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HANDOFFS BETWEEN TAKT TRAIN WAGONS: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Recent years have seen increased use of takt planning. With takt planning, trades are organized as wagons in a train moving through takt areas in the building. Using takt plans may result in hundreds of handoffs, where finished takt areas are passed on to the subsequent wagons in the train. How these handoffs are carried out can significantly impact a project.

This paper aims to gain an overview of the research literature on takt handoffs in construction projects. The paper identifies and analyses what has been written about handoffs in the takt literature through a structured literature review. The study identified 122 papers on takt in construction. While none of the identified papers dealt directly with handoffs, 22 had some discussion of handoff-related issues.

From the literature, the paper identifies several issues related to takt handoffs and possible solutions – most notably: 1) To ensure successful handoffs, capacity buffers and progress control may help ensure that the takt areas are completed on time. 2) Requirements for what wagons must do before handoff should be clear to avoid problems that can delay the entire train. 3) Contracts that structure payments after handoffs of fully finished areas will incentivize the wagons to finish their takt areas before the handoff. 4) A handoff protocol can be a helpful tool for structuring handoffs.

KEYWORDS

Lean construction, takt planning, handoff

INTRODUCTION

Over the past decade, takt planning has experienced increased attention – both within the lean construction community (Halttula & Seppänen, 2022) and the construction industry as a whole (Lehtovaara et al., 2021). The method has been used in several countries, such as the United States (Frandson et al., 2013), Germany (Haghsheno et al., 2016), Norway (Vatne & Drevland, 2016) and Finland (Lehtovaara, Heinonen, et al., 2020).

The term takt is probably best known in connection with music, where musical works are broken down into beats with a fixed frequency (Haghsheno et al., 2016). This principle has been transferred to the construction industry, where projects are broken down into work packages that can be carried out within a chosen time interval. Several specific approaches exist to manage projects in this way – notably Takt Time Planning (e.g. Frandson et al., 2013) and Takt Planning and Takt Control (e.g. Binninger et al., 2017). Both aim to create continuous project flow by balancing work packages so they can be carried out at a steady frequency – i.e., takt (A. Frandson et al., 2013). This paper uses *takt planning* to refer to all takt-based planning approaches.

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Building projects involve multiple trades with interconnected tasks that must be completed in a specific order. The workflow is characterized by chains of dependent tasks, which Tommelein et al. (1999) refer to as parades of trades. These occur in several areas of building projects, such as structural, technical and interior work. A parade of trades is similar to an assembly line; however, instead of the product moving through workstations, the workstations move through the product.

Takt-planning typically visualizes parades of trades as trains (Haghsheno et al., 2016). Each wagon in a train has workers, primarily from only one trade, who have fixed work tasks. When organized in the correct order and joined in a train, all tasks are represented by a wagon in the takt train. The fact that the train runs on rails illustrates the dependence between the wagons – no wagons can pass each other. Furthermore, the wagons are typically tightly coupled – i.e., there is no buffer between them. Therefore, if one wagon slows down, so will all the following wagons.

Takt planning divides a project into several parts, called takt areas or zones (Binninger et al., 2017; A. Frandson et al., 2013). The train moves through these takt areas in a specific order, so each wagon is alone in one takt area at a time. Each wagon's time in a takt area is called the takt time. Since the takt time is the same in all takt areas, the size of the areas must be adjusted so that the workload for one wagon is equal in all areas. At the end of each takt time, each wagon must hand off its takt area to the subsequent wagon.

Previous authors have used both *handoff* and *handover* to refer to a wagon completing its work in a takt area and the next wagon taking over the area. However, since the term handover is also used for handing over the final project deliverable to the owner, this paper will use the term handoff to avoid ambiguous terminology. More precisely, we define handoff as the situation where there is an interface between work operations (Lehtovaara et al., 2022), and finished work is handed off from one trade to another for further work (Biotto et al., 2017).

