Formoso, C. T., Tommelein, I. D., Barth, K. B., & Coelho, R. V. (2025). Takt control: Core concepts and preliminary propositions. In O. Seppänen, L. Koskela, & K. Murata (Eds.), *Proceedings of the 33rd Annual Conference of the International Group for Lean Construction* (IGLC33) (pp. 424-435). https://doi.org/10.24928/2025/0110

TAKT CONTROL: CORE CONCEPTS AND PRELIMINARY PROPOSITIONS

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ABSTRACT

Takt production refers to a construction planning and control method rooted in core concepts and principles of Lean Production. Several benefits have been associated with its use, including increased work efficiency, simplified control procedures, improved plan reliability, and reduced project lead times. Nevertheless, takt production deserves further study to fill existing knowledge gaps. First, many studies report on the successful use of takt production in construction projects, but they overlook takt control and the metrics required to assess project performance. Second, few studies on takt production in construction discuss the method's theoretical foundations and the need to make the method suit the level of complexity of any particular project. This study has developed a set of preliminary propositions for implementing takt control in construction projects, considering projects as complex sociotechnical systems. These propositions are grounded in core Lean Production concepts and principles and the requirements of control systems designed to manage complexity. Examples of takt control practices identified in case studies are used to illustrate these propositions.

KEYWORDS

Takt planning, takt production, takt control, Last Planner System®, complex systems.

INTRODUCTION

Takt (expressed in units of time) plays an important role in the coordination of activities in various industries, including manufacturing, transportation, information technology, and music (Haghsheno et al., 2016). It sets a regular beat for production so that work can flow in time and space (Frandson et al. 2013; Tommelein et al., 2022) to meet customer demand (Hopp & Spearman, 2008). Takt is a fundamental element in Just-in-Time production, one of the two pillars of the Toyota Production System (the other pillar is Jidoka, aka. autonomation).

The literature presents takt as a key element in production planning and control for various types of construction projects, such as residential buildings, linear infrastructure, cruise ship cabin refurbishment, and offshore wind farm construction (Tommelein et al., 2024). Some companies use takt planning and control (so-called "takt production") to augment the implementation of the Last Planner System® (LPS®) of project planning and control (Ballard & Tommelein, 2021), as both are grounded in core concepts and principles of Lean Production, whereas other companies use takt production as a stand-alone method (e.g., Riekki et al., 2024).

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Benefits of implementing takt production in construction, as in other industry sectors, include increased work efficiency, simplified control procedures, improved plan reliability, and reduced project lead times (e.g., Haghsheno et al., 2016).

Despite reports of successful use of takt production in construction, little attention has been paid to takt control and metrics. While plans establish targets and the course of action to reach them, control is the process that ensures the course of action is maintained and the desired goals are achieved (Laufer & Tucker, 1987). Reports on takt production in construction seldom discuss the theoretical foundations of takt or how takt methods need to be adapted to construction settings where projects are typically highly complex. Construction projects are complex sociotechnical systems, characterized by a large number of distinct parts that interact dynamically (Baccarini, 1996) and high variability in processes and goals (Williams, 1999). Furthermore, some reports refer to the use of metrics that emphasize strict adherence to the takt plan, an approach called "management by adhering." This all-too-strict approach was critiqued by Koskela and Howell (2002), who suggested an alternative approach known as "management as learning" or "management as organizing" (Johnston & Brennan, 1996). The study of takt control and metrics deserves to get more attention.

This paper reports on research to develop a set of preliminary propositions for implementing takt control in construction projects, grounded in core Lean Production concepts and principles and the requirements of control systems designed to manage complexity. Preliminary design propositions share similarities with hypotheses or propositions frequently used in descriptive sciences. However, unlike hypotheses—which are explanatory in nature—preliminary design propositions, once tested, can guide the development of prescriptive knowledge, expressed through design principles and prescriptions.

