

BEYOND LEAN PRODUCTION: INTERPRETING THE LAST PLANNER SYSTEM FROM A RESILIENCE ENGINEERING PERSPECTIVE

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ABSTRACT

The literature generally agrees that understanding the theoretical assumptions underlying the Last Planner System (LPS) is key to its successful implementation. However, most theoretical studies on LPS are based only on core Lean Production concepts and principles. Although valuable, this perspective alone does not fully explain why LPS is particularly suited to complex construction projects. To address this gap, this study analyses LPS from the perspective of Resilience Engineering (RE). The study draws on empirical evidence collected in an empirical study developed in collaboration with a Brazilian department store company that had implemented LPS in a large portfolio of projects. Sources of data included documents, semi-structured interviews, participant observation, and secondary data. The findings offer an alternative and complementary perspective for understanding LPS, with direct implications for practice. Specifically, this perspective supports: (i) more accurate assessments of LPS implementation; (ii) identification of LPS practices that should be emphasised when dealing with complex projects; (iii) recognition of complementary practices that should be integrated into the LPS; (iv) understanding informal practices that can facilitate the evaluation of their cost-effectiveness; and (v) setting as a basis for reviewing procedures and training programmes.

KEYWORDS

Last Planner System, resilience engineering, complex construction projects.

INTRODUCTION

Construction projects are widely recognised as complex socio-technical systems, whose performance depends on the interaction of social, technical, organisational, and environmental elements (Hendrick & Kleiner, 2001; Saurin & Rooke, 2020). These interactions are marked by uncertainty, variability, and frequent change, making construction projects particularly difficult to manage. Consequently, complexity management has been identified as a critical determinant of project success (Luo et al., 2017). Despite this recognition, complexity-related challenges persist due to dynamic external conditions, increasingly fragmented supply chains, and sustained pressure to reduce project lead times (Bakhshi et al., 2016).

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Traditional project management approaches have been criticised for relying on assumptions of linearity, predictability, and stability (Collyer et al., 2010; Koskela & Howell, 2002; Remington & Pollack, 2007). These assumptions are misaligned with the realities of construction projects, in which problems emerge, and plans frequently require adjustments. Insufficient consideration of complexity has been linked to poor performance outcomes, including project delays, cost overruns, quality issues, excessive rework, and low client satisfaction (Gemino et al., 2021).

Lean Project Management (LPM) has emerged as an alternative approach that seeks to better address complexity in construction projects (Tzortzopoulos et al., 2020). In fact, the lean construction community has increasingly acknowledged the role of complexity in project environments (Ballard & Tommelein, 2012; Bertelsen, 2002; Saurin et al., 2013). A central component of LPM is the Last Planner System (LPS), a hierarchical and collaborative production planning and control model (Ballard & Tommelein, 2021). LPS has been applied for more than three decades in construction projects across different countries and contexts. Several benefits have been associated with LPS implementation, including improved workflow reliability, enhanced coordination, and better schedule performance (Ballard & Tommelein, 2021).

These benefits are commonly attributed to the application of lean principles, such as increase process transparency, foster employee involvement (collaboration), and build continuous improvement (Hamerski et al., 2024a). Despite the extensive body of research on LPS, most studies focus on assessing implementation using technical audit tools, such as the planning best practice (PBP) index (see Castillo et al., 2018; Priven & Sacks, 2016; Viana et al., 2010). While useful, these tools offer limited insight into how LPS operates under conditions of variability and uncertainty.

Resilience Engineering (RE) offers a theoretical framework for understanding how complex socio-technical systems function and adapt under such conditions. Rather than focusing exclusively on failures or deviations from plans, RE emphasises everyday performance and the adjustments practitioners make to cope with changing conditions (Hollnagel, 2017a).

The increasing relevance of RE has been linked to the growing complexity of systems across several domains (Righi et al., 2015). Some studies on RE have been developed in construction. They have focused mostly on safety management (Melo & Bastos Costa, 2019; Peñaloza et al., 2020), disaster preparedness and recovery (Achour & Price, 2010), requirements management (Ransolin et al., 2020), supply chain management (Ekanayake et al., 2021), and analyses of resilience skills of frontline workers (Peñaloza et al., 2017).

Few studies have explicitly examined the relationship between LPS and resilient performance (RP). Hamerski et al., (2024b) examined how particular LPS practices align with resilience-related principles, whereas Hamerski et al., (2024c) investigated the gaps between planning-as-imagined and planning-as-done. While both studies provided important insights, they addressed resilience from partial and specific analytical perspectives. Therefore, there is still a lack of studies that analyse LPS through the lens of RE in a more integrated and comprehensive manner.