Takt planning has several advantages, but to achieve these, the interface between the train wagons is crucial (Frandson et al., 2015), and the handoff of work is necessary for further work to be carried out (Lehtovaara et al., 2022). In other words, good handoffs are essential to ensure that a takt plan is well executed. The tight coupling between the wagons in the takt train entails that untimely handoffs will cause severe issues for the construction process. In addition, handing off unfinished takt areas also causes issues. For example, handoffs of unfinished takt areas can increase the number of production delays (Dahlberg & Drevland, 2021).

While the literature acknowledges the importance of takt handoffs, no authors have published any works focused on the handoff of takt areas between takt wagons. The past decade has seen published over a hundred papers about takt in construction – encompassing many vital aspects of takt planning – but none dedicated to handoffs. To aid future research in this field, this study identifies and analyses literature on handoffs between takt train wagons in construction through a systematic literature review. This study was carried out as part of a larger Design Science Research based study on ensuring good handoffs when using takt in construction projects.

METHODOLOGY

We conducted a systematic literature review based on the methods described in Snyder (2019). The study relied on two databases to identify literature; Scopus and IGLC.net. Scopus is one of the world's largest databases for peer-reviewed literature and contains literature from the most prominent journals in many disciplines, including construction. Most peer-reviewed literature on takt can be found here – including most papers published through the IGLC. However, Scopus can be a year or two behind the IGLC conferences and what has been published on IGLC.net. Therefore, we conducted a supplemental search in the IGLC.net database.

Figure 1 illustrates the flow for identifying, screening, and including papers. Given that takt is a rather specific term and that the total body of literature on takt in construction is limited, we were able to start with broad search terms. First, in Scopus, we used the search string "TITLE-ABS-KEY (takt AND construction)" to identify all the works in the database related to takt in construction, yielding 106 papers. Then, with the IGLC.net database, we searched for "takt" and found a total of 84 papers; 68 were duplicates of the ones already identified in Scopus, leaving us with 122 papers.