LITERATURE REVIEW

PRODUCTION SYSTEM DESIGN BASED ON TAKT

In manufacturing, the takt at which a production line operates takes into account the market demand for a product and the available production time. The takt value computed based on customer demand (customer takt) defines the pace necessary to meet demand. This takt must then be met, given capacity constraints of production lines or cells (operational takt) (Hopp & Spearman, 2008). In construction, takt values are generally determined by dividing a project into phases and processes, and dividing work spaces or areas into so-called takt zones that represent work batches.

Of note is that production systems can be viewed from various perspectives and at various levels of abstraction. Shingo's (1988) conceptualization presents production phenomena along two orthogonal axes: (1) the axis representing the process perspective that focuses on the object of work (materials or products) advancing through different stages of production, and (2) the axis representing the operation perspective that focuses on the subject of work (workers or equipment) moving along time and space, possibly in a cyclical fashion. Shingo (1988) and others (e.g., Rother & Shook 1999; Modig & Ahlstrom, 2012) argued that, to improve production, processes should take precedence over operations, because processes result in delivering a product or service to the end customer.

According to Shingo's conceptualization, processes and operations are two perspectives from which to observe a single phenomenon. Taking on a product flow perspective of production phenomena, Monden (2012) refers to the time required to complete a single process from start to finish as the cycle time (others might call this lead time or throughput *time*). Taking on an operation perspective, Alvarez and Antunes Jr. (2001) define cycle time differently, namely as the time between the start and end of producing two successive units of the same product (or batches) under conditions of constant supply (others might call this throughput *rate*).

Of course, processes and operations intersect when a worker or machine performs a task that is necessary to produce a product (Isatto & Formoso, 1998). As operations supply parts needed in a process, the parts' rate of supply—what Alvarez and Antunes Jr. (2001) call cycle time—must match the takt at which process steps need them. These two perspectives highlight different opportunities for improving production systems. For instance, specific methods (standardized work) or concepts (cycle time slack) can improve operations but may not apply directly to processes from a product perspective (Martin & Bell, 2011).

When implementing takt production, managing cycle time (viewed from the operations perspective) plays a key role in synchronizing work of different crews and machines (Vargas et al., 2023). This synchronization encourages collaboration among crews, enabling information sharing and reducing the need for buffers. Takt production can also drive process- and product standardization (Martin & Bell, 2011). Strategies such as standardized work and the use of preassembled components or kits are often implemented to support takt production.

The overarching goals of takt production include reducing project duration and increasing efficiency. These goals are supported by intermediate objectives, such as reducing batch sizes, eliminating rework, avoiding crew stacking, synchronizing workflows, simplifying control procedures, and improving transparency. Alvarez and Antunes Jr. (2001) identified additional benefits of takt production: (1) it connects product flows and operations flows, creating a more integrated improvement effort, and (2) it enables the sharing of information or even activities between crews, as buffers between crews are substantially reduced. These two benefits demonstrate that takt production goes beyond managing routines; it serves as a driver for continuous improvement, acting as a catalyst for implementation of related lean construction practices (also see Tommelein & Emdanat 2022). Certain conditions must be met to achieve these goals. Eliminating quality problems is paramount—e.g., andon systems force an immediate response to address defects or inefficiencies during production. Additionally, a multiskilled and flexible workforce can prevent disruptions in production due to issues such as labor shortages or ensure resilience and adaptability in the face of unexpected events. Furthermore, extending takt production principles to the design phase and auxiliary project functions—such as quality control, material supply chains, and prefabrication facilities—offers additional benefits. Thus, takt production not only serves to set the beat of production processes and operations but also acts as a driver of continuous improvement throughout all phases of project delivery.

