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# AN EXAMINATION OF IGLC TAKT LITERATURE - LEARNINGS & OPPORTUNITIES

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## ABSTRACT

Takt is gaining attention in the Lean Construction (LC) community and is recognised as an enabler for continuous improvement and a more complete implementation of LC. Adopting Takt from its manufacturing roots to construction has not been straight forward. International Group for Lean Construction (IGLC) research has adapted Takt principles and practices creating several models for its application in construction.

This study is an integrative literature review of papers in the IGLC index with 'Takt' in the title. Forty-eight papers were critically analysed, and key findings were themed by content analysis.

Findings show increasing interest in Takt studies since 2012 with Finland, Germany, US, and Norway respectively producing most papers. Takt has evolved from early application of Toyota Production System concepts and, with the addition of production and LC theory, has developed towards a more complete production planning and control framework with the potential to stabilise construction inputs, outputs, customer value, and quality. Takt research is beginning to impact project delivery with positive results witnessed as well as numerous challenges and improvement opportunities being identified. It is now recognised as a viable and proven production system that can initiate systemic improvement in construction delivery.

The research suggests every project should consider Takt from the outset in its high-level strategic planning and continue to assess where several sub Takt-plans can contribute to the execution of the project, assisted by LPS and the broader suite of LC techniques.

## KEYWORDS

Lean construction, Takt planning, Last Planner® System, continuous improvement.

## INTRODUCTION & LITERATURE REVIEW

Construction project management has predominantly relied on the Critical Path Methodology (CPM) for over 60 years, but its traditional use has been critiqued for failing to address the needs of production management (Ballard and Tommelein, 2021). Over-running tasks, in addition to scheduled tasks being 'forced' to commence because they have been committed by the CPM schedule, cause excessive and unnecessary work-in-progress and knock-on coordination, safety, quality, cost, and people related issues on projects. Academics and practitioners alike have debated the shortfalls of CPM and have suggested alternative

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methodologies (Lean, Last Planner® System, Agile, Scrum, Takt) for the management of project controls, scheduling, planning, and execution. Recent years has seen an academic-led advancement of Takt planning studies in LC. Researchers Seppänen, Lehtovaara, Koskela, Ballard, Tommelein, Frandson, Drevland, Dlouhy, Schöttle, Nesensohn, Binninger, and Haghsheno have led and advanced application methodologies for utilising Takt concepts to enhance construction planning and production management. These studies illustrate how construction can incorporate Takt time as a work structuring methodology to align the production rates of trades by pacing work sequentially through planned zones creating continuous workflow, reliable handoffs, and an opportunity to continuously improve the production system (Frandson et al., 2013). Takt time regards 'space' as a resource to be considered when planning construction projects and designing production operations (Frandson et al., 2015).

## TAKT PLANNING

The word 'Takt' or 'Taktzeit' in German means 'beat', 'rhythm', 'cadence' or 'meter', implying the regularity with which something gets done. In the production context, Hopp and Spearman, (2011) defined Takt time as: '…the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)'. It is a design parameter used in production settings that asserts if a process proceeds too quickly it will overproduce, and if it goes slower there will be a bottleneck (Frandson et al. 2013). Another critical consideration is that in construction workers move around the work as opposed to the work moving to the worker, for example, through a manufacturing assembly line (Ballard and Howell, 1997). Frandson et al. (2013) suggests the difference between Takt time planning and other location-based planning methods is this balance between 'work waiting on workers' and 'workers waiting on work.'

Takt time is easiest to understand in a machine-paced flow line, where each workstation along the assembly line must complete its work during the time the product is in its work zone. If the necessary work is not completed, the product proceeds to the next workstation in an incomplete state causing disruption to operations flow (Frandson, 2019). To minimise worker movement, work zones are kept as small as possible, with consideration given to the speed of the line and the capability of each workstation (Hopp and Spearman, 2011). By addressing process flow instead of solely maximising labour efficiency, Takt production accommodates the development of overall flow, especially when strategic buffer management occurs in contrast to the traditional use of large time and space buffers (Lehtovaara et al., 2021).