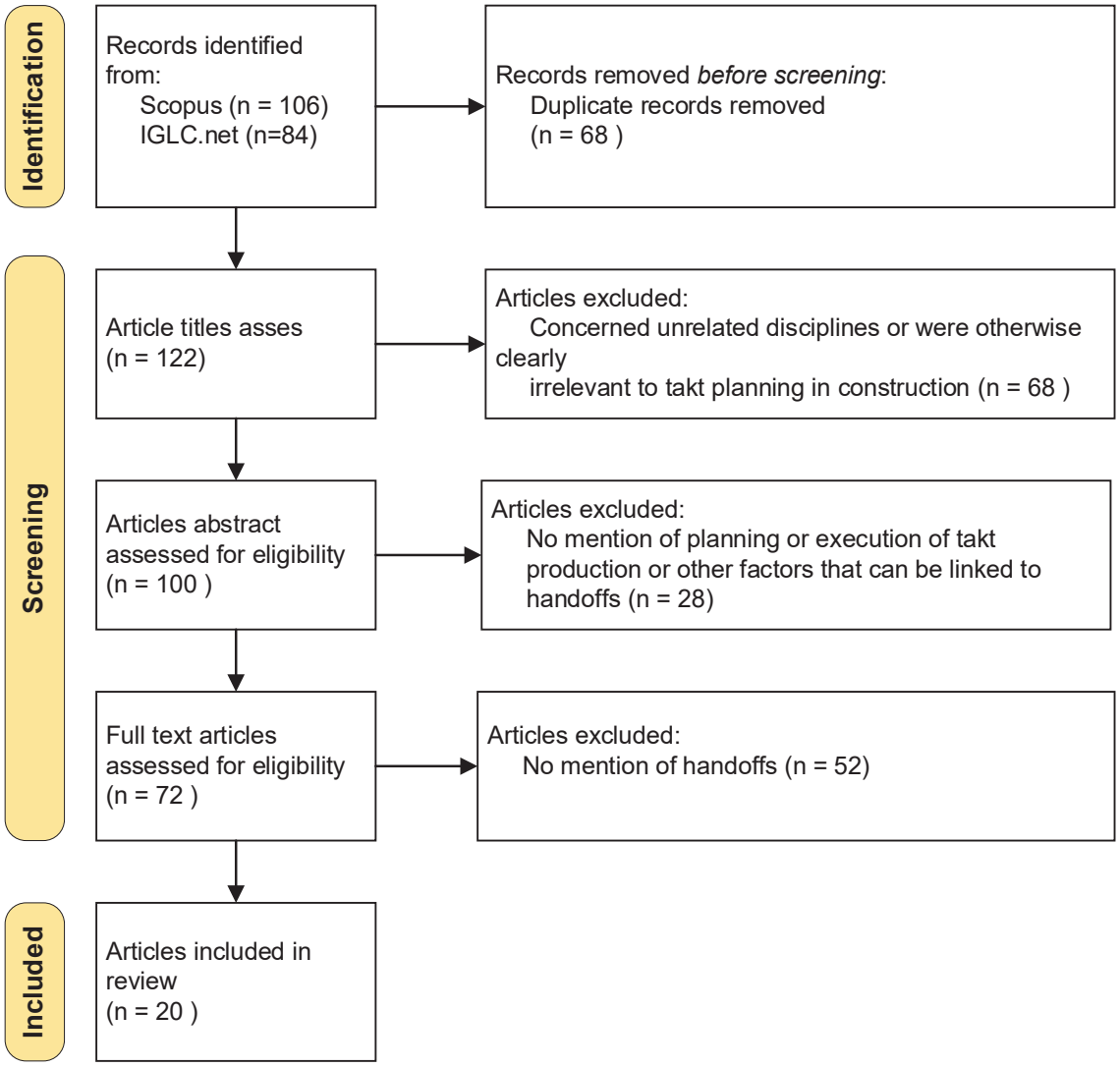

Figure 1: Literature review flowchart (based on Page et al., 2021)

In a systematic literature review, there must be clear selection criteria for the process to be transparent and accountable (Snyder, 2019). We carried out the selection process in three steps. In the first step, we reviewed the titles and excluded 22 papers that concerned unrelated disciplines or were otherwise clearly irrelevant to takt planning in construction. After that, in the second step, we reviewed the abstracts of the 100 remaining papers. Here we excluded papers whose abstracts did not mention planning or execution of takt production or other factors that can be linked to handoffs. In the third and final step, we read the full text of the remaining 72 papers and selected papers to include. Reading the full text was done to ensure we would catch all information related to handoffs. In the end, we found 20 papers that had content related to handoffs in takt.

The review relied on thematic coding analysis – per the guidelines of Robson & McCartan (2016) – to analyze the identified papers, using the computer tool *NVivo* (n.d.) to code the findings. All the selected articles were loaded into NVivo and read carefully. The codes used were created along the way and adapted as the analysis revealed new aspects of handoffs.

RESULTS

This section presents the results of the literature review. We start by making some general observations regarding what exists of literature, who has written it, and how handoff in takt ties in with the Last Planner System. Following that, we review the very limited part of the literature that describes in any detail how handoffs have been carried out in actual projects. Next, we describe several problems related to handoffs described in the literature and their suggested remedies. Thereafter, we cover how takt handoffs can be used for quality assurance purposes. Finally, we summarise the main findings from the literature review in a tabular format.

GENERAL OBSERVATIONS

What literature exists on takt handoffs?

Of the articles identified, none specifically were on handoff between takt wagons. Instead, most considered various aspects related to the planning and execution of takt plans; However, some considered planning methods in building and construction in general.

Who has written about handoffs in takt?