The aim of this work is to analyse the implementation of LPS through the RE theoretical lens, seeking to provide an alternative interpretation of this production and control model. This analysis is based on core RE concepts rather than specific principles. We consider that it is important to bring this topic to discussion within the IGLC community, given ongoing debates about how production planning and control systems can be adapted to deal with the characteristics of complex socio-technical systems.

RESILIENCE ENGINEERING

Resilience is a multidisciplinary concept that has been applied scientifically for around five decades, with its first widely recognised use commonly attributed to Holling's (1973) work on ecological systems. Since then, resilience has been studied in several domains, including psychology and critical infrastructures such as water supply, transportation, and telecommunications. The construction industry is closely linked to these infrastructures, which explains the growing interest in resilience in this sector.

Early studies on resilience in construction predominantly focused on technical solutions, such as designing structures to withstand extreme events. More recently, research has shifted towards an organisational perspective, adopting the socio-technical system as the unit of analysis. This broader view considers technical, human, organisational, and external factors (Hollnagel, 2017a).

Resilience has been systematically studied within the field of RE, which focuses on developing theories, methods, and tools to manage organisations' adaptive capacity (Nemeth & Herrera, 2015). Although the term "RE" was introduced in the early 2000s, the approach gained wider academic visibility following the first international symposium on the topic in 2004, organised by the Resilience Engineering Association.

RE is concerned with observing, assessing, and influencing RP (Nemeth & Herrera, 2015). RP is the ability of a socio-technical system to adjust its functioning before, during or after changes and disturbances to maintain required operations under expected and unexpected conditions (Hollnagel, 2017b).

RP has two main sources. The first arises from the system's intrinsic self-organisation or self-regulation, which occurs without the need of a centralised or formal control (Disconzi & Saurin, 2022). The second source derives from deliberately designed actions that create conditions or allocate resources to enable the system to cope with variability (Disconzi & Saurin, 2022).

An example of designed RP is the introduction of additional resources (i.e., slack), whether financial, capacity-related, or of another nature. These extra resources enable the system to better adapt to unexpected situations. Moreover, designed RP supports RP arising from self-organisation or self-regulation. For instance, when individuals need to act in an improvised manner or under pressure, the availability of support resources significantly facilitates their actions.

The different sources of RP demonstrate that it is an emergent property of systems (Saurin & Gonzalez, 2013). Emergent properties are characteristics that are not present in the isolated parts of a system but arise from the interactions among those parts.

Given its emergent nature, a major challenge for RE is to understand how RP manifests in everyday work. The basic idea is to understand how RP emerges and, subsequently, identify ways to influence it. This is done by comparing work-as-imagined (WAI) and work-as-done (WAD). WAI refers to the various assumptions, explicit or implicit, that people have about how work should be done, often prescribed in procedures or standards, whereas WAD refers to how something is actually done, either in a specific case or routinely (Hollnagel, 2017b).

A central assumption in this context is the inevitable existence of differences between WAI and WAD. Rather than being treated solely as deviations or failures, these differences represent an opportunity for learning, as RP often manifests in this space through the adaptations and adjustments (typically informal) required to fill these gaps.

A resilient system is typically characterised by four abilities (Hollnagel, 2017a): (i) respond: it refers to the system ability to adapt to regular and irregular events (challenges and opportunities) in an effective and flexible way; (ii) monitor: it means that the system is able to monitor internal and external conditions that may develop into challenges or opportunities; (iii) learn: it implies that the system is able to learn from past events by understanding why things go right and why

they go wrong.; and (iv) anticipate: it indicates that the system can anticipate challenges and opportunities in the near and far future.

RESEARCH METHOD

This work is based on empirical studies developed in partnership with a 25-year-old department store (company A) from Brazil, focused on the sale of apparel. At the time this study was conducted, this company had 385 stores, more than 20,000 employees, and a portfolio of 40 to 60 projects a year. These projects have been delivered in several states in Brazil and also in other Latin American countries.

Company A was chosen for this study due to the following reasons: (i) its well-developed LPS-based planning system; (ii) the high level of uncertainty of its refurbishment projects; and (iii) a long-term relationship (exceeding five years) with the research institution, making easy the access to a wide variety of data. External validity was addressed through the careful selection of the case (Flyvbjerg, 2006), which presented a well-developed LPS implementation and clear indicators of complexity.

Company A has a Department of Architecture and Engineering (DAE) that manages the design and production stages of projects. DAE is responsible for project management, hiring, and supplier coordination. Several types of suppliers work under the supervision of project managers from this department, including design companies, general contractors, construction management companies, specialty subcontractors, digital system suppliers, and furniture suppliers.