Several approaches to Takt implementation in construction have emerged from the literature. Takt Planning and Takt Control (TPTC) is highly structured and top down oriented (Dlouhy et al. 2018) and demarcates areas and repeatable 'Standard Space Units' (SSU) for each different function (such as an office). Work packages are then developed, and assignment metrics are calculated to assess the work content per work package. Takt areas then become combinations of SSUs (Binninger et al., 2017).

Allowing the trades involvement and consideration of the work sequence is a more bottom-up approach incorporated in Takt Time Planning (TTP) (Frandson et al. 2013); securing promises and social commitments speaks more to a softer collaborative environment. Focusing on maximising the amount of production activities performed with continuous use of resources is a critical element of TTP. This is possible by applying LPDS and TPS principles, and by taking advantage of the environment LPS provides (Frandson et al., 2014). TTP evolved by considering the use of 'space' and accommodating capacity buffers by scheduling less work than required to allow for variation (Tommelein, 2017).

'Work Density' is expressed in unit of time per unit of area and can be defined as: *Given a certain work area, work density describes how much time a given trade will require to do their* *work in that area, based on the product design and the scope of work done by that trade for a given task in the schedule (thus depending on the work already in place and work that will follow), the means and methods the trade will use to do their work while accounting for their crew's capabilities and crew size*, (Tommelein, 2017).

Takt production visualises the construction process in a way that includes work packages, work sequences, and Takt areas (Haghsheno et al., 2016; Dlouhy et al., 2016). Construction can utilise Takt time as a work structuring methodology to align the production rates of trades by pacing work sequentially through planned zones creating continuous workflow, reliable handoffs, and an opportunity to continuously improve the production system; Takt time is a design parameter for labour-paced flow of work (Frandson et al., 2013). Frandson et al. (2014) posits the objective of Takt time planning is to help create a more stable environment for the LPS by actively designing continuous workflow for trade activities wherever possible. LPS then provides the control mechanism and stability of the production system.

## RESEARCH METHODOLOGY

### RESEARCH OBJECTIVE & QUESTIONS

The paper reports on a review of only IGLC literature related to Takt planning. The primary objective is an examination of how Takt planning research has evolved and developed through the work of the IGLC academic community and how Takt is being interpreted and developed for use in construction. This will be achieved by answering several research questions. LC originated in the early 1990's with Ballard, Howell and Koskela's work in developing LC theory and LPS. Over subsequent years a growing body of knowledge has seen the development of specific tools for LC as well as the adoption of methodologies from other sectors. The first research question asks: What are the learning opportunities from the timeline and geographical spread of LC Takt publications? The second asks: How has LC Takt planning evolved over time? and the third question asks: What are the challenges/risks when implementing LC Takt planning?

### METHODOLOGY

The methodology to identifying and evaluating relevant Lean literature consists of an integrative literature review (Snyder, 2019) of IGLC research publications (available at: [https://www.iglc.net/papers](https://www.iglc.net/papers) ). Figure 1 presents the methodology utilised.


Figure 1: Integrative literature review methodology utilised.

In accordance with best practice described by Snyder (2019), the integrative literature review containing the keyword "Takt" in the title searched the entire IGLC database from years 1996 to 2022 inclusive. This search yielded 84 results. These were read, and some were discounted due to lack of relevance and for clarity the search was narrowed to only those papers with "Takt" in the title, reducing the selection to 48 IGLC conference papers. Each paper was critically analysed, and emerging themes were evaluated by content analysis in accordance with Creswell and Poth (2016). Findings were collated and key themes are discussed.

### LIMITATIONS

The study is restricted to IGLC literature with the word 'Takt' in the paper title. The authors acknowledge there are numerous studies within the IGLC index that refer to and contribute to the development of the construction Takt body of knowledge. Additionally, there are several publications available outside of IGLC that have not been considered in this study.

# FINDINGS AND DISCUSSION

## RESEARCH QUESTION #1. WHAT ARE THE LEARNING OPPORTUNITIES FROM THE TIMELINE AND GEOGRAPHICAL SPREAD OF LC TAKT PUBLICATIONS?

