

# BUILDING THE CAPABILITIES FOR TAKT PRODUCTION PERFORMANCE MEASUREMENT

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## ABSTRACT

Decades into the digital age, we are still struggling to manage construction production based on data. Past lean construction research has developed management processes such as takt production that use data; however, little attention has been paid to the data collection and processing capabilities. This study explored the challenges of building these capabilities. First, we sought potential performance measures and identified their data source requirements. Second, we examined the database of an ongoing takt production multiple case study to uncover the suitability of prevalent production-related data to fulfil these requirements. We found that progress tracking data was mostly available in all projects although not always of high quality. However, issue tracking and quality control data were predominantly either missing or disorganized. Furthermore, indicators were hardly produced even when data was available. Despite shortcomings in the observed data handling capabilities, encouraging practices were also observed. As a conclusion, we propose that standard operating procedures and technology integration are pivotal for building data-based performance measurement capabilities in construction, especially in takt production. While a detailed roadmap of developing these capabilities is a task for future research, we propose that raising awareness about data management practices is a crucial step in that direction.

## KEYWORDS

Takt production, Key performance indicators, Data-driven management, Capabilities

## INTRODUCTION

The ability to understand the current status sets the basis for steering and improving any production system. Hence, high-performance production requires collecting accurate data and processing it into information. This type of data-driven management includes performance measurement capabilities that would be desirable for construction companies for many reasons. For example, performance measurement enables aligning project-level goals with strategic goals, and facilitates communication across the organization (Kagioglou et al., 2001). The project-level performance goals should then be translated to key performance indicators on the

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operational level. These in turn should align local production-level decision-making with the company's strategic direction (Costa & Formoso, 2003). Furthermore, the ability to measure and therefore see changes in performance forms the basis of any continuous improvement cycle (Koskela, 1992). Similarly, comprehension of current performance is the first step of building situational awareness systems to aid and improve production control (Endsley, 1995). These broad benefits are lost without data management practices to support them.

Along a similar vein, lean construction research has contributed management methods that use data and instill performance measurement practices. For example, the Last Planner® System (Ballard, 2000; Ballard & Tommelein, 2021), Location-Based Management System (Kenley & Seppänen, 2010) and takt production (Frandsen et al., 2013) all both produce and utilize production performance related data. As an example with a continuous improvement focus, Lehtovaara et al. (2022) called for a data platform for a Failure Modes and Effects Analysis framework. Moreover, Alhava et al. (2019) presented an example of an integrated digital data platform to gain insight from the digital footprint of a project. These methods, processes and practical examples, however, scarcely clarify how their prerequisite data management capabilities could be built.

In this study, we aim at these prerequisites by examining current performance measurement practices and by looking for barriers to building the relevant data management capabilities, with a focus on takt production. Past research has proposed several guidelines concerning definition, implementation and evaluation of performance measurement systems (Costa & Formoso, 2003; Costa & Formoso, 2004; Lantelme & Formoso, 2000). More recently, Barth and Formoso (2021) studied how a set of case companies use performance indicators, and, further, developed a taxonomy of performance metrics for lean production systems. Other relatively recent publications have also featured different types of data-driven management systems in action (Dlouhy et al., 2018; Hamzeh et al., 2019). Through a closer look into the more specific procedures, Keskiniva et al. (2021) pointed out in a single case that even with modern technology data collection and management is associated with a significant burden. However, a previously barely explored route to address the issue of how performance measurement capabilities could be built is to take as the starting point the prevalent availability of data in construction projects.

Hence, we repurposed an ongoing multiple case study by examining its database from this angle. We narrowed our approach around takt production because of its data-intensive nature and growing use in practice. The repurposed case study also focused on takt production and therefore aligned well with the purpose of this research. Incidentally, takt production principles also provide certain structure to the data management issue, which can be an advantage. To begin, we gathered a set of candidates for takt performance indicators from the literature, grouped them according to their data requirements, and assessed their availability in the cases accordingly. For further insight, we tested the fitness of a set of statements designed to describe data-driven management capabilities on the cases.

