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ZONAL DELIVERY PLANNING IN THE CONSTRUCTION OF INFRASTRUCTURE PROJECTS: A CASE STUDY

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ABSTRACT

Takt Planning (TP) is a significant Lean methodology being used in construction projects. This paper analyses the implementation of Zonal Delivery Takt Planning (ZDTP) in extensive infrastructure projects. ZDTP, grounded on Takt planning principles, aligns work processes to optimise efficiency and minimise waste. The study utilises design science research to develop a logistics framework that enhances resource allocation and streamlines process. An analysis is conducted on a real-world case study of a road construction project facing significant delays. The framework, shown via a sequential process, encompasses plan analysis, zone and sequence determination, plan optimisation, and buffer integration. The research employs a work density method (WDM) to objectively analyse the productive efficiency of decision-making and determines the best number of zones, takt time, and total project length. The methodology is missing in the current state of takt and ZDTP in road construction and has been extensively examined in building projects, yet it remains underexplored in infrastructure projects, with minimal empirical findings reported. Therefore, the conducted research presents findings from a case study on the application of TP in large-scale infrastructure projects. Results demonstrate a substantial decrease in project time by 36 days and higher efficiency due to improved team organisation, increased transparency, and optimised material management. The paper closes with suggestions for further research and the use of ZDTP in construction of infrastructure and roads projects.

KEYWORDS

Zonal delivery, TAKT planning, resources optimisation, work density method, project control.

INTRODUCTION

TAKT planning (TP), derived from the German word "Taktzeit," meaning "cycle time," emphasizes the synchronization of work processes to enhance productivity and reduce waste (Kozlovská & Klosova, 2022). The implementation of TP as a planning method in the construction projects has garnered attention in recent literature, particularly regarding its efficiency and effectiveness in project management (Andreassen & Drevland, 2023). This approach is particularly relevant in the context of road construction, where timely delivery and resource optimization are critical for project success (Tommelein et al., 2024). Haghsheno et al. (2016) conducted a historical analysis of the origins of TAKT, which had an impact on its application in construction. This analysis extends back to a previous period. The number of construction projects worldwide that are implementing takt planning and control has increased in the current era. Various studies (Jabbari et al., 2020; Tommelein, 2017) have demonstrated

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that these projects are benefiting from the implementation of this approach. While existing studies have examined the theoretical frameworks and benefits of various lean methods, empirical research focusing on real-world applications and case studies in the construction sector remains limited (Yoon et al., 2016; Kamal et al., 2023). This paper addresses the significant gap in the literature by proposing a novel approach through the development of a ZDTP model, aimed specifically at resolving the inefficiencies related to project scheduling and resource allocation in construction projects. The primary objective of this research is to establish a comprehensive framework based on TP, which serves not only as a planning methodology but also as a mechanism for implementing lean thinking across the industry.

The paper begins with a detailed overview of the fundamental concepts that underpin takt planning, including its relevance to project delivery efficiency. Furthermore, it presents specific formulas used in calculating takt, supported by the rationale for their application. By illustrating the practical implementation of the ZDTP model through real-world project examples, the paper elucidates how lean tools and methods can be effectively integrated to optimize project delivery plans, thereby achieving greater efficiency and reducing waste in construction processes. Ultimately, this research aims to contribute to the creation of streamlined workflows in the construction sector, fostering a culture of continuous improvement through the adoption of the ZDTP model.

LITERATURE REVIEW

TP is fundamentally designed to enhance workflow by establishing a rhythm or cadence for construction activities, which is particularly advantageous in projects characterized by repetitive tasks. Dlouhy et al. (2018) highlight that TP can be effectively utilized across both construction and equipment phases, underscoring its versatility in various project contexts. This adaptability is especially relevant for infrastructure projects, where tasks such as paving, grading, and installation of utilities typically follow a predictable sequence.