Examination of the timeline of IGLC publications with 'Takt' specifically in the title highlights no publication before the 2012 conference. The initial paper in 2012 (Fiallo and Howell, 2012) was followed with papers at every subsequent conference, the peak being nine studies in 2019. Figure 2 presents the number of studies per year.

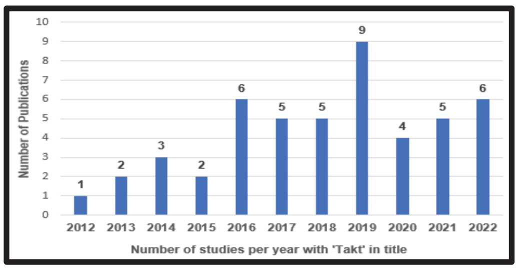


Figure 2: Number of studies.

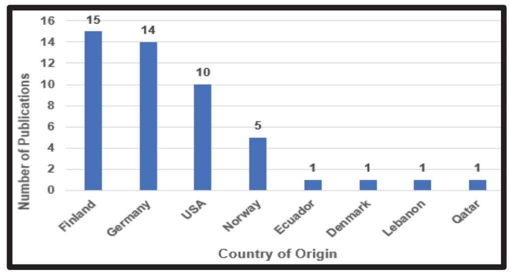


Figure 3: Geographical distribution.

The geographical distribution of studies is spread across eight different countries (Figure 3) with Finland and Germany leading the way with 29 out of 48 (representing 60% of the selected sample). Interestingly, the 2012 paper was a case study on an Ecuadorian project with Ripconciv Contractor and the lead author was both a Professor of Civil Engineering and a Lean Construction Coordinator with the case company. The co-author, the late Greg Howell, was President of the Lean Construction Institute. There has been an increasing focus on Takt planning research primarily driven by academic institutions in Karlshrue Institute of Technology, Aalto University, Norwegian University of Science and Technology, and UC Berkeley. Industry support has primarily come from the Boldt company, Sutter Health, BMW AG, Fira Oy, Skanska Oy, Consto, Veidekke, and Civil Soft Ltd. The research methodologies utilised are dominated by case studies with 35 of the 48 papers examined (73%) using this method.

## RESEARCH QUESTION #2. HOW HAS LC TAKT PLANNING EVOLVED OVER TIME?

While the first paper with Takt in its title didn't appear in IGLC until 2012, it is important to acknowledge that earlier contributions identify the importance of Takt concepts and how they could assist construction planning, for example, Bulhões et al. (2005). Takt concepts (value generation, customer focus, demand rate, throughput, production rate, bottlenecks, value stream mapping) were introduced from the Toyota Production System (TPS) onto construction planning on a case project (Fiallo and Howell, 2012) and highlighted the effectiveness of Takt time as a communication tool for translating project goals to production daily goals. Significant schedule reduction (11 months to 5.5 months) on an exterior cladding installation was presented by Frandson et al. (2013) by developing a production schedule with a 4-day Takt time. This study offered a distinct process of six phases for identifying a Takt time to be used in production planning and was based on repetitive activities on the case site. At the same time Linnik et al. (2013) experimented in Takt application to non-repetitive work (interior framing phase) on a Sutter Health hospital project. The study concluded that Takt planning does not require segregation of repetitive and non-repetitive areas and its application enhanced labour productivity through simplification and transparency of workflow and the drive for improved design of operations.

Also on the non-repetitive application theme, Tommelein (2017) reported on the ‘work-density method’ which proposed formalisation of a five-step process for collaborative Takt planning of non-repetitive work. Several papers bridged the gap from both LPS and Location-based planning to Takt planning and helped practitioners understand how they could transition towards keeping work flowing continuously (Frandson et al., 2014; Seppänen, 2014; Frandson et al., 2015; Schöttle and Nesensohn, 2019). Many studies (Faloughi et al., 2015; Emdanat et al., 2016; Heinonen and Seppänen, 2016; Vatne and Dreveland, 2016; Frandson and Tommelein, 2016) advanced knowledge by applying Takt concepts on individual case projects. However, the authors assert three critical bodies of work have contributed to the advancement of Takt planning knowledge; the work of Professor Haghsheno and the researcher teams from Karlsruhe Institute of Technology; Professor Tommelein and the researcher teams from UC Berkeley; and Professor Seppänen and the research teams from Aalto University. Despite having a lesser quantity of papers at IGLC the contributions from Norway and the individual cases from Denmark, Ecuador, Lebanon, and Qatar have contributed positively and enhanced the body of knowledge.