## METHODOLOGY

The multiple case study approach was a natural choice to investigate data collection and processing procedures in takt production because it is a contemporary phenomenon in a hard-to-discern context (Yin, 2018). However, the method in the present research resembles an archival analysis, because we repurposed an existing database of another case study. Although the original case study was not designed for the purpose of this paper the data were suitable with certain limitations. Also, we benefited from the direct observations in the original study in addition to the archived data.

We present general descriptive features of the 8 cases examined in this study in Table 1. All cases were indoor phases of Finnish building construction projects, but they represented both

renovation and new construction of different complexities and takt times. We evaluated complexity by qualitatively assessing the variability of workloads and space sizes in the building. The sizes of the cases also covered a wide range from 5 000 m<sup>2</sup> to 95 000 m<sup>2</sup>. As part of the original case study research, schedule progress records of some form were gathered from all the cases. In addition, any available issue, quality or material flow management data sources were sought for with varying success. The availability of these data and the data management practices in the cases are presented later in this paper as a part of the findings of this study and therefore not described here in detail.

Table 1: Description of cases examined in the study.

	<b>Size [m<sup>2</sup>]</b>	<b>Takt time</b>	<b>New / Renov.</b>	<b>Workload variability</b>	<b>Space size variability</b>	<b>Management team experience &amp; training</b>	<b>App</b>	<b>MM</b>
1	5 000	2 h	New	Small	Small	Some	S	Y
2	3 400	4 h	Renov.	Moderate	Moderate	Little; received coaching	TSA	N
3	9 900	1 d	New	Moderate	Moderate	Some	TSA	N
4	8 600	1 d	New	High	High	Some	S	Y
5	95 000	1 d	New	High	High	Experienced	S+	Y
6	15 000	2.5 d	New	Moderate	Moderate	None; some training	TSA	P
7	5 500	2.5 d	Renov.	Moderate	Moderate	None; some training	S	N
8	65 000	5 d	New	High	High	Some	TSA	P

Notation: App: Schedule application type; S: Spreadsheet-based schedule; S+: Spreadsheet-based schedule with specially developed synchronization features; TSA: Purpose-built cloud-based takt scheduling application; MM: specialty material management contractor; Y: yes; P: partially; N: No

The management teams were responsible for making sure data was gathered in all cases, although in cases 2 and 5 workers were also encouraged to take part in it. As software tools, both various purpose-built cloud-based takt scheduling applications and spreadsheet-based schedules were used. Case 5 was special in this regard; they used a self-developed integrated data platform that synchronized the spreadsheet-based schedule automatically with their specialized quality control application. Case 7 on the other hand started with a takt scheduling application but switched to a simpler spreadsheet-based schedule during the project. For quality control, all cases used a purpose-built cloud-based application. For material flows, cases 1, 4, and 5 had an external contractor who used a purpose-built software to manage them. In the other cases, material flows were managed with various mostly spreadsheet-based means, even when an external material management contractor was partially used. These features impacted the ways in which data accrued in the cases, so it was deemed important to highlight the role of the material management contractor in the cases.

The original case study design selected cases based on progress record data availability; hence, the case study design ensured the availability of these data. This could also be considered as a bias against other types of data sources considering the purpose of this study. On the other hand, arguably the cases that were able to provide progress records had higher chances of producing other kinds of data as well.

As a limitation, some of the data sets were incomplete because the cases were still ongoing at the time of writing. The first author visited all of the cases at least once and had the opportunity to discuss with the site management team their takt production practices. The limited amount of observation and participation may have caused us to miss some deeper features of the cases, but the breadth provided by several cases more than compensated for this for the purpose of this study.

To begin we searched the literature for performance indicators. Next, we identified the types of data that they require to be calculated. We then grouped the indicators based on their function and data requirements. Finally, we looked at the case datasets to evaluate the availability of the data required by the indicator groups. While doing this, we also made observations about the corresponding data management practices in the cases.