The integration of the zonal delivery method into TP further amplifies its effectiveness by dividing the construction site into manageable zones, allowing for parallel work processes. In large-scale infrastructure projects, this zoning approach enables multiple teams to operate simultaneously in different areas, thereby reducing overall project duration (Tommelein, 2022). Liu et al. (2022) support the application of zonal management principles in construction, noting that improvements in zonal-level management practices have resulted in significant enhancements in overall project performance, particularly in modular construction (Kucukvar et al., 2021). Despite the promising applications of TP and zonal delivery methods, a critical gap persists in the literature regarding their specific implementation in road and infrastructure projects. While existing studies have examined the theoretical frameworks and benefits of these methodologies, empirical research focusing on their real-world applications in the construction sector is limited (Fish et al., 2022; Frandson et al., 2013; Lehtovaara et al., 2019). This lack of targeted exploration is particularly pronounced in the context of roads and infrastructure, where unique challenges such as varying site conditions, regulatory constraints, and the necessity for coordination among multiple stakeholders remain inadequately addressed.

Moreover, the logistical aspects of implementing TP in infrastructure projects are an area that requires further investigation. Reck & Fireman (2023) propose a framework to support takt time planning, emphasizing the significance of logistics in successfully executing TP. Yet, the current literature lacks comprehensive guidelines on effectively integrating logistics with TP in delivering infrastructure projects, indicating a notable gap that necessitates further inquiry (Fish et al., 2022; Frandson et al., 2013).

Therefore, this research aims to fill these knowledge gaps by developing a framework that enhances the implementation of both takt planning and zonal delivery methods specifically tailored for road and infrastructure projects. By addressing the unique challenges inherent in these projects and incorporating logistical considerations, this paper seeks to advance the discourse on lean construction methodologies, ultimately contributing to improved efficiency and productivity in the sector (Hamaidi et al., 2024).

METHODOLOGY

The research employs Design Science Research to create innovative artefacts aimed at resolving specific real-world problems while contributing to theoretical progress (Lukka & Granlund, 2003). This study presents an artefact that is a logistics framework influenced by the systematic methodology of TP. It is intended to serve as a zonal project delivery method to enhance the efficiency of the handover phase. The research commences by delineating a series of pragmatic issues, particularly concerning the developing and implementation of sequential approaches. The goal is to guarantee that the construction site adheres to the TAKT time specifications. The framework was developed utilizing inTakt's planning guide, published by Moore (2023) as part of a case study on a large-scale infrastructure project, as illustrated in Figure 1.

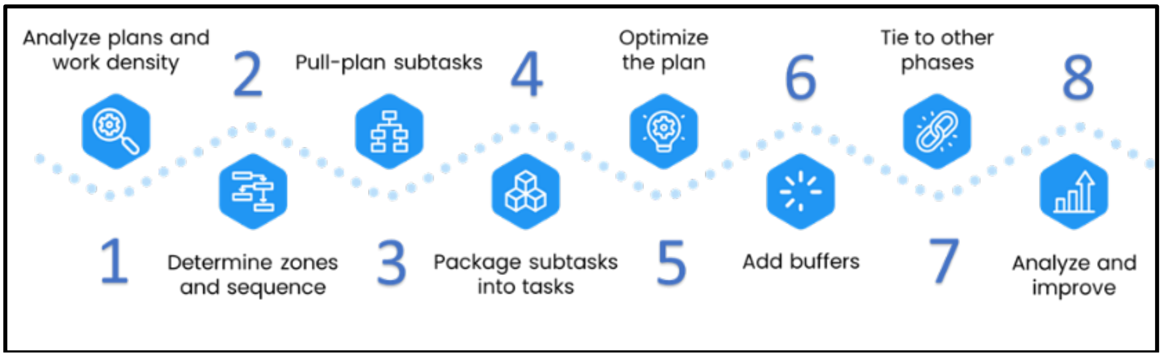


Figure 1: Methodology Framework (Moore, 2023)

Moore (2023) provided a detailed explanation of the approach to integrate takt time into continuous flow in their publication. Therefore, this paper adopts his methodology to develop a Takt Zonal Delivery Plan (TZDP) to suite the infrastructure construction works. The process comprises the subsequent eight phases and necessitates numerous iterations:

Step 1 - The plan commences with a meticulous examination of the drawings and scope of work to ascertain the necessary workload in each zone. It is the process of reviewing a comprehensive understanding of the scope. This entails examining the tasks associated with each segment of the project. Upon acquiring this comprehension, generate a comprehensive heatmap that quantifies the work necessary for each segment of the project. The WDM functions as an essential method for facilitating the establishment of equitable zones. Calculate the total for each zone of the heat map to assess their balance and make necessary adjustments.