PREVIOUS STUDIES ON TAKT CONTROL

An increasing number of studies focus on the implementation of takt production for construction project delivery in various countries, including the US (e.g., Frandson et al., 2013; Linnik et al. 2013), Germany (e.g., Binninger et al., 2017; Haghsheno et al., 2016), Finland (e.g., Lehtovaara et al., 2019), and Brazil (e.g., Vargas et al., 2023) to name but a few. The German Technical Takt Planning and Takt Control approach (Dlouhy et al., 2016), a three-level approach to planning (macro, norm, and micro levels), addresses challenges of managing construction projects. It is unclear how this approach addresses the conflict between the level of detail suited for a long-term takt plan versus the required level of detail for the execution-level takt plan, due to the high degree of uncertainty that usually exists in construction projects. At the strategic level, particularly for highly complex projects, the initial focus should be on analyzing the overall project strategy, rather than on creating overly detailed takt areas or setting daily or hourly targets. Moreover, by establishing takt areas that align with the appropriate level of planning, crews can be granted a certain degree of autonomy, enabling them to effectively respond to emerging events.

Takt control requires mechanisms for monitoring execution and adapting to changes. Daily huddles (short on-site meetings) and control panels have been suggested as mechanisms to get alignment among stakeholders (Lehtovaara et al., 2019). Furthermore, Binninger et al. (2017) proposed adjustment mechanisms to handle deviations in takt plans. Several metrics, such as flow efficiency and punctuality (Riekki et al., 2024) and perfect handover (Haugen et al., 2020), have been proposed for takt control. Although these metrics are useful for assessing the effectiveness of takt plans, they do not directly address corrective actions needed for achieving the goals established in takt plans. By contrast, LPS® metrics offer insights for analyzing planning reliability, identifying root causes of non-completion of work packages and reducing variability by addressing constraints early. The use of these metrics for takt control depends on the effective integration between LPS® and takt production.

An alternative to using plan adherence indicators is to use metrics that identify the root causes of deviations or anticipate risks of deviations, based on learning from normal work—a key strategy to achieve resilient performance in complex systems (Hollnagel, 2017). In other words, performance measurement systems in takt production should aim to make complexity visible so that teams can learn (Barth & Formoso, 2024) and adjust plans as needed.

Visual management practices enable managers and frontline workers to gain a clear, shared understanding of the status of production systems, thereby supporting decision making in complex environments (Grönvall et al., 2021). Digital technologies, such as BIM and IoT, facilitate progress tracking and allow for comparisons of planned versus actual outcomes. For instance, Alhava et al. (2019) used real-time digital tools to control making-do and task diminishment, with the aim of improving quality and achieving takt plan goals.

Despite the significant progress made in understanding and implementing takt control, challenges remain in addressing variability and integrating non-repetitive activities. Continuous improvement, supported by digital technologies and leading and lagging indicators, is crucial for enhancing takt control in complex construction projects.

DEALING WITH COMPLEXITY IN CONSTRUCTION

In construction projects, as in other complex systems, production management methods and practices must be able to cope with a high degree of unexpected variability. Managerial systems must have the capacity to (1) respond (knowing what to do), (2) monitor (knowing what to look for), (3) learn (knowing what has happened), and (4) anticipate (knowing what to expect) (Hollnagel et al., 2017). Hollnagel et al. (2017) named these the four potentials of resilient systems. A well-known approach to mitigating the impact of variability is to use buffers (Hopp & Spearman, 2008). However, integrating buffers into takt plans requires meticulous design. Buffers should be appropriately sized and strategically positioned. Over time, as reliability increases, it may become possible to gradually reduce buffers to a more acceptable level as part of continuous improvement.

Although traditional types of buffers, such as time, inventory, and capacity are useful for dealing with variability, several other types of slack can be used to deal with complexity (Saurin & Werle, 2017). Compared to buffers, slack is a broader concept that encompasses a wide range of strategies for protecting a production system from variability that cannot be removed (Browning & de Treville, 2021). Slack can be implemented by using different resources and strategies that allows an organization to adapt successfully to internal pressures for adjustment or to external pressures for change in policy (Bourgeois, 1981). Slack resources can include inventory, time, space, equipment, people, finances and information (Saurin & Werle, 2017). The strategies for implementing slack are classified as (1) flexibility, (2) redundancy, and (3) margins of maneuver (Formoso et al., 2021).