We chose the indicators based mainly on their fitness for takt production performance assessment and for being close to the operational level, as opposed to broader measures, such as the financial performance of the companies involved. We did not pursue an exhaustive list; instead, we sought to cover the common project goals of scope & quality, delivery, and cost effectiveness. In addition to these goals, the selection was also guided by the lean principles of waste reduction and continuous improvement. To avoid duplication, we also left out indicators that would have conveyed similar intent to any of the selected ones.

## **FINDINGS**

By reflecting on the case study findings, we describe here first the data source types required by the indicators and then the indicators themselves. We chose this reverse order of description, because some of the indicators require more than one data type. To conclude this section, we evaluate the availability of the indicators in the cases and the fitness of a set of statements about data-driven management on the cases.

### **DATA SOURCE TYPES**

#### **Start and end times**

These are the recorded start and end times of each wagon in each takt area. The takt time, that is, the batch-size of the schedule defines the granularity of the progress data.

All the cloud-based takt schedule applications used in the cases had direct support for recording these data. However, the timestamp that the applications record at the moment of data entry is not necessarily the correct start or finish time of the wagon. Most records are not entered at the exact time of the event. In situations where only a timestamp of data entry was recorded, inference based on other sources is required to find out the actual start and end times. For example, a wagon recorded as done one day after its planned end time could be inferred to have been completed as planned, especially if the next wagon started on time.

In cases where progress was recorded in a file-based schedule such as a spreadsheet, extra effort was needed to extract the data using the file version history. In these cases, the granularity of the data depends not only on the takt time but also on the frequency of versioning.

#### **Stopped times**

This refers to the start and end of any time that a wagon is stopped after it has started for the first time but has not yet finished. The distinction from the wagon start and end times is useful because this allows a finer view of the waste that might reside inside the wagons. The takt time of the schedule defines the granularity of these data as well. Batch-size reduction also diminishes the importance of these data, since the shorter the takt time is, the more the start and end times cover any stoppages.

All the cloud-based takt schedule applications had a feature to record the stopped times. In contrast to the wagon start and end times, the stopped times are more difficult to record because the moments of stopping and restarting are harder to evaluate. These data can also be recorded in spreadsheet schedules although with the same limitations as with the start and end times.

#### **Labor hours or actual resources**

Labor hours are simply the records of the time each worker has spent on site with the purpose of working on a wagon in a takt area. These are essentially the personal start and end times and

stopped times of each worker in each takt area. Slightly different, actual resources are the recorded number of workers that worked on each wagon and as such a coarser type of data.

Some but not all of the cloud-based takt schedule applications had a feature for recording the actual resources and labor hours. On the other hand, the labor hours could be calculated from all of the applications if each worker had an account in the system, had all their personal tasks predefined in the schedule and they entered the start and end time of each of the tasks. However, none of the schedules were constructed this way.

Other ways to record labor hours and actual resources can be separate time sheets filled by the workers themselves, access control devices such as gates, or worker tracking sensors. These may, however, require a separate data source to know which tasks the workers are assigned to.

### **Plan versions**

This data source type includes the version history of all plans related to the production phase in question. In a takt production context these data refer to the version history of the takt plan and to any separate plans or logs used to manage the make-ready process of wagon prerequisites.

None of the cloud-based takt schedule applications used in the cases had explicit support for recording the version history of the schedule. However, this functionality could be mimicked by manually copying and saving the schedule version at regular time intervals. The whole schedule evolution history could also in principle be reconstructed from the change log entries of the schedule database if they exist. The applications had also varied support for managing and recording data about the make-ready process.

The spreadsheet-based schedules produced a version history of the plans more naturally since the file versions were already being copied regularly for the purpose of progress records. However, analyzing the plan evolution requires considerable effort especially if no clear formatting procedures have been followed. Moreover, data related to the make-ready process could not be integrated into the schedule and therefore either did not exist or was disorganized.

### **Issue & quality logs**

This data source type refers to any kind of lists, tables or other logging systems that contain records of plan deviations related to production or quality. Each entry of this type implies the requirement of some type of activity to make up for the deviation. This activity could be a production task to be replanned or a make-ready task such as moving materials.

All the cloud-based takt schedule applications had a feature for raising and resolving production issues related to a takt wagon. Although the applications provided various tools to manage the issues, the issue description and relevant timestamps would be automatically recorded in a database through the use of these features.