Step 2 - The subsequent step involves partitioning the project into zones, guaranteeing they encompass equivalent workloads. It is essential to meticulously arrange these zones to efficiently facilitate site logistics.

Step 3 - Collaboration with the trades is crucial for the subsequent phase, during which a pull plan is collectively developed for a single zone, delineating the sequence of specific subtasks.

Step 4 - Then, consolidating these subtasks into tasks of equivalent duration.

Step 5 - Afterwards, investigating alternatives to enhance the quantity of tasks and zones to achieve project objectives is essential.

Step 6 - Next is performing a comprehensive assessment of risks and potential variances and incorporating suitable buffers into the plan.

Step 7 - Upon the completion of each phase, it is essential to integrate it with the other phases of the project.

Step 8 - Finally, it is imperative to convene the entire team to evaluate the plan, pinpoint deficiencies, and implement the requisite enhancements.

DATA COLLECTION

To apply theoretical concepts, we examined a particular case study that illustrated the identification of takt time and the modification of zonal delivery planning. The selected case is suitable as it centres on a project experiencing substantial delays, facilitating the implementation of takt time flow line visualization-based planning to suggest remedies and underscore the potential benefits. This study concentrated solely on specific tasks and activities associated with Zone 1 of the roadworks project to improve clarity. Thorough interviews were conducted with the contractor, project manager, and site engineer to obtain information on task specifics, crew efficiencies, and other essential details. A Microsoft Excel spreadsheet was utilised as a planning instrument to visually represent the current work schedule based on the collected data. The execution of flow line visualisation strategies allowed us to adjust the current production rates and ultimately ascertain the project's takt time. The revised tasks and activities were illustrated through a flow line visualisation schedule, in accordance with the principle of takt time. Subsequently, the previously mentioned results and deliverables were analysed and assessed, illustrating the impact of takt planning on this particular project delivery. The project comprises 338 residential plots, two mosques, utility plots, a government plot, one farm, and related internal roads. However, additional information regarding the project will be provided while the TZDP is being developed. It is approximately six months overdue, and there is an urgent necessity to complete it promptly. This study concentrates on the construction process, primarily addressing excavation, the laying of foul sewer and sewage water pipes, manhole installation, road cutting, utilities duct installation, road gully installation, kerbstone installation, and the installation of road-base and base course. This case study was ideal for this paper due to the considerable repetitiveness of its construction tasks.

DATA ANALYSIS

This section provides a concise overview of the computational foundations of TP and the mechanisms it offers to evenly distribute workloads and create a smooth workflow, based on the employed TZDP. Takt, also known as takt time, refers to the specific time period in which a product must be produced in order to meet the required demand rate (Ricondo et al. 2016; Gunduz & Ayman, 2019). Takt is determined in manufacturing settings using the following calculation:

$$Takt = (Available\ production\ time) / (Customer\ demand) \qquad (1)$$

Takt time is pertinent to both high-volume manufacturing, which is typically measured in seconds or minutes, and low-volume high-variety (LVHV) manufacturing, which is typically measured in hours or days (Ricondo et al. 2016). Takt is also pertinent to construction, a form of manufacturing that follows a fixed-layout assembly method, similar to certain other manufacturing systems. This suggests that personnel, equipment, and resources are organized in a systematic manner to expedite the completion of tasks in designated areas. Information flows are established in accordance with design decisions and supply chain considerations (Gunduz & Fahmi Naser, 2017; Naser et al., 2023).