Several types of slack can be introduced by using Lean Production planning and control methods. For instance, margins of maneuver are frequently adopted in production system design, LPS® introduces slack in the form of redundancy and flexibility, and time and capacity buffers are often used in takt planning. Many other types of slack can be explicitly used to improve reliability of takt plans (Formoso et al., 2021), based on the nature of complexity that exists in each type of project (Tommelein et al., 2024).

RESEARCH METHOD

The authors conducted two parallel activities over six months: (1) analysis of secondary data from three construction projects that used takt production with LPS®, and (2) theoretical discussions within the research team to develop prescriptive knowledge related to takt production. Two of the authors were directly involved in the three empirical studies, in which production planning and control models were developed using a design science research approach. Several takt control practices were developed, implemented, and assessed in collaboration with construction companies. While some practices were implemented by multiple companies, they are described only once in this paper to avoid redundancy.

The first empirical study was conducted at Company A (Formoso et al., 2022), a Uruguayan construction firm with a diverse portfolio that includes residential buildings, hospitals, industrial plants, bridges, and water and sewage systems. This study focused on linear infrastructure projects using a flow-based version of LPS®. The second study took place at Company B (Vargas et al., 2023), a Brazilian developer and builder of residential projects, and a leading adopter of Lean Construction practices. Their production planning and control system combined elements of LPS® with takt production and a robust quality control system. The third study was carried out with Company C (Barth & Formoso, 2021), a Chilean developer and builder of residential projects. Their production planning and control system also leveraged elements of LPS® and it applied location-based planning and control principles.

Multiple sources of evidence were used in all three empirical studies, including participant observation in planning meetings and workshops, semi-structured interviews, analysis of documents (e.g., plans, drawings), analysis of existing databases, and direct observation during site visits. The internal validity of the research findings benefited from the use of good practices of qualitative research, such as triangulation of data sources, partial overlap between data collection and analysis to allow the early identification of missing or inaccurate data and a revision of the collected data by company representatives.

This paper analyses and describes takt control practices from these empirical studies through secondary data analysis. The theoretical discussions conducted during this study used these practices as a starting point to develop preliminary propositions for takt control systems. The development of these was informed by previous studies on production planning and control, as well as performance measurement systems for construction, which have proposed prescriptive knowledge on these topics (e.g., Barth & Formoso, 2024; Bataglin et al., 2022). These propositions have yet to be tested and refined to apply in a wider range of projects.

RESULTS

PRACTICES IDENTIFIED IN COMPANY A

Practice 1: Use *the matrix of production status for WIP control.*

Company A developed and implemented a matrix (Figure 1a) for controlling the production status in each work zone, similar to the one proposed by Sacks et al. (2009). This control was enabled through the monitoring of crew check-in and check-out in various work zones. Using this system, it becomes possible to monitor whether tasks are completed, in progress, stopped, or not yet started. When emerging constraints cause variations (as is common in underground linear projects), it may be necessary to adjust priorities in the batch sequence and, as a result, modify the long-term takt plan. From a theoretical perspective, the production status matrix serves as a tool for pulling production, in line with the pull concept outlined by Hopp and Spearman (2008), releasing work "based on system status" rather than on customer demand.

Practice 2: *Divide the project into zones by using a location system.*
This practice consists of organizing the project using a hierarchical location system, in which the project is divided into zones, including both takt and off-takt zones. Lower-level work zones are defined as subdivisions of higher-level zones, although the criteria for subdivision may vary. For instance, a building tower might be divided by floors, while a façade could be divided into vertical sections. Each hierarchical level serves a specific function, and the appropriate control level for managing WIP should be determined based on factors such as the type of work and the intended goals. This approach allows for targeted analysis and control of WIP, uncompleted batches, and active production zones where crews are currently working.