Some of the schedule applications also provided features for quality checking. However, all cases used another cloud-based application dedicated to quality control. Similarly to the production issues, descriptions of quality issues and the timestamps of raising and resolving them were automatically recorded in the application database. But since this database was separate from the schedule application, the linkage between quality issues and takt wagons in the schedule relied mostly on manual entry procedures.

In situations where no purpose-built schedule or quality control application was used issues were handled in various other ways. These included issue lists in spreadsheets, mobile instant messaging groups, pen and paper notebooks, whiteboards either on site or at the site office, e-mails and meeting minutes. Of these the spreadsheets provided a data source with potential for further exploitation. In the others, however, the data was too disorganized for any such purpose.

### **Material flow records**

The material flow records refer to the timestamps of material packages flowing through the stages of the supply chain. In a takt production context the material packages are divided into

wagons and takt areas, and the most relevant stage is the timestamp of finished delivery to the designated area on site. In addition to the final delivery timestamp, other stages inside and outside the site could also be recorded.

The external material flow management contractors used purpose-built software applications that recorded the contents of all material packages and delivery timestamps. Hence, the material flow data accrued as a result of the material management process in cases that used such a contractor. Moreover, issues related to the delivery could be recorded in these systems, such as observations of broken materials. This provided another separate data source that resembled the issue & quality log data type.

Cases that did not employ an external contractor for the purpose had various other means of managing the material flows. Similarly to the issue & quality logs, these means left only disorganized records that are difficult to exploit for further purposes.

### Improvement archives

Following the lean principle of continuous improvement, we sought any recorded evidence of improvement activities in the cases. Examples of these could include memos of kaizen events and gemba walks or A3 reports on improvement projects. The depth of observation and participation in the cases was limited and we could therefore easily have missed some improvement efforts. However, we did not encounter any recorded evidence of systematic improvement activities in the cases.

### Costs & completion rates

A takt schedule can provide structure to the cost data of a production phase. Each wagon in each takt area can work as a data container for the planned and actual cost. They can also have a partial completion rate although their relevance decreases as the batch-size reduces.

Cost data was not in the scope of the original case study design, and they were therefore not included in the datasets. However, through observations and discussions it became clear that most of the cases controlled costs at a less granular level than the batch-size of the takt schedule.

## INDICATORS

This subsection describes the relevant indicators for takt production performance measurement. However, we first summarize the data sources and the indicators in Figure 1 to illustrate their somewhat entangled relationship.

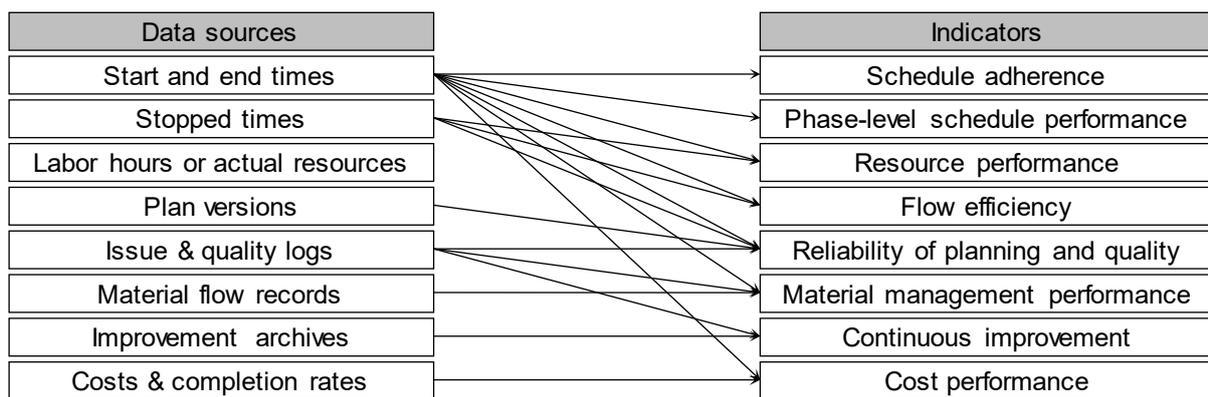


Figure 1: The data source requirements for the groups of indicators

### Schedule adherence

Schedule adherence can be measured in several ways. The indicators in this group can be calculated if the start and end times of each wagon in each takt area are recorded.

