

REVISITING THE TAKT MATURITY MODEL AFTER THREE INTERNATIONAL TAKT FORUMS

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ABSTRACT

Takt production has gained wide interest as a change agent for systemic change in recent years. A maturity model for the adoption of takt production based on and validated with Finnish case projects was published in 2020. However, that maturity model has not been validated internationally and companies have continued their development of takt-based operations. In this paper, we suggest updates of the maturity model by reviewing the best practices presented in three international takt forums. We also validate the model using international case projects presented in the takt forums. Industry participants have taken routes to takt production implementation other than those assumed in the initial model. Some have advanced to levels that were not included in the original model. Our suggestions consist of adding four new requirements and modifying the descriptions of eight existing requirements. A modification to the description of one of the levels in the model and the model itself are also suggested. The contribution to knowledge is a new maturity model to use for benchmarking and as a roadmap for improvement of takt production.

KEYWORDS

Takt production, maturity model, takt forum, driving change

INTRODUCTION

The use of takt production as a production planning and control method is becoming more common in the architecture-engineering-construction (AEC) industry. A range of practices and variations thereof can be observed on projects around the world. At the same time, certain companies are advancing the state-of-the-art practices of takt production, (1) to refine its use on the types of projects where proof-of-concept has already been delivered, (2) to extend its range of application from specific phases of construction, to applications upstream in design and downstream in commissioning, and (3) to change the whole company based on takt production principles, rather than consider individual projects only. A lot can be learned from

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these practices and their characteristics, and lessons learned can be compiled into levels of maturity.

In this paper we build on the maturity-level model for takt production introduced by Lehtovaara et al. (2020). The original maturity model can be found in Table 2 at the end of this paper for reference (black text is original, modifications are in green). This model was developed based on 24 Finnish takt production cases. It includes 15 requirements structured at three levels into (1) technical takt planning, (2) social integration & takt control, and (3) continuous improvement levels. According to the model, companies can start takt production implementation using existing contractual structures, but higher levels of maturity require wider engagement of stakeholders in the supply chain (SC) and learning between projects. As the model was created after just a few years of experience in the Finnish market, further validation and development is needed.

To hear how leading AEC practitioners are deploying takt production, P2SL, Vison, Aalto University, and RIL (Finnish Association of Civil Engineers) have been organizing online forums for practitioners around the world to share their knowledge about takt production. Three such forums have taken place to date, a 1.5-day forum on 18-19 August 2022, and two 0.5-day forums respectively on 9 November 2022 and 23 May 2023. The presentations and discussions at the forums give reason to revisit the takt maturity model.

This paper presents insights the forum organizers gained as they relate to the maturity model. Suggestions for updates to the maturity model are extracted through revisiting the recorded presentations and discussions. Validation of the maturity model with the international case examples is also discussed.

METHOD DESCRIPTION

Three takt forums were held with sessions addressing 8 themes, including 23 15–20-minute presentations and an additional 5-minute Q&A. For each theme, the organizers gave a 5–10-minute introduction and led a 10–25-minute discussion and Q&A. Small group discussions for each theme took place in breakout rooms, but these were not recorded and are therefore not part of the analyzed data. The breakout room discussions informed the theme discussions that were recorded. During the presentations and break-out rooms, Menti.com (an online interaction platform) was used for gathering questions and comments from participants, which facilitated the discussion. Menti was also used to survey participants about their familiarity with takt production and the Last Planner® System (Ballard & Tommelein, 2021). Table 1 presents the forums, sessions and presentations. The second, third and fifth author were organizers of all of the forums, and the fourth author was an organizer in the first one only. The selection of session topics and presenters was a result of discussions amongst the organizers while they were planning the forums. The aim was to invite the most mature state-of-practice companies to present their experiences.

A qualitative thematic analysis was carried out to synthesize the data. All authors were familiar with the data from the three live forums they participated in. As a first pass, the first author skimmed through the recordings to extract tentative topics (e.g., supply chain management (SCM)) for analysis. After identifying these tentative topics, the first author rewatched all the recordings and noted in a table the points of discussion that relate to the topics. The tentative topics and the most prevalent notes related to them were then discussed among all the authors, which resulted in three categories, presented in the following section. All authors then discussed the key findings and topic-related suggestions. The resulting topics were discussed and connected to the maturity model requirements in Table 2 of (Lehtovaara et al., 2020). Some discussion points noted in relation to the topics do not, however, correspond directly to maturity-level requirements. These connections and differences are discussed in the findings.