Practice 3: *Use metrics for WIP control.*
As the production status matrix (Figure 1a) enables visual control of WIP and task completion, two progress curves can be generated: one based on overall project progress (traditional earned value) and another that tracks only completed batches. The difference between these curves can serve as an indirect measure of WIP. Cycle time variation (Figure 1b) is another metric derived from the matrix, indicating the effectiveness of standardization and WIP control.

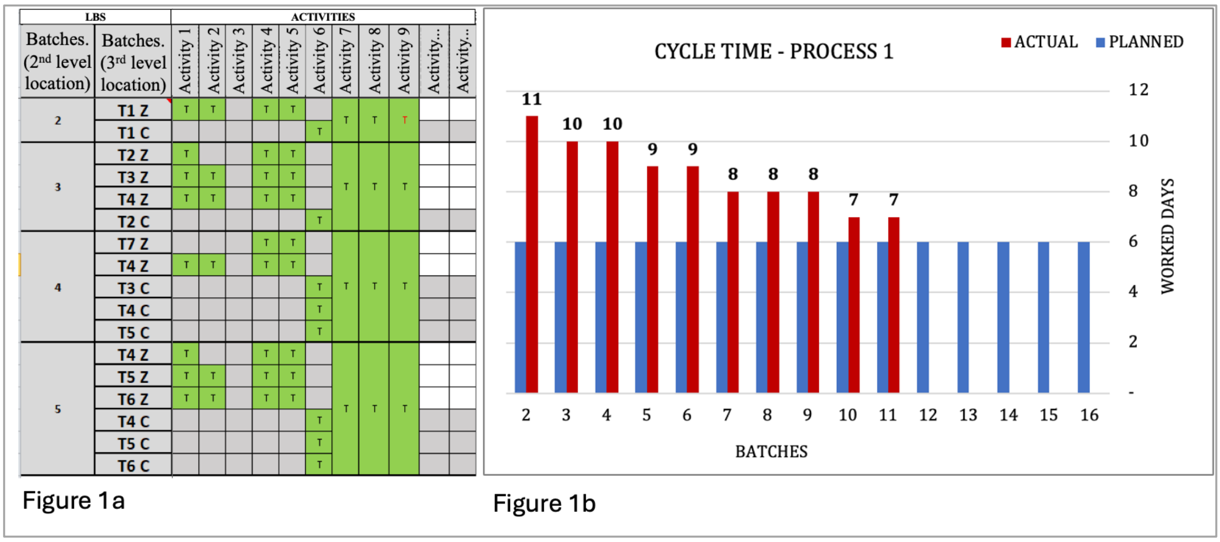

Figure 1: Examples of (a) Production Status Control Matrix, and (b) Cycle Time Variation

PRACTICES IDENTIFIED IN COMPANY B

Practice 4: *Adapt the standardized work approach to construction work.*
In the Toyota Production System, work standardization focuses on the cycle of operations performed by workers, defined by three elements: (1) takt time, (2) work sequence, and (3) available standard inventory (Martin & Bell, 2011; Ohno, 1988). In this company, the standardized work approach was adapted to the context of residential building construction. Rather than standardizing operations at a single workstation—as in manufacturing—it was applied to a set of five interrelated activities (wagons). This initiative was developed in close collaboration with frontline workers and involved balancing workloads across trades to align cycle times with the established takt time. Continuous improvement was encouraged through increased process standardization and short feedback cycles. A clear boundary was set between standardized operations and the decisions left to crews, acknowledging that a degree of crew autonomy is necessary in complex systems where unexpected events occur.

Practice 5: *Combine different types of slack to cope with variability.*
As a result of standardizing work, the company has explicitly incorporated additional types of slack beyond the traditional time, material, and capacity buffers. These include: (1) space buffers (designated areas where a crew can continue working if a task is completed ahead of schedule), (2) time buffers embedded within the standard operation cycle (different from those

used in CPM or Line of Balance), and (3) the deployment of multi-skilled crews, providing flexibility to accommodate personnel replacement or changes in the scope of work.