While conducting an extensive bibliographic analysis is outside the scope of this paper, we made some overarching observations regarding who has written anything about takt handoffs. Although there are many different contributors from around the world to the general field of takt, the papers we identified regarding handoffs cluster primarily around three international communities: The American – affiliated with Berkley (Frandson et al., 2013, 2014; Frandson et al., 2015; Frandson & Tommelein, 2016; Linnik et al., 2013; Salem et al., 2018; Tommelein & Emdanat, 2022), the Finnish – affiliated with Aalto University (Keskiniva et al., 2021, 2022; Kujansuu et al., 2020; Lehtovaara et al., 2021, 2022; Lehtovaara, Seppänen, et al., 2020) and the Norwegian affiliated with NTNU (Dahlberg & Drevland, 2021; Gardarsson et al., 2019; Haugen et al., 2020). Interestingly, while the German community behind the Takt Planning and Takt Control approach has been prolific in producing papers on takt, none of their publications directly concerned the handoff of takt areas.

LPS as the foundation of reliable and predictable handoffs

Several authors point to reliable and predictable handoffs as principles derived from the Last Planner® System (LPS) (Haugen et al., 2020; Kalsaas et al., 2014; Lehtovaara et al., 2022; Salem et al., 2018; Tommelein & Emdanat, 2022). In the context of LPS, takt planning will be a method used to stabilize production and make work events more predictable (Kujansuu et al., 2020; Lehtovaara et al., 2021; Linnik et al., 2013).

HOW ARE HANDOFFS CARRIED OUT?

Among the literature, few authors mentioned actual procedures used for handoffs in projects. Kujansuu et al. (2020) investigated a project that used weekly takt. The project contributors were satisfied and thought this fit well with their familiar weekly routines. They could use the last day to complete the takt area and carry out inspections and handoffs. One contractor in (Lehtovaara et al. (2021)'s study also preferred the use of weekly takt starting Mondays with handoffs on Fridays. Apart from these studies, only Haugen et al. (2020) mentioned any procedure used for handoff in real projects. However, the procedure was used to study the implementation of takt plans. To collect data, a handoff protocol was used. To ensure untampered data, the protocol was made jointly between the wagon that finished and the wagon

that was to take over a takt area. In the protocol, they had to note – among other things – whether the wagon had tidied the area, whether they had completed the area 100%, whether they had had to do rework in the previous takt areas, and whether they had carried out the work within regular working hours. If the area was tidied and 100% complete, it was called a perfect handoff, and the next wagon should thus be able to work independently of the previous one.

WHY DO PROBLEMS ARISE WITH HANDOFFS?

While the literature contained limited information about how projects concretely carry out handoffs, we found significantly more information about problems related to handoffs. Several prominent issues emerged from the literature review. Lehtovaara et al. (2022) highlight work not completed on time, not fully completed, of poor quality, in an illogical production sequence, or lacking the prerequisites to be completed. Yaw et al. (2020) also point out that multiple handoffs provide more chances of problems with the handoff. The interviewees of Dahlberg and Drevland (2021) voiced that delays in deliveries of materials, equipment and other necessary assumptions are the most common reason why work was not completed on time, thus resulting in takt areas not being handed off. Work not being finished for handoff was a common thread across several articles.

Takt areas not completed in time for handoff

For takt planning to be useful, all train wagons must finish their work before the time set for handoff (Frandson et al., 2015). If a wagon is delayed with its work and does not hand off the takt area on time, this will immediately affect the following wagon (Lehtovaara et al., 2022). Takt planning, therefore, uses capacity buffers to help ensure that takt areas can be handed off on time (Frandson et al., 2015).

A wagon in a takt train should only utilize 70-80% of its available working capacity (Lehtovaara et al., 2021). This way, workload variability can be managed, and delays avoided. In theory, the work should, on average, take less time than the takt time. This extra time is not wasted but can be used. For example, to prepare the takt area for handoff, assist unfinished takt areas, correct previous work, work in buffer areas outside the takt plan, quality assurance, or innovation and work on continuous improvement (Frandson et al., 2015; Lehtovaara et al., 2021, 2022). Lehtovaara et al. (2021) saw a correlation with good production control among the projects that managed to utilize this additional capacity.

