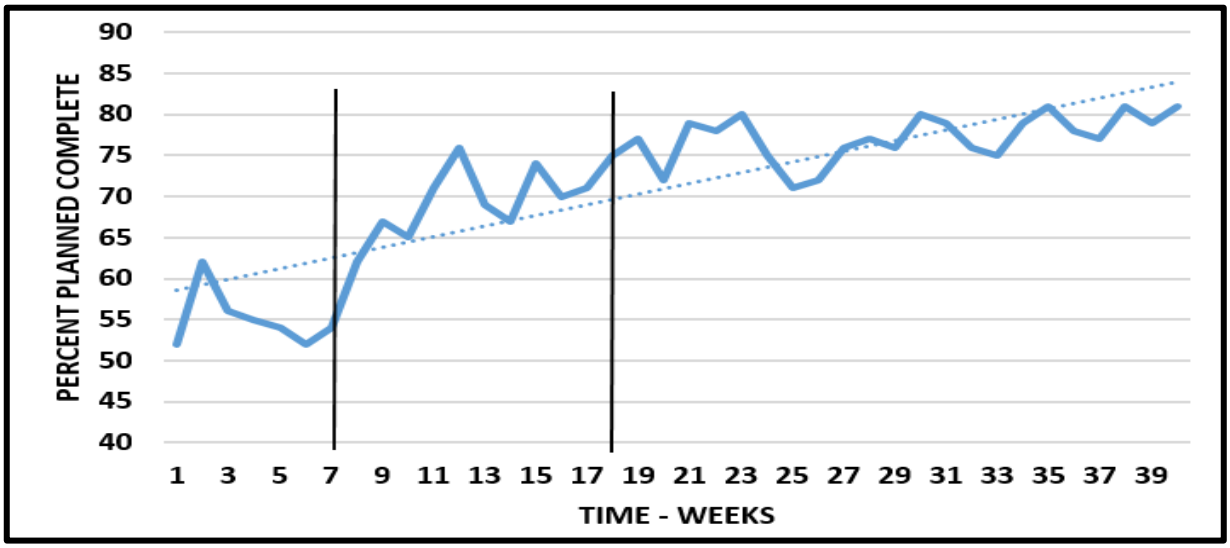

Figure 2: C&Q PPC over 40 weeks of Implementation

The immediate focus on removing insufficiently prepared or screened tasks from the workplan resulted in increased PPC on week two. However, this then regressed, and it needed the full impact of a three to four-week lookahead of preparing tasks for inclusion onto the weekly workplan before any degree of stability or predictability, and the accruing increase in PPC could be witnessed. From average of 55 percent PPC over the first seven weeks of the implementation, PPC steadily rose between weeks 8 to 17 averaging 69 percent. From week 18 to week 40 PPC stabilised at an average of 77 percent. This improved stability provided reliability and predictability in the planning process and as interim milestones were achieved client confidence improved. The trendline points to the improvement.

Although the greater project issue relating to scope addition and delayed handovers was outside the initial remit of LPS®, the impact of the unpredictability could now be highlighted; an absence of commitments, gaps in the look ahead plan, and the lack of a common understanding of what handover CoS were. The look ahead process, involving construction in constraint's identification, and engaging SLT in constraints resolution by introducing a 24-hour escalation process, all contributed towards greater reliability and predictability for the Delivery Teams around seeking commitments and planning their workload for the immediate weeks ahead. C&Q attended and contributed to construction's Pull Planning, Lookaheads, and Weekly Work Planning sessions and this increased visibility of when C&Q could expect a completed system handover. Heretofore, this visibility was

absent, and C&Q were working off P6 schedules that were not reflective of the live project status.

However, the greatest benefits emerged from weekly collection and examination of the RNC data; SLT examined the RNC and mitigations were implemented immediately to prevent reoccurrence of the highest impact RNC. Figure 3 presents the RNC for week 02.