Practice 6: *Monitor check-in and check-out events to control cycle time.*
With the implementation of standardized work, the focus shifted from monitoring production rates to monitoring cycle times. This is especially important early in the implementation of standardized work, when variability is still high and some crews operate across several work zones. Consequently, additional control metrics were introduced, including cycle time variation, production pace deviation, and batch adherence.

Practice 7: *Use a set of visual management practices to support autonomy.*
The implementation of standardized work was supported by a set of visual management practices. These included quality inspections to prevent the propagation of variability between crews, *kanban* systems to support site logistics, visual devices for identifying customized components, and clear signage for the delineation of work zones and pathways.

Practice 8: *Use pre-assembled kits or prefabricated components for reducing the cycle time of time-consuming tasks.*
Drywall, plumbing racks, electrical kits, and HVAC components were selected for pre-assembly as they had time-consuming operation cycles and needed to be synchronized with other tasks. Pre-assembled kits help align operations (wagons) within the same train by reducing cycle time, improving efficiency, and facilitating coordination between prefabrication and site installation, especially when integrated early in the design phase. BIM supports this process by enabling virtual prototyping, facilitating clash detection, and improving prefabrication layouts. At the construction stage, Company B also builds physical prototypes (mockups) to verify quantities and measurements and develop *kanbans*. The *kanban* system is used to manage site logistics, so that kits of components are pulled for site installation as needed. The integration of pre-assembled kits with prototyping and *kanban* systems offers several benefits: reduced cycle time by enabling quicker on-site installation, decreased material handling and on-site cutting, elimination of waste, and improved safety. In other words, Just-in-Time delivery supports takt production by creating a continuous and balanced workflow. As prefabricated elements are produced in controlled environments, defects and risks associated with on-site assembly can be minimized, leading to improved quality and reduced rework.

PRACTICES IDENTIFIED IN COMPANY C

Practice 9: *Divide the project into separate trains of synchronized activities.*
In complex projects, it is typically infeasible to have a single continuous train that includes all activities due to uncertainty, task diversity, and resource constraints. Instead, Company C adopted the practice of dividing projects into separate, partially synchronized trains of activities. Each team progresses independently but remains aligned with the overall takt time. The strategy is to decouple processes that have high levels of uncertainty and variability. Trains are separated by pre-defined time buffers (Figure 2a). Handoffs between trains are planned to minimize idle time and prevent bottlenecks. This approach increases the reliability of the long-term plan and provides slack for adjustments in the event of unexpected delays (see Practice 10).

Practice 10: *Assess project performance and revise takt plans based on projections.*
The assessment of project performance combines tracking actual progress with projecting future outcomes, enabling continuous refinement of takt plans when needed. By analyzing both lagging indicators (such as project progress) and leading indicators (such as planning reliability and projected delivery performance), management teams can gain insights into execution trends. The use of actual pace curves and other performance charts supports decision making by allowing early identification of deviations and the anticipation of future scenarios. By

comparing real-time progress with projected timelines, teams can identify emerging issues and implement corrective actions before they escalate, ensuring that project goals remain on track.

***Practice 11:** Control informal work and other deviations.*

This practice involves tracking deviations between work-as-imagined and work-as-done by monitoring informal work, formalizing non-visible tasks, and identifying construction wastes, such as unfinished work, rework, quality failures, making-do, and logistics inefficiencies. Such deviations can be monitored by examining the nature of work packages in short-term planning (Figure 2b). Analyzing the root causes of those deviations helps uncover inefficiencies, bottlenecks, and misalignments in workflows. A high volume of informal work suggests that part of the team's capacity is being diverted to unplanned activities, many of which do not add value. At the same time, informal work often serves as a compensatory mechanism when essential resources are unavailable. To effectively manage this, it is essential to evaluate whether these informal practices are necessary and to understand their impact on achieving the desired outcomes (Saurin et al., 2013). Moreover, visual management can help make the gap between work-as-imagined and work-as-done more transparent (Hollnagel et al., 2017).