Table 1: Takt forum sessions and presentations

Session	Presentation
Forum 1, day 1: 2022-08-18	
1. Strategic takt planning and using takt in design	1. Aleksi Heinonen (Vison Oy, [F]) 2. Adam Frandson (DPR [US]) 3. Cory Hackler (DPR [US])
2. Takt plan development and supply chain management	1. Van Kristensen (Turner [US]) 2. Marco Binninger (Weisenburger bau [G])
Forum 1, day 2: 2022-08-19	
3. Takt control including daily takt plan management and change management	1. Jukka Rannisto (Haahtela [F]) 2. Samir Emdanat (vPlanner [US])
4. Future of takt production in construction	1. Olli Seppänen (Aalto University [F]) 2. Iris Tommelein (UC Berkeley [US]) 3. Kim Lindholm (HOAS [F]) 4. Digby Christian (Sutter Health [US])
Forum 2: 2022-11-09	
1. Cultural change with takt production	1. Takt production in Skanska Nordics – We are better together (Pekka Kujansuu and Magnus Vissebråten, Skanska Norway/Finland [F], [N]) 2. Takt as a production system: Business portfolio flow and situational awareness (Kasper Koivu, Fira [F]) 3. Takt method in everyday life of the SME company – journey to get there (Mikko Hirvonen, Respect Project [F])
2. Client involvement in project delivery with takt	1. Delivery of a megaproject with 1-day takt: Helsinki airport terminal 2 (Jasmiina Hietala, SRV [F]) 2. Why a superintendent uses takt even when the owner does not ask for it (Dan Murphy, Turner [US]) 3. Industrial owner's strategy with takt (Janosch Dlouhy, BMW [G])
Forum 3: 2023-05-23	
1. Learning takt production from other industries: manufacturing, marine refurbishment and construction	1. Lean cruise ship cabin refurbishment (Jaakko Mäkikalli, Makinen [F]) 2. Plan for every part (Ari Viitanen, Carinafour [F]) 3. Concept of takt time in construction and other industries (Peter Meijnen, Denkyu Consulting [G])
2. Takt beyond phase planning in building construction	1. Application of takt production in underground linear infrastructure construction projects (Veronica Ksiazienicki, Stiler [U] and Carlos Formoso, UFRGS [B]) 2. Takt in design at the Life Science project / The journey of applying takt (Hans Thomas Holm Statsbygg [N]) 3. Takt – LPS connection (Spencer Easton, Mortenson [US])

Notation: Presenters reported on projects in the following countries: B: Brazil, F: Finland, G: Germany, N: Norway, U: Uruguay, US: United States.

FINDINGS

The authors grouped the findings in three categories to emphasize what was deemed novel and controversial, and to de-emphasize repetition of points that have previously been discussed in takt production research. The goal was to suggest how the maturity model could be improved.

The three categories are (1) Strategic takt planning, which refers to an early holistic conceptual approach of applying takt production; (2) Supply chain management, which covers preconditions to be met before production (tasks) can happen on site, such as the design process, trade partners, procurement, prefabrication, and material flow, and (3) Driving change, which refers to using takt production to identify potential production system improvements (e.g., Tommelein & Emdanat 2022). These categories connect many detailed requirements together and can be seen as “change agents” towards successful takt production implementation.

In the following, the contents of the forums are discussed in light of the maturity model divided into these three categories. The data is referred to with the following notation: F: Forum, i: introduction to session, p: presentation, d: discussion and Q&A of the session, with the numbering of the forums, sessions and presentations as presented in Table 1.