The investigations of Kujansuu et al. (2020) indicate that production becomes more stable when efforts are made in the handoffs between the wagons. Lehtovaara et al. (2022) and Frandson et al. (2014) support the claim that clear handoffs in takt provide a more transparent and stable production. To achieve this stability, and ensure that the areas are ready for handoff in time, Lehtovaara et al. (2022) point to the importance of production control – including meetings, measurements and visual aids that will indicate whether the wagons are on schedule or not.

According to Frandson et al. (2015), controlling progress at shorter intervals than the takt time is crucial to determine as early as possible whether the handoffs will occur as planned. In practice, projects can do this through short daily meetings called “daily huddles”, which aim to coordinate the wagons and uncover any problems so that all of them will complete their work on time for handoff (Frandson et al., 2013; Lehtovaara , et al., 2020). With longer takt times, such as weekly takt, some also use weekly meetings for production control (Dahlberg & Drevland, 2021). These meetings should be held halfway through the takt time so that any delays are detected when there is still time to take measures to make the handoff happen on time. If it is impossible to catch up with the delay in the same week, the project can use a more invasive measure; to stop the takt train. Doing so prevents unfinished takt areas from being handed off; however, it also delays the train’s later wagons by the same time the train remains

stopped. This delay will not be possible to catch up without making significant changes to the timetable.

Dahlberg and Drevland (2021) found that wagons handing off unfinished takt areas can lead to even more delays later in the takt train. The reason for this is the irrational way wagons must work to circumvent the unfinished previous work, and the lack of sound conditions to carry out their work. It also results in wagons having to return to previously completed areas to correct the non-completed work. All of this can contribute to what they call a parade of delays. Salem et al. (2018) saw a similar effect. They observed that work that was not 100% finished but handed off to the next wagon created costly additional work. The shortcomings could be anything from the workspace not being cleaned to leaving larger tasks behind. According to Linnik et al. (2013), the work in a takt area is only complete when it is ready for handoff for the next wagon. Therefore, it needs to be clear what it takes for a takt area to be considered complete.

Different perceptions of what finished takt areas mean

According to Salem et al. (2018), some people consider their work "done" when they have done enough to allow them to continue in the next workspace. In other words, this does not include the work a wagon must do for subsequent wagons to work unhindered. Furthermore, it does not include tidying up or other work they must complete before they wholly finish an area. This thinking illustrates the difference between being "done" and "done-done."

Salem et al. (2018) found several causes of not being "done-done". In one of the case projects they refer to, no individuals were held responsible for post-work clean-up, and there were no processes to ensure that the areas were tidied after the work was completed. Frandson et al. (2013) point out that the handoff of takt areas actually provides such an opportunity to ensure that the previous work is completed.

According to Bølviken et al. (2015), handoffs must confirm that the work in a takt area has been completed and is of the right quality. Salem et al. (2018) argue that the quality of the work handed off must meet the standards of both the wagon that carried it out and the following wagons. A handoff is an interface between wagons – a lousy finish of one wagon's work will give a bad start for the next. The challenge is that the earlier wagons have few incentives to facilitate the later ones, as there are usually different people who perform the tasks.

Another finding made by Salem et al. (2018) was that there was a lack of a clearly defined standard for what was a finished area. In interviews conducted by Lehtovaara et al. (2021), it emerged that it should be clear which tasks, inspections, and tidying wagons must do before handing off an area to the next wagon. In their research, Haugen et al. (2020) used two requirements for handing off takt areas. These requirements were no more detailed than 1) specifying that the areas should be tidied and 2) the work should be 100% finished. Salem et al. (2018) provide several examples of work that must be completed to be "done-done": Tools, equipment, materials and temporary structures must be cleared away, defects must be corrected, and the area must be tidied. Linnik et al. (2013) argue that the takt plan should specify all the activities that must be done before the handoff.

Lack of incentive to finish

Keskiniva et al. (2022) investigated how contracts between main contractors and subcontractors could be adapted to takt production. One finding was that the subcontractors were incentivized not to finish in the takt areas before handoff because of how their work was compensated. Salem et al. (2018) support this finding, arguing that the traditional way of paying the subcontractors does not consider that the work will be handed off.