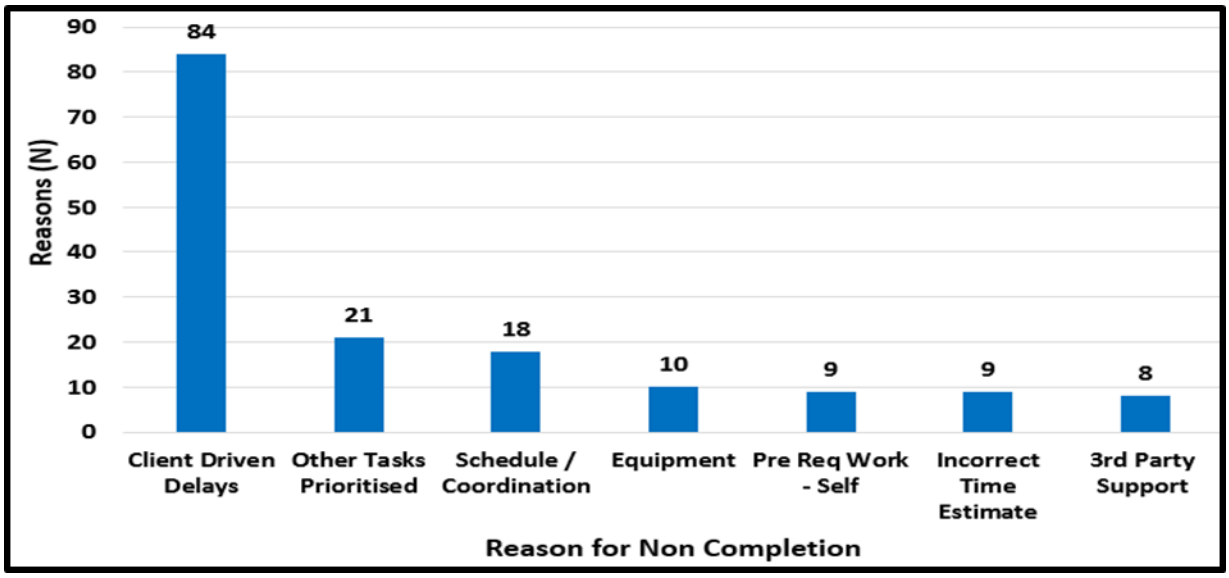

Figure 3: RNC for Week 02

Visualisation of the data channelled focus on the highest impacting issues. Accurate categorisation at the huddles provided greater detail into the constituent reasons for the highest impact RNC. The client placed great value on the RNC data and the analysis of the causes (not root causes at this stage). Figure 4 presents the 'deeper dive' into the detail of the 84 'Client Driven Delays' category.

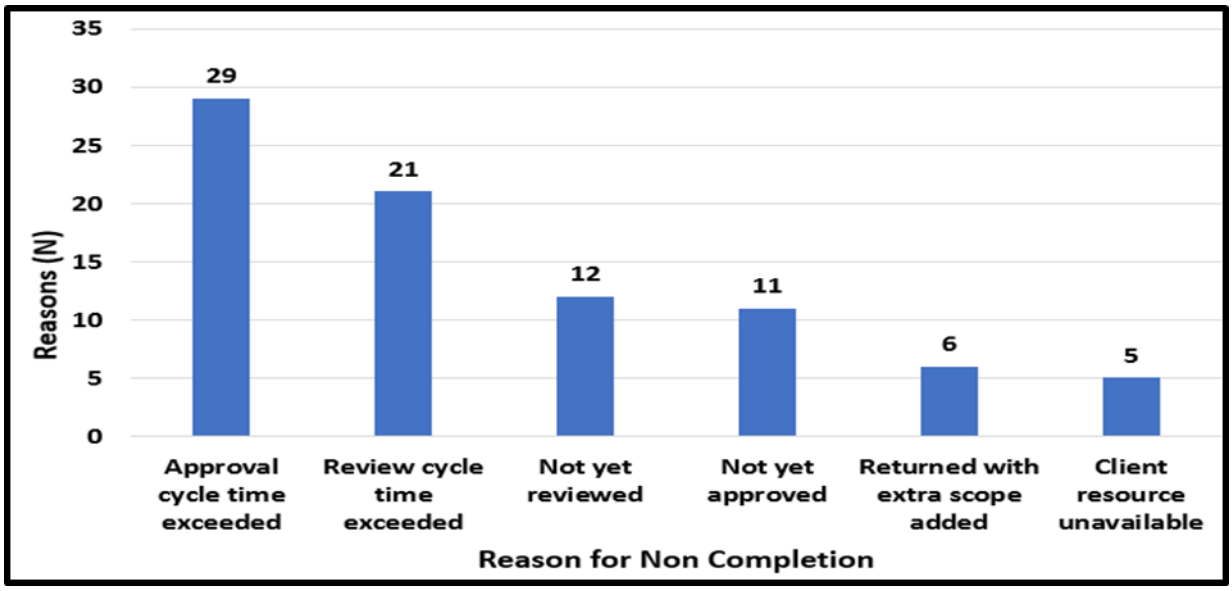

Figure 4: 'Client Driven Delays' RNC detail Week 02

Figure 4 has taken the highest category (Client Driven Delays n=84) from figure 3 and highlights the constituent sub-reasons. This level of detail allowed SLT to focus on

resolving the critical highest impacting RNC immediately. A specific intervention to the issues in figure 4 was the introduction of the 'Documentation Alignment Scrum' (noted in Table 6 and Table 7).