CATEGORY 1: STRATEGIC TAKT PLANNING

Strategic takt planning is defined here as engaging in takt planning early in the project while taking a holistic view of the whole scope of production. Approaching takt production as a project’s operations strategy has previously been introduced in Lehtovaara et al. (2021). A similar view of planning in levels of detail is also found in the three-level method of takt production (Dlouhy et al., 2016) and was introduced much earlier in the planning levels of the Last Planner® System (Ballard & Tommelein, 2021). The key idea about strategic takt planning is to enable early responsible commitments and create a concept that sets targets for future development of the plan. The early concept should be based on data such as historical knowledge of production rates. (F1.1.i), (F1.1.p1), (F1.1.p2)

An early concept, i.e., a generic idea of a takt plan where takt production principles are applied, enables choosing and integrating supply partners who are willing and able to deliver to the takt. This may affect the cost structure and business plan of the partners and is therefore important to know before signing a contract. The early takt concept can set requirements for the supply of design, labor, and materials before they are procured. It enables the potential partners to evaluate whether they can conform to the plan and speak up about their concerns. This is also a tool for gaining client involvement since the plan is built to their targets and crucial decision-making points can be identified early. Strategic takt planning can drive takt production on an organizational level. Integration of trade partners with an early concept is at the same time an opportunity for training. It is a way to build organizational competence for aligning everything that has to come together for a stream of projects to work, to get better across projects, and to enable sustainable profits for all companies involved. (F1.1.p2), (F1.1.d), (F1.2.p1), (F1.2.p2), (F1.4.p4), (F1.4.d), (F2.2.p3), (F2.2.d), (F3.1.p3)

Strategic takt planning is not mentioned in the maturity model although the requirements R1 (The production plan fits the client’s requirements) and R2 (Takt areas, takt time and wagons with resourcing are unambiguously determined) on level i) (Technical takt planning, project-level) of the model can be interpreted to have a similar intent. The SC integration view is on level ii) (Social integration & takt control, project and organization level) with R5 (The logistics are integrated and takted with the production plan) and R6 (The design process is integrated and takted with the production plan) but there is no clear connection to the strategic planning level. The organizational level of continuous improvement is the intent of level iii) (Continuous improvement, organizational and regional level) but, again, the maturity model lacks explicit reference to the strategic planning level.

The early takt concept should show how the flows of work in different phases of construction are connected to create an overall flow. The aim is to meet the client's demand even at the expense of loss of capacity in the short term in some parts of the system. Different phases may have different kinds of variabilities and challenges. For example, they may have different location breakdowns, different buffering strategies and different batch sizes, i.e., takt time and takt area combinations. Unique areas of the project that do not fit well into the production system of other phases should be identified and pulled to the overall flow of the project. Possible workable backlog areas should be identified as they can be leveraged to make up for low density work in other areas. The phase breakdown can also be used to divide management responsibilities. The early overall takt plan should give an anchoring point to the project. As the project advances towards the execution phase, the strategic takt concept is developed into a takt plan where the details are filled in to meet the targets. (F1.1.p1), (F1.1.p2), (F1.1.p3), (F1.1.d), (F1.2.p1), (F1.3.d), (F2.1.p2), (F2.2.p2), (F2.2.d), (F3.1.p3)

Breaking up the project into phases and connecting them to an overall project flow is not explicit in the maturity model. Requirements R1, R2 and R3 (Effective visual management is ensured) on level i) include this intent but it is not clearly visible.

Historical knowledge of past projects should be gathered and used when shaping the early strategic takt plan. Reusable production steps and work packages (i.e., standardized operating procedures for construction) are created and developed on the execution level, but knowledge of indicators that describe them can be used for setting goals on the strategic level. These may also vary depending on the geographical area and on the trade partners to be considered, so understanding the variabilities involved would be useful. The historical data could be used to set up a production strategy in new projects early and to guide improvement activities. The mathematics of takt production on a strategic level can be simple but the ability to handle the complexity that comes with integrating the SC and the large amount of data requires digital tools. (F1.1.d), (F1.1.p1), (F1.1.p2), (F1.1.d), (F1.2.p2), (F1.3.d), (F1.4.p1), (F1.4.p2), (F1.4.d), (F2.1.p3), (F2.2.p1), (F2.2.p3)

Leveraging data is mentioned in R14 (Standardized, takt-based work quantity libraries) and R15 (Improving through KPI's and data-driven decision making) but the use of data to create an early strategic takt concept and to manage the complexity is not clearly visible.

Suggestions for augmenting the maturity model:

- S1: Level i) should be modified to consider only one phase and to the second level a requirement should be added that most or all project phases are considered.
- S2: To level ii) of the maturity model, a requirement should be added for the ability to form a takt production strategy before supply-partner contracts are signed.
- S3: On level iii), requirements R14 and R15 should be modified to include the ability to leverage historical knowledge of production rates and other indicators.