While takt, which is employed in construction planning, is being developed through practical experimentation, theoretical exploration, and the development of support tools, it is essential to acknowledge its mathematical underlying principles. Takt necessitates a calculation that ascertains the optimal speed at which a manufacturing system must operate in order to satisfy consumer demands (Tommelein, 2022). Demand can be categorized as either external, which represents the demand of the entire consumer base, or internal, which pertains to the system itself. This internal demand is evident in each assembly line within the manufacturing context, necessitating the synchronization of production rates between preceding and succeeding lines to collectively satisfy the overall consumer demand. In order to satisfy the overall consumer demand, it is essential that each work phase in construction projects be coordinated with the production rates of the preceding and succeeding phases. In the construction industry, demand refers to the specific project that is considered a cohesive entity and is concluded within a specified timeframe. Employees execute tasks in sequential phases, with clearly defined transitions and standardized protocols for each phase, conducted in specific locations known as zones. These zones are characterized by an intrinsic 2- or 3-dimensional characteristic and can be identified using a variety of methodologies (Tommelein & Lerche, 2023).

ZONAL DELIVERY PLAN

In executing a construction project, it is essential to delineate the work area into zones to enable concurrent operations and improve crew management at the site. WDM is employed in takt planning to visualize and analyse the distribution of work over time and space within a construction project. Illustrated by Tommelein (2022), WDM focuses on understanding how tasks are concentrated in different areas, allowing project teams to optimize workflows and resource allocation. Therefore, to develop a WDM, detailed data on the various tasks involved in a project is required. This data includes the time required for each task, the location of tasks, and the sequence in which they are to be performed. Then, the collected data is then represented on a grid or map of the construction site. Each zone on the map represents a specific area of work, and the density of work in each zone is visually indicated, often using color-coding or shading. Higher densities may be shown in darker colours, while lower densities might be in lighter shades. Takt is the predetermined duration that a trade is allotted to complete their duties for a specific step within a designated area. Several steps are included in an approach, ensuring that every stage of the process across pertinent zones are concluded within the stipulated phase or project timeline. In practice, the analysis conducted at the phase level is used to determine the construction takt, as there are substantial differences between work phases. It is seldom computed at the project level. A unique takt may be used to synchronize each phase. A phase is a set of construction activities that share similar characteristics, such as subterranean work, structural elements, overhead systems, in-wall systems, garnishes, or testing procedures. Phases are distinguished by distinct transitions, such as third-party inspections. The takt can be calculated based on a specified phase duration and the number of phase steps as follows:

Initially, it is essential to define Logistics and takt zones accurately, as illustrated in Figure 2, utilizing Schroeder (2023)'s template. Identifying initial takt zones will enable the systematic organization of installation activities. The zones will be segregated to optimize resource allocation and maintain uniform workload distribution. This will enhance the learning curve and promote mutual comprehension of the activities undertaken. This can be considered the initial phase in the development of a TZDP, with the optimization stage focusing on identifying the optimal number of zones.

Upon completion of this task and the extraction of the initial representative takt zone, it is necessary to preliminarily arrange these into work packages and Takt wagons. Upon examining the sequence, the average Takt time for each activity may become evident. The duration of each work package will determine the appropriate Takt wagon it must align with. The various sequential activities are coordinated with their respective durations through the establishment and equilibrium of work packages. These work packages are the critical tasks that must be executed with precision. Figure 3 illustrates that the work package has assigned an identical duration for construction to ensure a uniform timeline for the development of a takt's wagon. The next step in assessing the total duration of the work wagons is to generate a map, as depicted in Figure 3. It offers a detailed visual representation that highlights the required quantities and resources essential for meeting the construction timeline. A Takt sequence, or Takt train, comprises a series of Takt wagons.