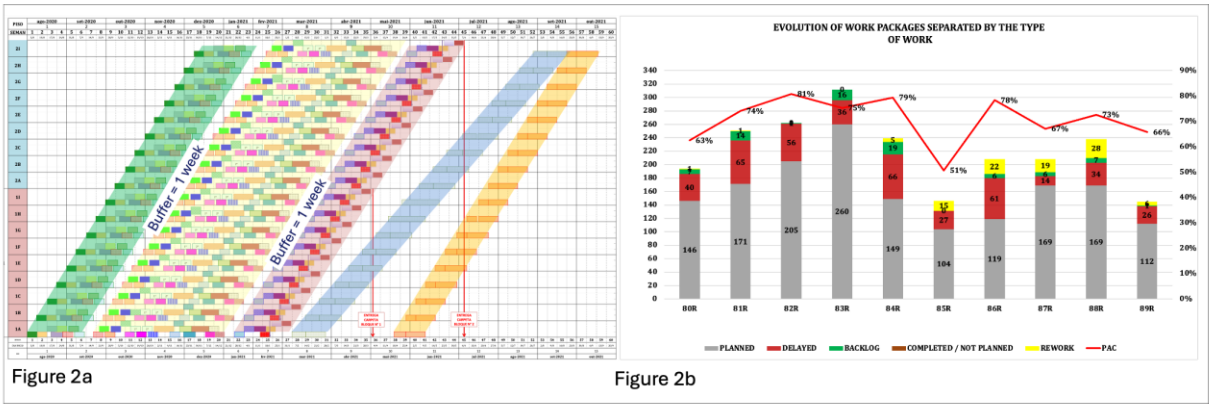

Figure 2: Examples of (a) Takt Plan with Separate Trains of Activities, and (b) Graph for Monitoring Nature of Work

***Practice 12:** Use digital performance dashboards produced from digital plans.*

Information technology can automate data collection and processing, enabling the timely delivery of information. A short information delivery cycle allows for early detection of deviations, enabling quick decision-making and corrective actions. The introduction of automation in data collection, processing, and dissemination facilitates the use of digital performance dashboards generated from digital plans. Moreover, automation reduces manual data handling and minimizes errors, fostering a more proactive and data-driven approach to construction management. By integrating real-time data from various project sources, these dashboards streamline information flow and enable comparisons between different projects.

PRELIMINARY PROPOSITIONS FOR TAKT CONTROL

Table 1 presents a set of 12 preliminary propositions for takt control systems developed in this study, which unveil the underlying ideas of the practices identified in the three empirical studies. Each proposition is linked to core Lean Production concepts and principles and also to the four resilience engineering potentials proposed by Hollnagel (2017).

Some propositions, such as (1), (5) and (12), have been explored in previous studies on takt production. Others, particularly (2), (4), (6), (7) and (10), have not been explicitly discussed in the takt production literature, although they may have been informally applied in practice. Some of these propositions address concepts that have been somewhat overlooked in takt production studies, such as slack, pull production, and the perspectives of product and operations flow. Notably, the set of propositions contributes to different resilience engineering potentials proposed by Hollnagel (2017): monitor, anticipate, respond, and learn. However, none of the propositions individually address these four potentials, indicating that they complement each other in promoting resilient performance.