CATEGORY 2: SUPPLY CHAIN MANAGEMENT

A takt production environment creates a clear and stable demand for products and services to be supplied as needed for production. It enables delivery of smaller batches following the just-in-time principle. Proper SCM requires attention at the early strategic planning level and is crucial at the project execution level. (F1.2.p1), (F3.1.p1), (F3.2.p3)

Delivery strategies for different types of material flows must be planned strategically. Strategic takt planning changes the conversation in the SC from describing general needs to defining more understandable chunks. It also enables standardizing the SC processes to a takt plan and helps in mapping out the whole SC. Creating an overall vision of the flow of the project depicted in a strategic takt plan is important because the complexity of SCM can grow very quickly. (F1.2.p1), (F1.2.d), (F2.1.p2), (F1.3.p2), (F2.2.p1), (F3.2.d)

SC integration is mentioned in the maturity model in R5 and R6 on level ii) and in R13 (Industrialized logistics and material flow) on level iii). They do not clearly show how SCM should be considered early in a project on the strategic level.

Design development is better done by setting milestones and defining points of design deliverables based on the takt plan instead of managing design activities directly. Defining the milestones and deliverables should start with defining the functionality of the building; the design deliverables can then be packaged to supply the project by pulling to the takt plan. This also enables the decentralization of the design process to create flexibility for the design teams. The milestones and deliverables should match defined design-value steps that follow a model of design maturity for defined purposes in a takt plan. At each point of design development, the designers need to understand what is fit for purpose (aka. 'good enough') for the next customer in the SC to use their deliverables. Standardizing design and taking full advantage of Design for Manufacturing and Assembly (DFMA), prefabrication, and industrial construction must also be done at the early strategic level, with continuous improvement across projects.

Planning design to a takt in smaller batches is a problem, because designers are not used to thinking about the design process in such a way. The execution-phase design work (aka. construction documents) should be attuned to the takt plan and be made responsive to any issues encountered on site, especially in a project where information required for the final design is discovered only during construction. This is why designers should also understand the principles of takt production. (F3.2.p2) (F2.2.d), (F3.2.p2) (F2.1.p2) (F3.2.p2), (F3.2.d)

Design process integration and its connection to the takt plan is included in the maturity model in R6 on level ii). The connection to strategic takt planning is however not clear. The execution level of design process management covers many smaller steps that are not detailed in the maturity model.

At the execution level material delivery strategies such as designated logistical routes, the use of off-site buffers for just-in-time deliveries of large materials and on-site buffers (supermarkets) for smaller materials must be planned in connection with the takt plan. To make the just-in-time deliveries in small batches to suit the takt plan, logistics operations and material flow should be separated from trade work. Although the takt plan defines the logistical process, logistics can be used to control production by delivering the materials to be installed to work areas according to the takt plan. Smaller material and WIP buffers require better management of prerequisites, but they also enable better management by bringing clarity to the delivery needs. Any data that accumulates in a digital material handling system offers a way to learn about production flow. (F1.3.p1), (F2.2.d), (F3.1.p1) (F3.1.p3) (F1.3.d), (F2.2.p1), (F2.2.d) (F3.1.p2)

The requirements R5, R6 and R13 cover the intent of these viewpoints. However, the use of logistics for controlling production and leveraging data in material management systems are not described in the maturity model.

Execution-level design and material planning are a crucial part of a takt production system although they are not directly a part of the production system on site. The design must be developed to serve detailed material planning to meet the planned needs. Just-in-time material deliveries to the takt plan in small batches require detailed bills of materials, especially when striving for greater production speed. The bills of quantities used for cost estimation and workload calculations are not detailed enough for industrialized material flow management. In addition to providing the design documents for the trades following the takt plan, the design process could be connected to the takt plan to deliver the bills of materials as required by the material procurement lead times. (F.1.1.d), (F1.3.p1), (F1.3.d), (F2.1.p1), (F2.2.p1), (F3.1.p1), (F3.1.p2), (F3.1.d), (F3.2.p1), (F3.2.p2), (F3.2.p3) The maturity model does not consider the dependence of material flow management on design maturity.