The research comprised four main activities: (i) a preliminary literature review; (ii) an in-depth understanding of company A's production planning and control system; (iii) analysis of the results achieved through the system's implementation in three projects of the company; and (iv) analysis of the implementation process using RE as the theoretical lens. Sources of data for this analysis involved documents, semi-structured interviews, participant observation, and secondary data (Table 1), which enabled data triangulation.

Table 1: Sources of evidence used in this research study

Source of evidence	Detail	Project 1	Project 2	Project 3	Count	Total
Document analysis	Planning handbook, product development protocol, portfolio long-term plan	-	-	-	3	21 documents
	Contract	1	1	1	3	
	Design drawings	1	1	1	3	
	Budget	1	1	1	3	
	Long-term plan	1	1	1	3	
	Look-ahead plan	1	1	1	3	
	Short-term plan	1	1	1	3	
Semi-structured interviews	Handbook clarification ($\approx 1h$)	-	-	-	3	6 interviews (6h)
	Project characteristics ($\approx 1h$)	1	1	1	3	
Participant observation	Production system design meetings ($\approx 2h$)	6	7	7	20	98 meetings ($\approx 158h$)
	Look-ahead meetings ($\approx 2h$)	13	12	12	37	
	Short-term meetings ($\approx 1h$)	14	12	12	38	
	Lessons learned meeting ($\approx 2h$)	1	1	1	3	
Secondary data	Planning indicators database	1	1	1	3	6 records
	Visual board	1	1	1	3	

Two types of semi-structured interviews were conducted in this study: the first focused on clarifying the handbook, which outlined the intended functioning of the planning system, including planning levels and their objectives, participants' responsibilities during planning meetings, among others. The second examined the characteristics of the studied projects, such as project type, area, estimated duration, and main construction technologies.

Regarding participant observation, the first author attended the meetings as an observer only and had no authority for any type of decision-making impacting on production planning and control. Observations and insights were recorded in a field diary. To mitigate potential bias, key elements of participant observation were followed, such as going to the place where the action was taking place, building rapport with the participants, and spending enough time interacting to get the necessary data (Jorgensen, 1989).

Data from all sources were subjected to a thematic analysis, guided by the stages proposed by Pope et al., (2000). This involved coding the data into themes based on the study's theoretical perspective, i.e., RE core concepts.

The empirical study adopted embedded units of analysis. Table 2 summarises the three projects included. These were selected based on the following criteria: (i) a common typology - refurbishments within operating shopping malls; (ii) the willingness of project managers to participate; and (iii) projects ongoing during the research period.

Table 2: Overview of the three projects

Project	Area (m ²)	Type	Location	Estimated duration (days)
1	1,063.00	Refurbishment	Shopping mall	120
2	1,402.00	Refurbishment	Shopping mall	120
3	2,027.00	Refurbishment	Shopping mall	90

These projects had characteristics of complexity, as described below:

(i) high level of uncertainty: the locations where stores were built were occupied by other stores, making difficult the precise collection of data on existing buildings during design. Several problems emerged post-dismantling and stripping activities;

(ii) short project durations: project durations of 90 to 120 days resulted in tightly coupled processes - this condition amplified the impact of unexpected events;

(iii) large number of stakeholders working in relatively small areas: a wide diversity and large number of elements (e.g., various crews executing different processes) in close physical proximity increased the likelihood of unanticipated interactions;

(iv) shared resources with other projects: some managers were responsible for multiple projects in parallel, which restricted their availability and created opportunities for common-mode failure and hidden interdependencies; and

(v) strong influence of the external environment: projects were executed in operating shopping malls, intensifying interactions with external actors and conditions.

RESULTS

OVERVIEW OF COMPANY A'S PRODUCTION PLANNING AND CONTROL SYSTEM

The production planning and control system of company A was divided into three hierarchical levels: (i) production system design (PSD) and long-term planning; (ii) look-ahead planning; and (iii) short-term planning. Several indicators were included in the system, such as lead time deviation (milestones), constraint removal index (CRI), percentage of plan completed (PCP), and causes for the non-completion of work packages.

A clear difference between this system and the original LPS proposed by Ballard & Howell, (1998) was the inclusion of a pre-construction planning stage, named production system design (PSD) and location-based planning at the long-term planning level. In company A, PSD encompassed different decision categories: identification of stakeholders' requirements, division of the project into work zones, definition of the construction sequence, estimation of production capacity, and planning of logistics operations and layout. The long-term plan was represented using a line of balance and other visual tools, in order to facilitate decision-making during planning meetings.