Keskiniva et al. (2023) introduced several indicators of this type. (1) *The punctuality* is the difference between actual start (or end) time and planned start (or end) time of each wagon in

each takt area. (2) *The wagon start (or end) interval* indicates how much the interval between the start (or end) times of two adjacent takt areas of a wagon differ from the takt time. (3) *The wagon duration and work in progress (WIP)* represent the amount of takt times and takt areas that a wagon actually occupies relative to what was planned. Related to this, (4) *the wagon overlap* indicates to what extent a wagon occupies takt areas that were planned for another wagon (Keskiniva et al., 2023).

The construction flow index parameters introduced by Sacks et al. (2017) can also be adapted for takt production. While (5) *the sequence adherence* tracks whether wagons are executed in the planned takt area sequence, (6) *the continuity* points out any breaks at the time of these takt area transfers (Sacks et al., 2017).

The last indicator in this group, namely, (7) *the percent complete per takt*, has found use in practice based on the author's experience. This is simply the percentage of planned wagons that were completed during a takt time.

### **Phase-level schedule performance**

The start and end times also enable indicators to assess schedule performance on a broader phase level. Lehtovaara et al. (2021) introduced indicators of this type. (1) *The lead time* is the total duration of the takt phase from start to finish. (2) *The batch-specific lead time* is the duration of an individual takt area within the takt phase. (3) *The production rate* is the speed of production, that is, how fast the trades progress through the locations. This is essentially set by the proportion of the takt area size to the takt time (Lehtovaara et al., 2021). In addition, (4) *the cumulative percent takts complete* is another indicator of this type that has found use in practice based on the author's experience. This is similar to the percent wagons complete per takt but on a broader level. It is the proportion of all wagons planned and completed in all takt areas to those that were planned up to the time of examination.

### **Resource performance**

These resource-related performance measures described by Lehtovaara et al. (2021) require tracking the labor hours or actual resources in addition to the start and end times of wagons in takt areas. (1) *The production tightness* refers to the average area occupied by a single worker, which can be calculated from the labor hours or actual resources by dividing the takt area sizes by corresponding worker counts. (2) *The productivity* of workers can also be calculated from the labor hours or actual resources by dividing the amount of work completed as gross area of finished work locations by the labor hours spent (Lehtovaara et al., 2021).

### **Flow efficiency**

Flow efficiency as introduced by Binninger et al. (2019) in general refers to the proportion of value adding time to the total time from start to finish of a flow unit. In a takt schedule, both the takt areas and the wagons can be interpreted as flow units. Hence, (1) *the trade flow efficiency* and (2) *the product flow efficiency* can be calculated from the start, end, and stopped times of the wagons in the takt areas (Binninger et al., 2019). The stopped times are important since they contribute to the total duration but not to the value adding time. As a measure of the flow perspective of production, the flow efficiency is a simple indicator of waste.

### **Reliability of planning and quality**

These indicators assess performance through the lens of reliability by revealing errors in planning, preparation, and final quality of the production tasks. As such, these metrics arguably correlate with waste. (1) *The planning reliability metrics* of the Last Planner® System (Ballard & Tommelein, 2021) adapt to takt production straightforwardly. Calculating them requires version records of the takt schedule, any logs related to the make-ready process, and the progress records of takt wagons. From another angle, issue and quality logs can be used to

produce indicators that assess the nature and number of defects requiring rework. While (2) *the quality inspection pass rate* gives an overview of quality reliability, (3) *the reasons for variance* provides a closer look at it (Ballard & Tommelein, 2021).