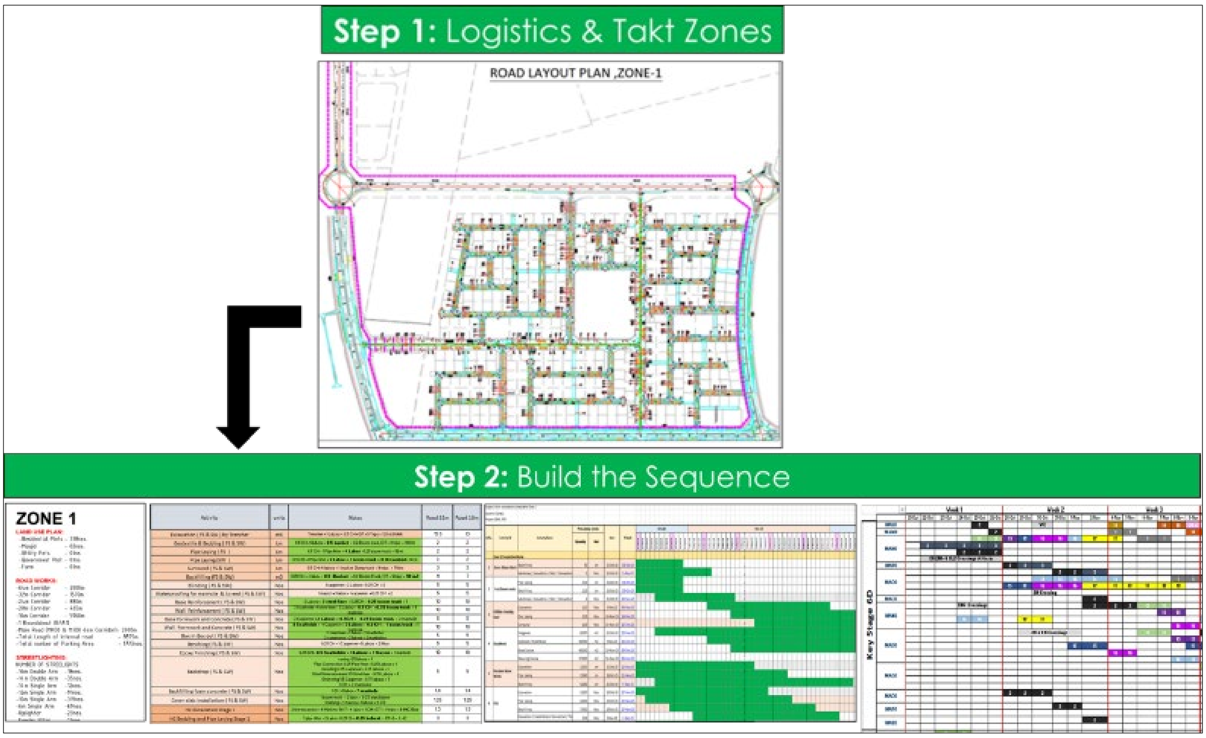


Figure 2: Logistics and initial takt zones (Schroeder, 2023)

Each Takt wagon is outfitted with one or more work packages, and each work package comprises multiple work steps. Currently, the sticky notes from the pull plan sequence have been classified as either a Takt wagon, a work package, or a work step, according to their dimensions and packaging. Comprehending the translation process necessitates guidance and expertise. Generally, an activity that entails summarising a wide range of work conducted within a designated time period may be termed a Takt wagon. A collection of tasks within the same domain, when consolidated into a succinct unit, is termed a work package. If the activity was a specific and complex element within a defined scope of work, it is likely to qualify as a work step. Currently, we need to ascertain which Takt wagons will accommodate our single representative Takt zone within one Takt time.

A Little's Law facilitates the calculation of takt time, cycle time, zone length, and total time span (Howell et al., 2001). By analyzing the mean waiting time of an item in the system and the average arrival rate of items per unit of time, a theorem is established that calculates the average number of items in a stationary queuing system.

$$Duration = (TW + TZ - 1) * TT \qquad (2)$$

The formula in equation 2 is the sum of Takt wagons (TW) and Takt areas (TZ) minus one. The product of that and the Takt time (TT) equals the throughput time or duration according to Little’s Law. A Takt sequence comprises a series of Takt wagons. Each Takt wagon comprises one or more work packages, with each work package encompassing multiple work steps, culminating in a horizontal summary of the work in that area as depicted in Figure 4.

The present initial takt zones, takt time, and sequence are all preliminary findings. A supplementary task requires completion. It is improving the efficacy of the entire Takt planning process. Equation 1 is utilised to enhance the efficiency of the ZDTP. Figure 5 illustrates the results of the optimisation process. The optimal takt zones can be determined through a programming method that assesses the efficiency of parametric values, tightly encompassing the data under particular assumptions about the production structure.