Haghsheno et al. (2016) took the approach of controlling takted construction processes by agreeing that ideal process analysis and the standard room units preceded determining the effort levels required for each activity. The goal is to level out the work packages ensuring the single unit of Takt time is not exceeded. Attention is focused on the detailed analysis and integration of customer demand, space, crew size, output, and buffer allocation to achieve stable construction processes. Key to this study’s success was the focus on shorter cycle Takt time and quality completion of tasks. An interesting difference in approach is Frandson et al. (2013)’s use of a four-day Takt time, and Frandson and Tommelein (2016)’s use of a five-day Takt time as opposed to the Karlsruhe researchers who preferred to get as close as possible to a short-cycle or single day Takt. An exception to this is Dlouhy et al. (2016) who filled ‘wagons’ to achieve a five-day Takt time to level with longer duration activities. Binninger et al. (2017) used two and half day Takt on the first floor and five-day Takt on the ground floor of the case project. When Dlouhy et al. (2018, p.892) examined 10 construction case studies they found an average Takt time of 4.4 days and add ‘…Takt Time can have duration from a few minutes up to one week.’ Studies show that in construction projects the Takt time generally lies between half a day and one week. This study asserts an opportunity exists for researchers to collaborate and agree the ideal process and approach towards establishing Takt time for the wide variety of scenarios that exist in construction and along its supply chain.

When reporting on the case of combining Takt with prefabrication, Chauhan et al. (2018) aggressively sought a one-day Takt time and again highlighted success by combining multiple Lean concepts. In a seven-story apartment project, Lehtovaara et al. (2019) combined a one-day and five-day Takt when interior finishing 42 apartments of varying layouts and floor areas. In summary of this point, Binninger et al. (2018) analysed 80 construction projects where Takt planning was used and found approximately 75% used a Takt time of one week. In contrast, an example of Heinonen and Seppänen (2016) describes a Takt time of 15 minutes which presented excellent improvements in cruise ship cabin refurbishment and posed the challenge to construction that improvement goals set in construction have been too low, possibly due to lack of external pressure or demand. Binninger et al. (2017) conclude that every project could have a different Takt time while noting that in practice a weekly Takt is often selected due to the instability of construction processes.

The contributions presented in table 1 assess the emerging themes from 41 of the 48 analysed papers that have emanated from four research institutes. Table 1 highlights the broad range of technical, tactical, cultural, and softer aspects to be considered in Takt implementation.

Interestingly, recent years has seen more interchange of ideas and views with collaborative studies presented, for example, Lehtovaara et al. (2022).

Table 1: Principal research contributions (41 of 48 papers)

| Authors | Content focus & contribution |
|---|---|
| **Haghsheno & Karlsruhe researchers** | Shortest possible Takt time – measuring tasks in decimal minutes, one-hour Takt time tested, single day is recommended; quality completion of tasks; Introduced three levels – Process Analysis, Takt Planning, Takt Controlling. Takt Planning and Takt Control Method (TPTC); Case studies in automotive sector construction projects (BMW); Takt learning simulation game; Use of Takt in equipment installation; Introduced flexibility - decoupling of Takt area, empty buffer wagons, phase interlinking, soft start, and train stoppage; Takt applied on large scale project; introduced double packaging and sequencing; comparing construction and equipment phase Takt planning; Focus on buffer management; Takt workflow. |
| **Tommelein & UC Berkeley researchers** | Six sequential phases of Takt planning process; Takt Time Planning Method (TTP); Determine Takt time by overall duration allowed or consider available resources, identify bottleneck, improved bottleneck becomes demand rate. Case studies primarily in Sutter Health projects. Four- or five-day Takt time. Introduced 'Work Density Method' to find repetition in non-repetitive work. Formulated five steps for collaborative Takt time planning; Visual digital tools; Takting the Parade of Trades Model; applying Failure Mode & Effects Analysis (FMEA) to control Takt; |
| **Seppänen & Aalto researchers** | Linked existing research on location-based techniques to Takt for construction; Cruise ship refurbishment showed huge benefits terms of quality, productivity, work-in-progress and cycle time and highlighted Takt potential; combining Takt and pre-fabrication; focus on short Takt times (15 minutes – cruise ship, one day on prefabrication); Discussed impact of logistics and external variation; compared US (Californian) and Finnish approaches and maturity level; Model describing Takt maturity; Takt in renovation project; Client's perspective on value-creation and flow; Introduced visual management and digital technology as part of Takt Control; Continuous improvement system; applying FMEA to control Takt. |
| **Drevland, Lædre, Andersen & Norwegian University of Science and Technology researchers (NUST)** | Proposed aligning salary / payment terms to facilitate Takt; consideration of Takt overhead costs; suggest development of guidelines for consistent Takt implementation; considers early division of the project into many smaller phases and postpone the details until the individual phase is to be performed; highlight impact of delays in disrupting Takt. |