Possession of such RNC data would be valueless in the absence of implementing countermeasures that would ensure learning from the breakdowns. The Delivery Team leads received training on A3 Problem Solving and, in conjunction with the LPS facilitators, A3 reports were conducted weekly on the top-three highest-impacting issues. Some of the mitigations implemented are presented in Table 7.

Table 7: Mitigations Implemented

Interventions & Augmentations Applied
Weekly pull plan sessions per Delivery Team
Additional support on calibrations reviews
Key construction-completion tasks micro-managed through Scrum
Agile craft support-team daily huddle
External office design support
Request for additional IT support
Daily documentation review workshop
Client adherence to duration of approval cycles
Daily SLT escalation huddle sponsored by Director
Client securing schedule alignment with key vendor

The interventions and mitigations in table 7 emerged as countermeasures to weaknesses identified from the RNC data. Rapid implementation (endorsed by SLT) maintained momentum and flow for the Delivery Teams. Also, while the Delivery Teams were under considerable pressure it was satisfying for them to see SLT quickly responding to the issues and this fostered a positive working environment.

The clarification of the demand or "pull" from C&Q was also a weak link. It was unclear what C&Q required to be 'execution ready'. Therefore, it was difficult for construction to satisfy the unclear demand. Huddles were established to get the parties (customer and contractor and CMT lead) together to define what exactly was the request and to generate a clear priority list. This format cleared the path to enable tasks progress and scrum concepts and techniques were utilised to achieve completion of highest priority tasks. In effect, this was an 'agile' implementation of the Make Ready Planning function of LPS.

Stabilising Construction Turnover

Examination of the variances concluded that the handover from construction to C&Q was both unpredictable and unreliable as unfinished elements of scope are being passed on to C&Q and being defined as complete. The traditional mindset of passing-on incomplete handoffs to satisfy CPM schedule requirements, for example, stating that Mechanical Completion (MC) targets have been achieved by re-categorising the severity of punch items was delaying commissioning commencing execution of their testing. Confusion existed because of the lack of clarity around the CoS of the package and system handover. Consequently, C&Q found themselves expending time and effort clarifying the quality deficit, establishing outstanding scope, and organising craft to execute tasks. This issue was exacerbated by the fact there were so many work fronts and interfaces open. To resolve this, dedicated planning was focussed at the transition stage between construction

handover to C&Q. Scrum concepts and principles were introduced to address this shortfall. A backlog was created from issues raised at earlier daily huddles as shown in table 6. 'Agile Craft' teams were formed to rapidly resolve the backlog of electrical, mechanical, instrumentation, and automation tasks that would then transition the construction handoffs into an acceptable condition for the commissioning teams. This created the quality handoff while also protecting safety as the agile craft team were more familiar with the systems status than the commissioning engineers.

Discussion

The study clearly highlights the problems encountered at the later stages of construction project execution and proposes the advantage that Lean Construction thinking and tools can bring. The C&Q phase has both upstream and downstream inputs; upstream in the guise of completed systems handed over from construction, and downstream in the form of the client operations team reviewing, approving, and accepting completed documentation validating that the plant is commissioned as per current GEP requirements. The authors propose that traditional, siloed, transactional handover processes must be eliminated, and a holistic, end-to-end, single project mindset must be adopted by project leadership. In all aspects of construction project delivery both upstream and downstream voices must be expressed and heard. This requires behavioural change by both client and project delivery leadership however, it is incumbent that an environment exists where upstream and downstream voices can be spoken, listened to, and acted upon as early as possible in the engineering, construction, and commissioning phases. Collaboration and communication must be enabled between all parties; concepts from scrum and agile can contribute to resolving constraints and releasing minimum viable product to get the commissioning team progressing on systems.

Overall schedule

A key contribution of the LPS® implementation was the early determination of where the project truly stood regarding schedule milestones; LPS® focuses on production operations and utilising PPC data enables accurate weekly schedule status measurement. The lead LPS® facilitator (corresponding author) had come from another project so fresh eyes were able to candidly review the schedule status from an unbiased viewpoint. As C&Q is the last phase prior to client operations handover, it must be realised that any delay in handoffs will 'squeeze' C&Q. Therefore, Phase Milestones must be regularly updated with inter-discipline pull planning sessions to ensure early awareness of delay impacts. Of critical importance is the common understanding of the CoS of the handoffs. Both construction and C&Q must be aligned on the interpretation of what 'ready' and 'complete' means and the schedule must reflect this. Collaborative planning of downstream operations is a critical component of production planning; the interface between construction and C&Q should not just be a transactional handover on a date. It should be an interactive planning and production process discussed and designed in advance of the handover and overlapping with construction support into the C&Q execution phase.