### **Material management performance**

Data accrued in the material flow management process enables various ways to measure its performance. Since logistics is a major part of any site operations, its performance is inevitably reflected in the production performance. We propose here three examples although many more could be created. (1) *The punctuality of material deliveries* can be calculated as the difference between planned and actual delivery time for each wagon in each takt area. Combined with the start and end times of the wagons, (2) *the material buffer on site* can be calculated as the difference between delivered and consumed materials. (3) *The amount of wasted materials* could also potentially be measured if the return flows of materials are properly sorted and recorded.

### **Continuous improvement**

Indicators reflecting continuous improvement efforts can be constructed from records of such activities. These could simply be counts of conducted gemba walks, kaizen events, or A3 reports.

### **Cost performance**

The cost performance of a takt phase can ostensibly be evaluated by adapting the location-based cost control method introduced by Kenley and Seppänen (2010) for takt production. The required data consists of a cost-loaded takt schedule and completion rates that could be calculated from the progress records. These data would also enable the use of the earned value method, although it is further from the operational level (Kenley & Seppänen, 2010).

## **INDICATOR AVAILABILITY AND DATA MANAGEMENT PRACTICES IN THE CASES**

We present a qualitative evaluation of the availability of the indicator groups from the case data sets in Table 2. To assess the impact of the schedule batch-size the schedule adherence indicator group was divided into three levels of granularity. Availability means here that the data required to produce the indicators exists in the case data set.

Based on the evaluation it seems clear that only the phase-level schedule performance indicators are available in all cases. These indicators rely on the same type of data as the schedule adherence indicators but require less granular or accurate data. For example, in case 1 there were gaps in progress tracking leading to only partial availability. Cases 3 and 4 had full data sets but they contained small errors that limited the accuracy. In cases 6, 7 and 8 these data were accurate, but the batch-size limited the granularity. It is worth noting that case 8 coordinated the one-week takt twice a week, but the data accrued from this process was too disorganized for producing indicators. Flow efficiency availability was similar to schedule adherence, but its accuracy was reduced by missing data on stoppages.

Actual labor hour or resource data were only found partially in one case data set, which indicates that they are not as accessible as the progress records. A similar finding pertains to the reliability of planning and quality indicators. Although quality inspection records existed in most and schedule versions in some of the cases, they were too partial or disorganized for feasible extraction of the indicators. The evaluation also reiterates the lack of recorded evidence of any improvement activities. The cost efficiency indicator group was dropped from the evaluation since these data were not included in the cases.

Another noteworthy finding was that the material management process produced well-structured although siloed data for performance measurement purposes in all cases where an

external contractor handled the process. This strengthens the view that this process has potential to contribute significantly to performance measurement.

Table 2: Availability of indicator groups based on the data accrued in the cases.

Indicator group	Case & takt time							
	1	2	3	4	5	6	7	8
	2 h	4 h	1 d	1 d	1 d	2.5 d	2.5 d	1 w
Schedule adherence: daily	P	A	A-	A-	A	N	N	N
Schedule adherence: bi-weekly	P	A	A-	A-	A	A	A	D
Schedule adherence: weekly	P	A	A-	A-	A	A	A	A
Phase-level schedule performance*	A	A	A	A	A	A	A	A
Resource performance*	P	N	N	N	U	N	N	N
Flow efficiency*	P	A-	A-	A-	A-	A-	A-	A-
Reliability of planning and quality*	D	P	D	D	P	N	N	D
Material management performance*	A-	N	N	A-	A	P	N	D
Continuous improvement	N	N	N	N	U	N	N	N

Notation: **A**: Available, **A-**: Available with limited accuracy, **P**: Partially available, **D**: Disorganized data only, **N**: Not available, **U**: Unclear, \* Up to granularity of takt time

To supplement the findings, we constructed a set of statements about data driven management and evaluated the cases based on them in Table 3. The statements are based on observations in the study and designed to clarify and to provide additional depth to the findings. Although the evaluation is based on subjective judgment, it illustrates some aspects of the current state-of-practice. For example, although some effort was put into planning the data collection procedures, they were less rigorously controlled. A reason for this may be that the technological tools had limited integrated functionality, and procedures for handling several systems in an integrated manner were found mostly unfeasible.

Table 3: Fitness of propositions related to data-driven management on a scale of 1 (does not fit) to 5 (fits very well).