Four specifically different approaches become evident from analysis of the studies. A synopsis of the steps in each approach is presented in table 2.

Two alternatives to define the overall Takt time are suggested by Frandson et al. (2013). The first is based on the duration to complete work and the second is to consider available resources, identify the bottleneck, study if the bottleneck's rate can be improved, and use the improved rate as the achievable demand rate (Heinonen and Seppänen, 2016). Setting the Takt time in Heinonen and Seppänen's (2016) study was a mathematical exercise dependent on the number of cabins, scope (man-minutes / cabin) and project duration (mandated by the owner) as it was impossible to compromise on the customer's lead time due to the owner's high opportunity cost. The calculated Takt time must accommodate both contractor's and owner demand perspectives and can be adjusted through reduction of buffer times or through further optimisation and acceleration to adjust customer demand (Haghsheno et al., 2016).

Table 2: Suggested process steps in selected approaches

| Authors | Suggested Process Steps |
|---|---|
| **Linnik et al. (2013)** | 1) Identify the trades that will work in the phase and how their tasks will be grouped together.<br>2) Gather information from trade partners.<br>3) Sequence trade groups and the trades within groups, identify bottleneck trades in each group, and roughly estimate their achievable production rates within the Takt areas.<br>4) Balance workflow determining Takt time in each sub phase. Adjust area structure if needed.<br>5) Use Takt time strategy to plan for resources, materials, and information. |
| **Frandson et al. (2013)** | 1) Gather information.<br>2) Define areas of work (zones).<br>3) Understand the trade sequence.<br>4) Understand the individual trade durations.<br>5) Balance the workflow.<br>6) Establish the production plan. |
| **Haghsheno et al. (2016)** | 1) Process analysis.<br>2) Agree working steps.<br>3) Establish standard room units.<br>4) Determine effort values.<br>5) Takt harmonisation.<br>6) Add buffers.<br>7) Takt control. |
| **Heinonen and Seppänen (2016)** | 1) Defining Standard Workflow Within Construction Train – scope of work, set of tasks, workload value per task in minutes, Takt time is the time the system has available, select optimal crew size, assess logical and resource dependencies, bundle standard set of tasks (repeated each Takt time by same crew) into wagons, size buffer into Takt time, define material delivery and garbage collection points.<br>2) Define logistics – design one-piece flow of materials at first point of packaging, material delivery trollies, pick one cabin at a time.<br>3) Management roles and responsibilities – train drivers, (co-driver, logistics manager, logistics foremen) |