LPS® Implementation

Previous LPS® research should be utilised as a foundation from which to build the implementation process. Rushed implementations of LPS® as 'rescue attempts' are doomed to fail as the overburdening of already overloaded teams with new working practices will provoke resistance to the new methodology. Established change management processes should be referenced and familiarisation with current LPS® best practice thinking should be communicated to the team members. Facilitation of the implementation by a knowledgeable champion is a critical enabler and all functions of LPS must be utilised as it is a 'series of interconnected parts.' The data and learnings generated from LPS® implementation should be utilised to identify weaknesses in the delivery process and, following detailed root-cause analysis, improvement projects should be implemented to promote a culture of continuous improvement.

Team Alignment

The entire team must be aware of the LPS® process and understand the interconnection of LPS® functions to ensure best results. Amongst the challenges on the case project was the different backgrounds of the team members; some were lead designers involved in the project from concept stage; some were experienced C&Q engineers familiar with commencing the commissioning process with a clean system completion handoff from construction; others were junior design and/or C&Q engineers that needed direction on the next tasks to be completed. Clarifying team behaviours, integration of all members, and determining what defines value to the team on the project should be established to ensure the team is aligned and focused on a common goal. Regular facilitated team pull planning sessions will assist keep the 'eye on the prize' and ensure engaged participation of all team members.

Client and Management Support

It is critical that both client and the SLT visibly support the implementation and are actively involved in responding to early escalation and resolution of constraints. Middle management should be trained in the soft skills necessary to empower their teams to participate in the collaborative planning process. The client also needs to visibly support the LPS® implementation and ensure that this support is consistent throughout and across their teams. Trust must be built within the 'whole' project team; SLT commitment, by exhibiting correct behaviours, is a critical enabler to supporting the implementation.

Stakeholder Alignment

The LPS® process cannot be limited within C&Q only; it must be extended across all stakeholders encompassing design, construction, key vendors, client documentation review teams, and client operations. The concept of 'next-customer' mindset must be established within the entire project supply chain. Collaborative pull planning develops the concept of 'next customer' to understand the interfaces in the project production process. The greatest challenge to address within the C&Q process is the creation of smooth and even workflow from construction system handover, to C&Q documentation generation, executions, client reviews and approval cycles, and final acceptance by the client operations team.

Iterative Learning and Action Cycle

A critical function of LPS® is learning from task failures and implementing countermeasures to ensure similar failure will not reoccur. However, the authors assert that management teams should not be waiting for RNC data to implement countermeasures; effort should be applied towards proactively designing production systems to enable smooth workflow without unnecessary interruption. A more holistic project-wide implementation of the principles of LPS®, allied to the adoption of a Lean mindset and behaviours, would proactively contribute to less RNC, higher PPC, and higher productivity.

Conclusion and Recommendations

The study highlights the issues arising from the TCPM mindset of transactional handoffs between siloed project phases. A 'single-project' mindset is called for necessitating behavioural change by both client and project delivery leadership. It is incumbent that an environment is created and inspired where upstream and downstream voices in the construction production process can be spoken, listened to, and acted upon as early as possible.

The application of LPS® to the C&Q phase of project execution can bring substantial advantage in the form of greater collaboration, increased visibility of workflow, and the resulting productivity, schedule alignment, safety, cost, and client value-add benefits. However, practitioners must be mindful that differences exist between LPS in design and construction and LPS® in C&Q. The C&Q process is the ultimate quality sign-off and handover to the client; it therefore becomes the 'Value' outcome of the entire design and construction phase. Therefore, late, incomplete, or substandard handover from C&Q to client constitutes 'Value-loss'. This research presents the opportunity a holistic, project wide LPS® implementation can offer to the C&Q process. However, it is incumbent on the client that best-practice, building on existing LC research, is followed in the implementation. Clients should sponsor team-wide and supply chain alignment that would foster a 'project-first' mindset towards the execution process.

SLT and middle management need on-going education in the philosophy and concepts of Lean and LC. The application of construction-sector-wide Lean thinking should be a key objective of both Government and private sectors. Extending LPS® across the entire Lean Project Delivery System is a step towards a more complete end-to-end LC implementation – this requires cultural change on both client and Architectural, Engineering, Construction and contractor sides.

Future research is recommended to examine the development of a single LPS® project implementation as opposed to phase by phase implementations. Research should also examine the creation of Standard Work and Work Structuring in the C&Q process; the application of Takt and Scrum principles should be evaluated as potential may exist for incorporating their concepts into the C&Q process.

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