Traditionally, renumerating subcontractors have been based on measurements of the amount of work performed (Salem et al., 2018). There are several ways to measure the amount of work done, but no matter which one is used, the subcontractors will make an extra effort to improve the metrics on which they are measured. Doing so comes at the expense of what is not

measured – for example, quality or whether the area handed off is 100% finished. According to Keskiniva et al.(2022), such measurement and compensation schemes encourage subcontractors to leave small tasks unfinished in the work areas rather than finishing up in full before moving on

An alternative approach is to divide payments based on milestones, as proposed by Keskiniva et al. (2022). Under this method, subcontractors receive a percentage of the contract amount upon reaching predetermined milestones, encouraging them to complete work quickly and providing easy progress monitoring. Frandson et al. (2013) highlight the benefit of takt planning in measuring progress in smaller and more precise segments, and Keskiniva et al. (2022) recommend linking payments to completed work packages corresponding to takt areas to incentivize and motivate subcontractors to finish their work on time.

More handoffs lead to more problems

Yaw et al. (2020) proposed minimizing the number of handoffs as a strategy to improve handoffs – based on the reasoning that fewer handoffs lead to less time spent waiting and transferring work areas. Supporting this, in a study of six projects, Lehtovaara et al. (2021) found that the takt plans implemented with smaller batch sizes, and thus more handoffs, required more follow-up and effort from managers. They mention the organization of handoffs as a notable reason for the increased need for management. This notion could be related to the observation that small batch sizes gave less time to carry out the takt area handoffs.

Small batch sizes in takt planning have advantages such as shorter construction time (Lehtovaara et al., 2021) and lower cycle time for control of progress (Dahlberg & Drevland, 2021; Frandson et al., 2013). Yaw et al. (2020) argue that a conflict arises between the desire for smaller batch sizes and the benefits of reducing the number of handoffs. Furthermore, they say that the large number of handoffs in construction projects is due to tradespeople being so specialized that they can perform only certain tasks. A recommendation for reducing the number of handoffs is thus to make use of interdisciplinary work teams so that all trades can finish in the work areas without having to visit them several times.

HANDOFFS AS A QUALITY ASSURANCE TOOL

Several authors point out that if the handoff of takt areas is carried out in a good way, then this provides an excellent opportunity to regularly quality assure the work that has been done (Frandson et al., 2013; Haugen et al., 2020; Kalsaas et al., 2014; Lehtovaara et al., 2021; Tommelein & Emdanat, 2022). In the same way that the numerous and regular handoffs in takt planning provide immediate feedback on progress, projects can also use handoffs for quality assurance (Frandson et al., 2013). Lehhtovaara et al. (2020) point out that errors can be corrected immediately among the advantages of using handoffs for quality assurance. The need to return to previous takt areas for rework – disrupting the work of others – disappears. Instant feedback about errors also makes those who cause an error aware of it. Thus, they avoid making the same mistake several times. Over time, they make fewer errors, yielding improved quality. Quality assurance in the handoffs can thus prevent subsequent cars from continuing to work in areas with errors (Tommelein & Emdanat, 2022).

SUMMARY OF FINDINGS

Table summarises the main findings presented and discussed previously in the results.