While many of previous case studies were conducted on aspects of a single project, for example, internal drywall or on selected floors, Dlouhy et al. (2018a) reported Takt success on a large-scale project in Mexico. Extending beyond the pure construction phase, Dlouhy et al. (2017, 2018b) compared Takt in the construction and equipment phases of the same project and found recognisable benefits in collaborating and considering interfaces to upstream and downstream phases. Managing inputs and controlling variation is an essential component of Takt and was a specific focus of Chauhan et al. (2018) and Tetik et al. (2019) when examining prefabrication and logistics management in the context of Takt planning. On a similar theme, Vatne and Drevland (2016) found Takt implementation made it easy to spot errors and continuously steer the production proactively. However, despite much improved throughput time (reduced by 30%) and the project being lauded as successful, Alhava et al. (2019) found the flow of the Takt process allowed next tasks to proceed without full root cause assessment of errors, therefore allowing the errors to be repeated. This illustrates how using selected LC methodologies can highlight improvement opportunities in the existing process. However, to ensure delivery system advancement it is important that each opportunity is addressed by utilising the entire suite of LC methodologies - ultimately the project and stakeholders will develop their own Lean Project Delivery System. Table 3 summarises the key contributions of Takt to improving construction delivery.

Table 3: Takt contributions to improving project delivery.

| **LC Takt contributions to improving project delivery** |
| --- |
| Initiation & driving of continuous improvement culture. |
| Introduction of disciplined process analysis to trade workflow & supply chain inputs. |
| Focus on error-proofing and FMEA. |
| Importance of softer aspects alongside scientific approach. |
| Improved communication through visualisation of production goals. |
| Introduction of Lean concepts from TPS (value generation, customer focus, demand rate, throughput, production rate, bottlenecks, value stream mapping). |
| Visualisation of buffers. |
| Focus on balancing trade cycle times – from 15 minutes to a single day or 5 days (as determined mathematically). |
| Bringing stability to constructions supply chain inputs & logistics organisation to help control variation. |

Stabilising inputs and effective logistics organisation are critical components of construction planning; Vatne and Drevland (2016) highlight this in a residential construction case study. Using Takt to plan materials and information inputs and well as coordinating Just in Time (JIT) deliveries is highlighted by Linnik et al. (2013, p.616), where Takt allowed supervisors and construction engineers more time to '…support the trades in determining quality requirements and in performing first run studies to test and refine the design of construction operations. They can spend more time on material and quality planning, and on root cause analysis of accidents, defects, and plan failures to avoid similar problems in the future.' An examination of flow in Takted projects (Binninger et al., 2019) found significant difference between planned and actual flow efficiency; the authors posit consideration of and balancing the mix of short delivery times of the product from the client perspective and stability and consistency of resources from the subcontractor's perspective. Flow and value-creation specifically from the client's perspective was examined by Lehtovaara et al. (2021), noting the proactive role of a client helps to put customer value in the centre of Takt production. Takt was also found to contribute positively to the flow of the trades while noting the importance of trust between stakeholders (Kujansuu et al., 2020). Practitioner awareness and knowledge of LC and Transformation, Flow, Value theory, as well as practice in all function of LPS, is an important enabler of Takt implementation;

logistics, supply chain, and multi-interface management requires technical and theoretical understanding of multiple LC and production system concepts.

The importance of the softer aspects also emerged in a comparison of collaboration and trade partner commitment in Californian and Finnish Takt implementations; Kujansuu et al. (2019) found the strong Lean culture established by the Californian companies allowed more reliance on social aspects and trust between stakeholders. People engagement, openness to new ways of working, and cultural aspects were highlighted as challenges by Schöttle and Nesensohn (2019). This highlights the importance of having the softer and people-related aspects of change-management in place when projects are introducing 'new' methodologies that challenge traditional approaches within construction delivery.

The strong knowledge on the technical aspects of production planning established a platform to build the Finnish model of Takt implementation. A study by Lehtovaara et al. (2020) recognised the construction sector was missing an opportunity to develop a shared understanding of systemic Takt production implementation. Academic discussion had primarily focused on how to technically implement Takt production in single projects while a few pioneering clients and contractors had experimented with aspects of Takt on elements of projects. However, a study of Takt application on a large-scale project ($1Billion) by Abou El Fish et al. (2022), allied to Dlouhy et al. (2018a) highlighted how Takt helped the construction team to properly control, organise, and place resources into projects to achieve desired goals. In an examination of Takt as an enabler for LC, Tommelein and Emdanat (2022) suggest Takt should be considered at early project strategic level, thereby assisting align design and supply chain. They add that a Takt implementation should be viewed as foundational to a framework that supports continuous improvement efforts. Additionally, Tommelein and Emdanat (2022, p. 876) conclude '…teams interested in implementing LPS on their projects start by designing their production system using Takt, and then design their LPS implementation to take advantage of all the opportunities production management and control offers.'