Table 1: Preliminary Propositions and Related Concepts

Preliminary propositions	Practice(s)	Core concepts	
		Lean production	Resilience engineering
1. Divide the project into small batches by hierarchically organizing work zones and separating different types of zones	2	- Reduce batch size - Slack	- Monitor - Respond
2. Use different types of slack resources by combining redundancy and flexibility strategies	4, 5, 9	- Slack	- Respond - Anticipate
3. Control WIP at an appropriate level in the location-based system hierarchy	1, 3, 4, 6, 11	- Reduction of WIP	- Monitor
4. Detect deviations from takt plans early and develop strategies for recovery or improvement	4, 9, 10	- Continuous improvement	- Anticipate
5. Foster information sharing through visual management mechanisms as a strategy to deal with complexity	7	- Process transparency	- Monitor - Respond
6. Standardize cycles of operations by involving frontline workers	4	- Product and operations flow perspectives - Reduce variability - Continuous improvement	- Monitor - Learn
7. Define the degree of team autonomy to make operational decisions to cope with emerging events	4	- Slack	- Respond - Anticipate
8. Extend the application of takt to quality inspections to detect problems early	4	- Reduce variability	- Monitor - Anticipate
9. Upstream processes (e.g., prefabrication and kit preparation) must be capable of fulfilling the demand established by takt time	8	- Simplify by reducing the number of parts and steps - Slack	- Respond
10. Apply pull production by controlling system status as a mechanism to cope with variability	1, 3, 6	- Pull production - Slack	- Respond
11. Promote improvement and learning, e.g., by understanding the gap between work-as-imagined (planned) and work-as-done	11	- Continuous improvement	- Learn
12. Use digital technologies to introduce some degree of automation in data collection and processing and to support visual management	12	- Real-time control	- Monitor

As presented in Table 1, some propositions, namely (2), (3), (4), and (10), are connected to several practices, meaning their application requires a combination of practices to be effective. For instance, proposition (2)—using different types of slack resources—can be implemented through the adaptation of the standardized work approach, the adoption of organizational slack, and the division of takt plans into partially synchronized trains. In contrast, the practice related to the standardized work approach, which demands a collaborative effort to standardize and synchronize, with active participation from the workforce, contributes to six different propositions, namely (2), (3), (4), (6), (7), and (8).

The list of practices presented in Table 1 does not include certain elements of LPS®, as the authors assumed that these are well-known in the Lean Construction community. However, it can be inferred that some key LPS® practices align strongly with several propositions developed in this study—e.g., using hierarchical levels of planning to define confirmation points, maintaining a backlog of made-ready work packages, and establishing learning cycles based on identifying the causes of planning failures. This suggests that LPS® also contributes to resilient performance, as noted by Hamerski et al. (2024), and could play a key role in the effectiveness of takt production.

CONCLUSIONS

This study proposed a set of 12 preliminary propositions for implementing takt control in construction projects, recognizing them as complex sociotechnical systems. These propositions were illustrated using examples of takt control practices from three case studies.

The literature suggests that takt production in construction can improve efficiency, predictability, and workflow synchronization. However, for takt production to be effective, planning and control systems must be able to cope with variability that cannot be removed. Given that construction projects are complex sociotechnical systems, takt control must go beyond strict adherence to predefined plans. It should incorporate mechanisms for anticipating possible scenarios, monitoring execution, responding to deviations, and learning from both regular operations and unexpected changes. By promoting information sharing, autonomy of frontline teams, and the use of appropriate slack resources, construction projects can better manage complexity and variability while maintaining a stable and predictable workflow. Moreover, performance indicators should be designed to anticipate outcomes, providing early warnings of deviations and indicating their possible causes. Although the combination of LPS® and takt production can support this approach, the propositions presented in this study aim to promote resilient performance, regardless of the planning and control method adopted.

A limitation of this research is that the preliminary propositions are derived from only three empirical studies. Consequently, a number of other takt production practices were likely not identified in those studies, indicating the need for further research. Suggestions for future work include: (1) testing the set of propositions in the development of new takt planning and control systems, and (2) exploring how these propositions can be extended to companies that implement takt production without the LPS®.

ACKNOWLEDGMENTS

This study was supported by members of the Project Production Systems Laboratory (P2SL) at UC Berkeley and the Building Innovation Research Unit (NORIE) at UFRGS. We gratefully acknowledge all support received. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of members of P2SL and NORIE.

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