Statement about case	Case & takt time							
	1	2	3	4	5	6	7	8
	2 h	4 h	1 d	1 d	1 d	2.5 d	2.5 d	1 w
Data collection procedures were clearly planned	3	4	2	3	5	3	2	4
Data collection procedures were tightly controlled	1	3	2	2	4	1	1	4
An integrated technology platform was used	1	3	2	1	4	2	1	3
Real-time indicators were available	1	1	1	1	3	2	1	2
Indicators were used to guide decisions	1	1	1	1	1	1	1	1
Production was forecasted based on data	1	1	1	1	1	1	1	1
People were trained in data driven management	1	2	1	1	3	2	1	2

It was also clear that even when the data existed, indicators were hardly produced, much less utilized. This may be another sign of lack of technological support. On the other hand, even when some indicators were made available in real time, evidence of them being used for steering or forecasting production was not found. Together with the observation that little training was provided, this suggests that these capabilities also involve new management skills.

## DISCUSSION AND CONCLUSION

This study examined takt production cases to uncover their data management practices and infer approaches for building performance measurement capabilities. Our findings indicate that fragmented data management procedures and software tools impede the generation of most performance metrics. These insights offer guidance for future research in this domain.

As an intermediary contribution, Figure 1 clarifies the relationship between various data types and indicator groups. Based on this, progress records are a central data type to collect, as they are essential for most indicators. However, additional data types are necessary to support a broader range of performance measures.

While existing progress records sufficed for phase-level schedule performance reporting, they fell short in capturing precise schedule adherence and flow efficiency indicators. Cases with shorter takt times showed that achieving 1-day accuracy in progress records is rare due to the rigorous and fast-paced demands of data collection. Conversely, longer takt times ensured more stable progress records but sacrificed granularity. The complexity of the building, targeted production speed, and management team maturity arguably influence the choice of this balance. However, no clear conclusion about the more advisable balance of these factors could be drawn from these cases, which motivates further research into the topic.

Our study also highlights that software tools and their usage in data management remain fragmented in takt production. Although purpose-built scheduling applications offer advanced features, spreadsheet schedules often win out for simplicity and flexibility. Despite their capabilities for progress tracking, resource recording, and issue management, scheduling applications are underutilized due to a lack of standard operating procedures and training. Moreover, these tools do not support planning reliability metrics and version control, which would be valuable additions. Notably, cases that favored spreadsheets achieved similar progress records and more complete and accurate schedule version datasets. This was possible with self-developed low-code solutions in the spirit discussed by Martinez and Cisterna (2023). Such an approach could also be employed to integrate the issue and material flow management systems with scheduling, which could enhance the availability of additional indicators.

Intriguingly, we found no evidence of systematic improvement activities. According to Tommelein and Emdanat (2022) takt production serves as an enabler for other lean construction tools. The absence of such evidence likely does not indicate that no improvement occurred; rather, it suggests a lack of organizational maturity, such as described by Lehtovaara et al. (2020), even among the more experienced management teams.

Furthermore, despite the lack of cost data in the database, site visit discussions suggested that costs were controlled with a less granular batch size than schedules. This is reasonable since the principles and benefits of batch size reduction in schedule control may not directly apply to cost control. Future research could adapt the LBMS cost controls presented by Kenley and Seppänen (2010) to takt production and seek to establish these principles.

Another noteworthy observation was that the two significantly larger and more complex cases placed a greater emphasis on data management. This finding is unsurprising, as larger projects generally allocate more resources for these purposes, while smaller projects can be managed more effectively with tacit knowledge. This disparity, however, underscores the challenge of scaling data-driven management practices across the entire industry.

Although this study limited to interior phases of Finnish projects, the findings likely reflect broader industry trends. Furthermore, despite the limited depth of the study, the observed similarities across cases suggest these findings could be indicative of more general conditions.

In conclusion, this study showed that fragmented data management procedures and insufficient technology integration severely limit the ability to measure takt production performance. We urge researchers and practitioners to develop and document standardized procedures to facilitate the development and implementation of technological applications.

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