Client decision making is also considered here as a part of the SC. Takt production speeds up construction, which sets new requirements for the client's ability to make timely decisions. Client decision-making delays have been brought up as a cause for delays and they may also amplify the risks of trade partners who have resources committed on site. However, a takt plan is also a tool for guiding the decision-making process by bringing clarity to the required decision-making points at the last responsible moments. Decisions to be made need not follow the takt plan directly but understanding the decision-making time is important for alignment to site requirements. (F1.2.p2), (F1.2.d), (F1.4.p4), (F2.1.p3), (F2.2.p3), (F3.1.d), (F3.2.p1), (F3.2.d) The client decision-making process is not considered in the maturity model.

SCM is referred to in the maturity model in the requirements R5, R6 and R13 but the emphasis on the subject in the takt forums gives reason to highlight its importance even more. The points of view of design and material flow warrant maturity models of their own or could be detailed with sub-requirements to the existing requirements.

Suggestions for augmenting the maturity model:

- S4: The project production strategy view to SCM should be considered in the maturity model with a new requirement on level ii). This can be combined with the earlier suggestion S2.
- S5: Description of R6 should be updated to consider maturity of design to milestones set by the takt plan and to require understanding of takt principles from designers.
- S6: To level iii), a requirement should be added for the ability to standardize and continuously improve the design process and design handoffs to improve efficiency through Design for Manufacturing and Assembly (DFMA) and prefabrication.
- S7: Description of R5 should be augmented with detail of different types of material flows. Description of R13 should be updated with the use of logistics and material deliveries to control production, and the use of material handling system data for improvement.
- S8: To level ii), a requirement should be added for the ability to manage client decision making. Description of R11 should be augmented with requirements for the client.

CATEGORY 3: DRIVING CHANGE

Takt production can be a gateway to lean. Its implementation requires structuring everything in the production system, standardizing processes, and developing tools and methods to overcome problems. Takt production requires many other lean principles to be in place to work well. The journey advances in stages, first the project level, second the production system across projects, and third the corporate view, culture, and leadership. (F1.2.p2) (F2.1.p1), (F2.1.d)

While takt planning can be a gateway to lean, for many project teams especially in the US, the segue into lean came with implementation of the LPS (Ballard & Tommelein, 2021). In the LPS, takt production (called operational takt planning) was first seen as a work structuring and production method applied on the phase planning level. Work structuring is the process of breaking work into pieces to promote flow and throughput, and production strategy includes an optimization process of planning the project in interconnected but separate phases. The case study by Tommelein and Pak (2019, Figure 6) then pointed to the strategic importance of trade partner- and SC alignment to takt planning on the master schedule level (called strategic takt planning). The route to takt production via LPS is however not mentioned in the maturity model.

Previous publications also suggest that takt production can drive change (Peltokorpi et al., 2021), (Tommelein & Emdanat, 2022). The maturity model itself is built to drive change by showing takt implementation as a journey. Adding a fourth layer to the maturity model aimed at driving cultural change was conceptually suggested in (Peltokorpi et al., 2022), although it was not discussed in detail.

The maturity model implies that takt production starts with technical takt planning on site on the project level. After getting good initial results, developing social integration of the SC

and takt control begin on the organizational level. Going forward with the requirements should increase benefits until the third organizational and regional level of continuous improvement is achieved.

The maturity model was based on and validated with only with Finnish cases. Of the forum presentations, the cases (F1.3.p3) (Finnish), (F1.2.p2) (German), (F2.1.p1) (Norwegian), (F2.1.p3) (Finnish) and (F2.2.p1) (Finnish) seemed to have followed a journey similar to what the maturity model suggests. But cases (F1.1.p3) (US), (F1.2.p1) (US), (F2.1.p1) (Norwegian), (F2.2.p2) (US), (F3.2.p1) (Uruguay) and (F3.2.p3) (US) referred to LPS as a starting point to their takt journey. The Norwegian case (F2.1.p1) cited both LPS and the maturity model in their presentation. However, in all these cases, the general structure of the maturity model still seems to have been followed. This suggests that the maturity model has some international validity.