The planning process began with meetings for the development of PSD. Given the short duration of the projects, the identification and removal of constraints were initiated during those initial meetings. At the end of this stage, a look-ahead planning meeting was held, with a planning horizon corresponding to the total duration of the projects. After execution began, look-ahead planning meetings were held fortnightly with a one-month planning horizon. Short-term planning meetings took place weekly. At the end of the short-term meetings, a certain time was allocated to the management of emerging constraints. Each meeting typically lasted between one and two hours, fostering collaboration among different stakeholders.

RESULTS ACHIEVED THROUGH SYSTEM IMPLEMENTATION

The implementation of the system increased the effectiveness of the planning and control process, which is supported by planning and control metrics indicators (Table 3). The projects were delivered on time, with one completed 15 days ahead of the original deadline. The PPC and the CRI remained stable, close to or above 80%.

Table 3: Overview of project indicators

Planning level	Detail	Project 1	Project 2	Project 3
Long-term planning	Time deviation (days)	0	0	-15
	Average CRI (%)	90%	82%	85%
Look-ahead planning	Average number of constraints to remove in each planning cycle	10	13	11
	Main categories of constraints	Construction design: 26% Materials: 17% Workers: 17%	Construction design: 31% Documents: 18% Materials: 15%	Construction design: 29% Materials: 22% Workers: 13%
	Average PPC (%)	84%	76%	93%
Short-term planning	Main categories of causes	Planning: 49% Workers: 23% Materials: 14%	External causes: 29% Planning: 24% Workers: 23%	Planning: 43% Design: 36% Workers: 7%
		Modification of plans: 18% Delay in delivery of interdependent work package: 16% Absenteeism: 11%	Covid-19: 24% Modification of plans: 15% Overestimation of productivity: 15%	Design conflict: 35% Modification of plans: 28% Poor specification of work packages: 14%
	Causes (detailed)			

ANALYSIS OF THE IMPLEMENTATION PROCESS THROUGH RE LENSES

During the study, several practices were observed as important through the RE perspective. These practices can be grouped into three categories: (i) LPS practices; (ii) formal practices not explicitly part of the LPS; and (iii) informal practices (i.e., practices that were not prescribed in the company planning and control handbook).

Regarding LPS practices, hierarchical planning proved particularly important for dealing with uncertainty. By postponing certain decisions until more reliable information became available, plans were progressively detailed and adjusted according to on-site conditions. This gradual refinement enabled the planning system to remain flexible to incorporate emerging issues.

A practice connected to hierarchical planning was the overlap of planning horizons at the look-ahead level. Adopting a planning horizon longer than the re-planning frequency (e.g., four weeks versus two weeks) allowed for redundant checks, increasing the likelihood that constraints would be removed on time. These redundant checks represent a specific form of slack, a central component of RE.

Collaborative meetings also played a significant role in addressing uncertainty. These meetings brought together people with different skills, experiences, and perspectives, supporting shared situational awareness and more informed decision-making. From a RE perspective, people are not viewed as sources of error or unwanted variability, but as essential resources whose adaptive adjustments and compensations enable successful performance under varying conditions.

The systematic use of both lagging and leading indicators (e.g., time deviation, CRI, PPC), together with visual devices (e.g., work trajectories that crews should follow, developed on PSD), supported continuous identification of performance variations. These practices enabled short feedback and control, with weekly short-term planning representing the most frequent formal control cycle. Monitor is one of the main abilities of a resilient system, and may trigger actions that support RP (Hollnagel, 2017a).

Another important practice observed was the intentional decision to underload resources to increase the reliability of the planning system. This type of slack (capacity buffer) was important for dealing with uncertainty, especially in processes with high variability. For instance, at the short-term planning level, some work packages with an estimated duration of 2 days were scheduled for 3 days. This was usually done for some work packages that were not predecessors of other packages in the same week.

The systematic identification and removal of constraints was also an important practice. Constraints included not only material and labour availability, but also information, space availability, access conditions, and others. Therefore, this practice supported anticipating resource gaps and opportunities, a well-known ability of resilient systems (Hollnagel, 2017a).

Similarly, the use of a backlog of tasks in short-term planning served as a contingency mechanism, allowing alternative tasks to be executed when planned activities could not proceed as expected. This practice increased the system's flexibility and reduced the impact of unforeseen disruptions.

Learning was supported through the systematic identification and elimination of the causes of problems. This practice focused on analysing situations where things went wrong (e.g., when a work package was not completed).