Table 1: Summary of findings

Findings	Source
Handoffs provide an opportunity to regularly verify progress and ensure quality	Bølviken et al. (2015), Frandson et al. (2013), Haugen et al. (2020), Kalsaas et al. (2014), Lehtovaara et al. (2020), Lehtovaara et al. (2021), Tommelein & Emdanat (2022)
Activities and completion criteria for wagons should be planned and clearly defined	Frandson & Tommelein (2016), Lehtovaara et al. (2021), Linnik et al. (2013), Salem et al. (2018)
Better handoffs contribute to stabilize production	Frandson et al. (2014), Kujansuu et al. (2020), Lehtovaara et al. (2022)
A Monday-to-Friday weekly takt with handoffs on Fridays aligns with workers' familiar weekly routines	Gardarsson et al. (2019), Lehtovaara et al. (2021)
The use of a handoff protocol can facilitate the process of handoffs	Haugen et al. (2020)
Problems with handoffs include work not completed on time, not fully completed, of poor quality, in an illogical production sequence, or lacking the prerequisites to be completed	Dahlberg & Drevland (2021), Lehtovaara et al. (2022)
Handoffs of unfinished work lead to more delays and costly additional work	Dahlberg & Drevland (2021), Salem et al. (2018)
Capacity buffers are utilized to ensure that work is completed on time for handoff	Frandson et al. (2015), Lehtovaara et al. (2021), Lehtovaara et al. (2022)
Production control monitor progress in intervals shorter than the takt time to ensure timely handoffs	Dahlberg & Drevland (2021), Frandson et al. (2013), Frandson et al. (2015), Keskiniva et al. (2022), Lehtovaara et al. (2020), Lehtovaara et al. (2022)
Payment of subcontractors should be linked to takt areas to incentivize the completion of work	Frandson et al. (2013), Keskiniva et al. (2022), Salem et al. (2018)
Smaller batch sizes have advantages, but also increase the number of handoffs, which increase the likelihood of problems occurring	Dahlberg & Drevland (2021), Frandson et al. (2013), Lehtovaara et al. (2021), Yaw et al. (2020)

DISCUSSION AND CONCLUSIONS

The purpose of this paper was to conduct a structured literature review of the literature on the use of takt planning in production to identify what has been written about handoffs between takt wagons. None of the articles identified directly concerned takt handoffs, but several papers had some material concerning handoffs. However, from the analyzed articles, the literature review identified several factors for enabling and supporting good handoffs.

One of the key aspects of ensuring good handoff between the wagons is to ensure that the takt areas are completed in time for the handoff. If a takt area is not completed, it will immediately affect the rest of the takt train. Measures that help ensure that takt areas are completed on time can be using capacity buffers and production control – in the form of meetings that follow up progress.

Setting precise requirements for what should be done before handoff can also help ensure a good handoff. People will have different notions of what lies in the term done and, thus, what they must do before the handoff. The consequences of such a vague understanding of the term

can be grave. For example, if a wagon hands off an unfinished takt area, it can affect the conditions that later wagons have for carrying out their tasks, leading to delays. Therefore, what a wagon must do before handoff should be clarified and clearly communicated.

Another finding was that the contracts with the subcontractors might provide incentives not to complete the takt areas. To ensure good handoffs – and that all wagons are entirely done in the takt areas – it may be necessary to adapt contracts specifically to takt production. By basing the payments on the handoff of finished takt areas, contractors will be incentivized to hand off takt areas that are "done-done" – i.e., 100% finished.

The literature review uncovered little regarding actual handoff procedures used in projects. Only one study contained detailed information about how handoffs were handled, employing a handoff protocol. Nevertheless, we would argue that such a handoff protocol can contribute to sound handoff. For example, in a handoff protocol, a takt wagon can record that it has carried out its work as described and that the area is tidy and ready for the next wagon. This way, a structure is created for how handoffs are carried out.

Summarizing the above leads us to four main recommendations for takt handoffs:

- Ensure that takt areas are completed on time through the use of capacity buffers and production control
- Set precise requirements for what should be done by a wagon before handoff
- Use contracts adopted for takt construction
- Consider a handoff protocol to structure the handoff procedure.

Concerning further work, it is evident from the literature review that there is a need to study takt handoffs on construction projects in more detail – how are they carried out, and how can we best enable them? Additionally, it may be worthwhile to investigate the impact of takt handoffs on project performance, such as productivity, quality, and safety. Moreover, future studies could investigate the role of technology in facilitating takt handoffs and improving their effectiveness.

As mentioned in the introduction, this literature review is the first step of a more extensive Design Science Research based study on ensuring good handoffs when using takt in construction projects. Presently, we are investigating the practices of a major Norwegian contractor – aiming to develop better tools and guidelines for them to ensure good handoffs.

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