Presentations (F1.2.p4) (US), (F2.2.p3) (German), (F3.1.p1) (Finnish, cabin refurbishment instead of construction) and (F3.2.p2) (Norwegian, design process management in construction by the owner) suggest that owner demand can also function as the driver for starting a takt implementation journey. The reasons for owner demand are manifold. (F1.4.p4) and (F3.2.p2) addressed the owner's desire for clarity of milestones in a takt plan, (F1.4.p3) and (F3.1.p1) aimed for speed of production, and (F2.2.p3) pursued increased stability and flexibility in addition to speed. Owner demand as a driver was also discussed in (F2.2.i), (F2.2.p1) and (F3.2.d). One case (F1.1.p3) (US) mentioned, in addition to referring to takt production as a part of their LPS journey, an organizational lean leadership training program as a starting point. One case (F3.1.p2) (Finnish, ship building) focused on a "plan for every part" philosophy, where managing the material flow is regarded as the first step. These examples suggest that the maturity model outlines but one progression for companies to implement takt production.

Shifting people's mindsets is an important and difficult step in implementing takt production. Thinking in smaller batches, especially in the design process, is not something that people are used to and the takt principles may seem counterintuitive and constraining for people who are used to traditional production management methods. Gaining alignment with the people involved in a project can be a bigger problem to solve than creating technically sound plans. To overcome this barrier people should be prepared before they embark on takt planning. Preparation would include lean leadership training, teaching the terminology and definitions of takt production, simulation games, and showing the mathematics of takt production. On a hopeful note, it was mentioned that by bringing clarity, takt production can help with making the construction industry a less toxic environment for people to work in, which should make it more attractive to new talent. (F1.1.d) (F1.1.p2) (F1.1.p3) (F1.2.p1) (F1.2.d), (F1.4.p4) (F1.4.d) (F2.2.p1), (F2.2.p3) (F2.2.d) (F3.2.p2) (F3.2.d)

The required mindset shift is implicit in the model in R4 (Training and involvement of the project participants is ensured) on level ii) and in R10 (Formulation and development of teams) on level iii). The need for learning new and unlearning old habits is not, however, emphasized.

Integrating the SC implies developing partnerships. Supply partners all the way to the worker level should see the benefit of takt production so that they want to come back to takt projects. The value on sites is created by companies, many of which may be small and medium-sized, so to change the industry, they must be involved in developing the production system. Organizations on higher levels of maturity should provide support for the newcomers through training and building partnerships. Lean enabled by takt production can provide structure for managing different levels of hierarchy in the organization, including sharing knowledge and sustainable problem-solving at the right levels. Building a more holistic production system with takt principles should not lead to more centralized management but better onboarding, more involvement, and more transparent risk management. Building partnerships around takt production may lead the market to segregate groups of companies willing to adopt takt principles from those who are phased out because of lack of interest. Takt production will start

to dissolve trade boundaries so that the overall system can be balanced better. (F1.1.p2), (F1.1.d), (F1.2.p1), (F1.2.p2), (F1.2.d), (F1.3.p1), (F1.4.p3), (F1.4.p4), (F2.1.p1), (F2.1.p3), (F2.2.p1), (F2.2.p3), (F2.2.d), (F3.1.p1)

Partnership building is not explicit in the maturity model, although R4, R5, R6 and R8 (Barriers are tackled through continuous and collaborative improvement) on level ii) and R10 and R11 (Contractual integration) on level iii) can be interpreted to have the same intent.

Technology is seen as a part of the takt journey. Software tools are required to handle the information flows and data that comes along with detailed planning, smaller batches, and the upstream SC processes. Digital data handling leaves a footprint that can be structured around the takt production system and leveraged for improvement. Sensors, automated monitoring, and visualization tools built around the takt production system can improve situational awareness, inform workers of site conditions such as humidity and temperature, and support data gathering for improvement metrics and control (including replanning). Prefabrication and robotics may change the way work is done, and sites planned with takt can help to reveal the best opportunities to serve the overall system. (F1.1.p2), (F1.2.p2), (F1.3.p2), (F1.3.d), (F1.4.p1), (F1.4.p2), (F1.4.d), (F2.1.p2), (F2.1.p3), (F2.2.p1), (F2.2.p3)

Technological competence is not considered in the maturity model. Including a requirement for adoption of technology in the maturity model was discussed among the authors. It is however left for future research because the practical case presentations in the takt forums did not show sufficiently detailed examples to make relevant suggestions.