Beyond the LPS, other approaches were also observed within the company A's formal production planning and control system. PSD, for instance, contributed to RP by incorporating contingency planning at a strategic level through the development of alternative long-term plans. Likewise, the use of location-based planning helped manage uncertainty through properly designed time buffers.

Finally, informal practices were also observed. Adopting RE as a theoretical perspective directs attention to how work is actually done, making informal practices visible. Although often underexplored, these practices can play a critical role in system performance. One example was the creation of informal communication channels, such as a multi-platform messaging app group. This app was used to exchange information, ask questions, and promptly address constraints that required collaborative effort. These interactions enhanced situational awareness and facilitated rapid coordination among project participants. Another informal practice was working overtime when necessary to recover delays or complete critical activities, providing additional capacity to maintain workflow continuity.

DISCUSSION

The three projects analysed achieved positive outcomes, as reported in the Results section, including on-time delivery and high average PPC. While multiple explanations for such outcomes are possible, this paper interprets these results through the lens of RE. In fact, this paper contributes to a new understanding of the LPS based on that approach. This differs from previous studies that explained LPS functioning based on the lean production philosophy (Ballard & Tommelein, 2021; Hamerski et al., 2024a).

Some insights from this new LPS account must be emphasised. While formal LPS practices provide structure, other formal and informal practices also help to address complexity in construction projects. Therefore, the successful implementation of LPS requires a balance between adherence to core principles and flexibility to incorporate and adapt practices to project-specific conditions. This interpretation is consistent with the findings of Hamzeh et al., (2012), who suggested that lookahead planning goes beyond a purely technical process of constraint removal. In their study, constraints are addressed in a situated manner, depending on actual resource availability, informal decisions, and emerging priorities, highlighting the role of local adjustments in coping with variability.

This paper also has some practical contributions. The use of RE lenses acknowledges the possible coexistence of different practices and may support a more realistic assessment of LPS implementation. Similar findings have been reported in studies of lean production systems in manufacturing (Gayer et al., 2022). This perspective helps practitioners identify which LPS practices should be prioritised when dealing with high levels of complexity, particularly in contexts characterised by uncertainty. It also enables the recognition of complementary practices that may be incorporated and makes informal practices more visible, allowing reflection on their contribution and cost-effectiveness. By bringing such practices to light, they can be better aligned with the formal planning system, potentially reducing wasteful overlaps and revealing gaps that can inform adjustments to procedures and training programmes.

When examined from an RE perspective, the LPS also reveals some limitations. One limitation is its strong emphasis on production, often at the expense of other functional dimensions. Another concern is the relatively low frequency of control, which may hinder timely responses to emerging problems. This is different from other complex socio-technical systems, such as healthcare and aviation, where control is performed in much shorter cycle times (Hollnagel, 2017a). In addition, LPS performance indicators tend to capture when activities take place rather than how they are carried out. Finally, learning is largely triggered by undesired outcomes (i.e., things that went wrong), with limited attention to understanding why things went right.

CONCLUSIONS

This paper presents the results of a research study which aimed to analyse the implementation of the LPS through RE theoretical lens. This study is grounded in a literature review and insights

from empirical studies conducted within a department store company in Brazil, which applies LPS across a large portfolio of projects every year.

The main conclusion of this study is that, when interpreted through a RE perspective, the LPS can be understood as a mechanism that supports RP in construction projects. However, it is not sufficient on its own to fully address complexity, and therefore needs to be complemented by other practices, whether formal or informal.

Another conclusion of this study is that a portion of the performance associated with the LPS remains structurally invisible to the system itself. While the system is designed to stabilise production through reliable planning, the findings show that its effectiveness also depends on adaptations - such as quick management of constraints through a multi-platform messaging app - that are neither explicitly represented nor systematically tracked. These adaptations are not random, but enabled by the planning structure, allowing teams to cope with complexity. However, because they remain outside the system's formal logic, their contribution is neither fully understood nor consistently managed.

The study also identifies limitations of the LPS when analysed from an RE perspective, which suggests opportunities for future research. Future studies could investigate how LPS can be adapted to better integrate non-production dimensions, such as safety and quality, and analyse these adaptations from an RE perspective. In addition, research is needed to explore shorter control cycles or other mechanisms to enable the identification of performance variation and allow timely actions to support RP. Further studies could also focus on developing performance indicators that capture how work is carried out, rather than only when it occurs, as well as expanding learning mechanisms to include both successful and unsuccessful outcomes.

One limitation of this study is that it is based on the implementation of the LPS within a single organisation. In different contexts, other practices may be observed and additional insights obtained. Therefore, a comprehensive understanding of the LPS's strengths and weaknesses in light of RE may not have been fully achieved.

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