In conclusion, Takt research is beginning to impact project delivery with positive results witnessed as well as numerous challenges and improvement opportunities being identified. Takt started from consideration of directly applying production concepts from TPS, evolving from LBMS and LPS practices, considering technical and mathematical aspects, and testing hypothesis on different construction projects across geographical locations and cultures. Takt is now recognised as a viable and proven production system that can initiate systemic improvement in construction delivery.

## RESEARCH QUESTION #3? WHAT ARE THE CHALLENGES/RISKS WHEN IMPLEMENTING LC TAKT PLANNING?

Vatne and Drevland (2016) identified a key challenge to Takt implementation on projects where the payment system (piece work) doesn't align with splitting of work packages into multiple Takt trains. This concern was also voiced in Lehtovaara et al. (2019) and Binninger et al. (2018) and was mitigated by a commitment to fully pay the subcontractors for a three-day trial even if no work was completed. According to Binninger et al. (2017), Takt has undergone criticism due to its scheduling rigidity during construction and its perceived hinderance to adjustments on a project. Handing over unfinished Takt areas tends to lead to more delays later because of irrational work sequences and correctional work (Dahlberg and Drevland, 2021), concluding that Takt is a fragile production system needing daily monitoring and readjustment. Extra management resources are possibly required as, according to Binninger et al. (2018), close supervision and comprehensive documentation are required to achieve and maintain low Takt times. Caution must also be exercised as Alhava et al. (2019) discovered the implementation of digital methods found a lot of waste in the project; despite reporting a successful project and achieving a 30% cycle time reduction a lot of waste was made visible.

The intensity of Takt planning can catch subcontractors and material suppliers unawares meaning procurement and payment models must align to suit (Lehtovaara et al., 2019). Additionally, incomplete design cannot become a cause of bottlenecks, drying times and critical tasks must be thoroughly planned, and Takt must become a holistic approach as opposed to just managing an individual construction phase (Lehtovaara et al., 2019). In a collaborative research paper (UC Berkeley and Aalto University) Lehtovaara et al. (2022) examined FMEA as a countermeasure to Takt failure and offer a framework for Takt control that uses the FMEA process logic. This study presented a systematic guideline for problem-solving in a Takt control context and illustrated examples of failures, failure modes, root causes, and control actions to assist in applying the framework.

# CONCLUSION, RECOMMENDATIONS, & OPPORTUNITIES

It is evident from the IGLC literature that Takt has become a much-researched topic that has acquired attention from academics and practitioners alike. The examined studies are unanimous in agreement of advantages accruing from Takt implementation and a broad list of disruptive issues are presented. However, the authors assert such 'making-do' issues are an everyday aspect of construction delivery and it is only when such an intense but fragile framework like Takt challenges the status quo can practitioners truly acknowledge the amount of variation and variability that exists.

Takt is now recognised as viable and proven production system that can initiate systemic improvement in construction delivery. To ensure continued advancement it is important that each identified improvement opportunity is addressed by utilising the entire suite of LC methodologies and ultimately the project and stakeholders will develop their own Lean Project Delivery System and culture. Allied to the development of this improvement culture is the importance of having the softer and people-related aspects of change-management in place as efforts that challenge traditional construction delivery approaches can meet active or passive resistance.

Despite the pioneering research and advancement, studies have highlighted the need for a consistent globally agreed framework that aligns thought leader's ideal-state perception of Takt implementation. This would accommodate geographical distinctions, cultural and softer aspects, and encourage a more holistic implementation both upstream and downstream of the specific construction execution phase. Researchers must also be cognisant that innovation must be encouraged as consistently testing hypotheses and methodologies on live projects exposes the daily challenges that stifle productivity improvement within the sector.

Every project should consider Takt from the outset in its high-level strategic planning and continue to assess where several sub-Takt plans can contribute to the execution of the project, assisted by LPS and the broader suite of LC techniques.

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