Suggestions for augmenting the maturity model:

- S9: To the description of the maturity model should be added that there can be starting points for takt production other than an urge from the site, projects where the Last Planner® System is used, and client demand.
- S10: A more explicit requirement for development of people should be included by modifying the description of R4 to include general lean leadership training, changing of habits, the use of simulation games, and the mathematics of takt planning to shift mindsets.
- S11: A requirement for building partnerships between companies should be added by modifying R10 to include the formulation of partnerships in addition to teams, and by emphasizing in its description that this should happen across companies. R10 should also say that more mature organizations should help build the capabilities of the runners-up.

DISCUSSION

The maturity model updated with the suggestions is presented in Table 2. In the model's description, it should be added that takt production implementation can have several starting points such as (1) urge from construction sites (2) as a part of LPS, and (3) client demand. The description modifications of requirements denoted with an asterisk (*) are not included but the authors intend to publish an updated model with this detail in the future.

In the process of writing this paper, a discussion came up regarding the importance of legal and commercial terms between the owner, trade partners, and labor, to drive change in the behavior of companies and people implementing their takt production journey. This was touched upon in (F1.4.p3), (F1.4.p4) and (F2.1.p3) but warrants further study with more data.

All requirements of the model except R7 (The common situational awareness during production is ensured), R8, R9 (Quality control is systematic and takt) and R12 (Systematic waste elimination over projects) are impacted by the suggestions. However, the intent of R7 might be impacted by new requirements addressing technology adoption. R8 and R12 relate to building partnerships and R9, that quality tends to improve in takt production, was touched upon in (F1.4.p3) and (F2.1.p3). Updates of these requirements also deserve further study.

Based on the takt forums, the maturity model seems valid for the most part, but note that companies that presented in these forums would not necessarily gain from meeting the requirements of the model exactly in the order presented, level-by-level. Every company is on its own journey; nevertheless, this raises the question whether some requirements should be characterized differently or reassigned to different levels. This also warrants further study.

Finally, we propose two additional avenues for future research. First is to expand the model to include relevant metrics to assess the organizations' advancement through levels and requirements; and second is to explore longitudinally how implementing the model impacts an organizations' effectiveness in advancing takt production and its related benefits.

Table 2: The updated maturity model (changes in green, (*) denotes description update)

Level i)	TECHNICAL TAKT PLANNING IN ONE PROJECT PHASE (project-level)
R1	The production plan fits the client's requirements
R2	Takt areas, takt time and wagons with resourcing are unambiguously determined
R3	Effective visual management is ensured
Level ii)	SOCIAL INTEGRATION & TAKT CONTROL (project and organizational level)
NR1	All or most of the phases of the project are takt and connected
NR2	The strategic takt concept is formed before the selection of supply chain partners
R4*	Training and involvement of the project participants is ensured
R5*	The logistics are integrated and takt with the production plan
R6*	The design process is integrated and takt with the production plan
R7	The common situational awareness during production is ensured
R8	Barriers are tackled through continuous and collaborative improvement
R9	Quality control is systematic and takt
NR3	The client decision-making process is systematic and takt
Level iii)	CONTINUOUS IMPROVEMENT (organizational and regional level)
R10*	Formulation and development of teams and partnerships
R11*	Contractual integration
R12	Systematic waste elimination over projects
NR4	The design process and design handoffs are standardized to meet Design for Manufacturing and Assembly (DFMA) and prefabrication requirements
R13*	Industrialized logistics and material flow
R14*	Standardized, takt-based work quantity libraries
R15*	Improving through KPI's and data-driven decision making

CONCLUSIONS

In this study, we revisited the takt production maturity model formulated in 2020. This was done by analyzing recordings of three online takt forums held in 2022 and 2023. These forums provided insights into the most recent industry advancements of takt production implementation, thus providing grounds for validating and updating the model.

When revisiting the model against the forums' insights, even though the models' initial levels and requirements reflected the industry's experiences quite well, we found several interesting areas where the model could be updated to reflect the current state of practice. Through three formulated categories (strategic takt planning, supply chain management, and driving change) 11 suggestions (numbered in the findings section) were presented to update the maturity model. Following these suggestions an updated version of the maturity model table was presented.

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