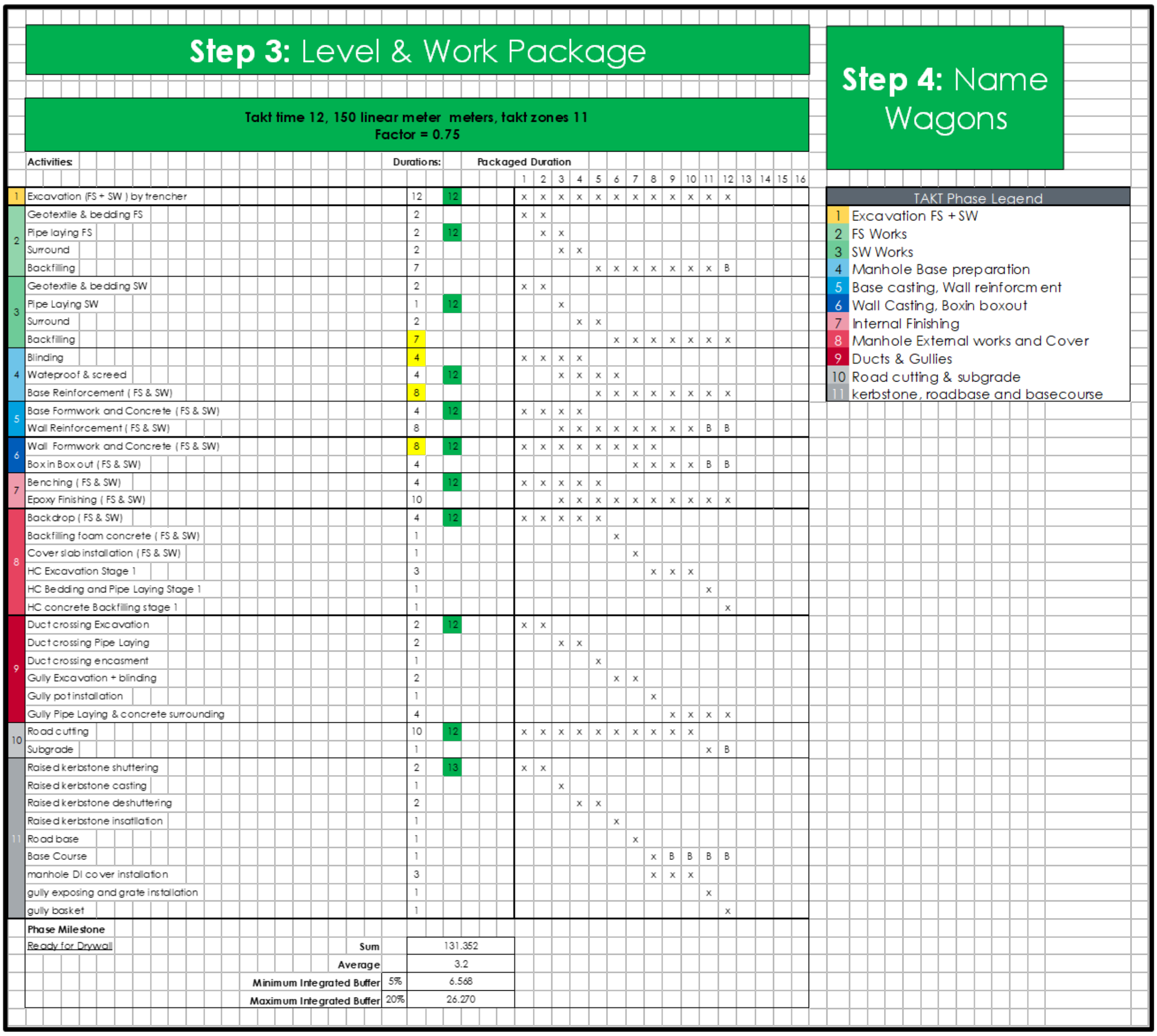


Figure 3: Work packages and Takt wagons (Schroeder, 2023)

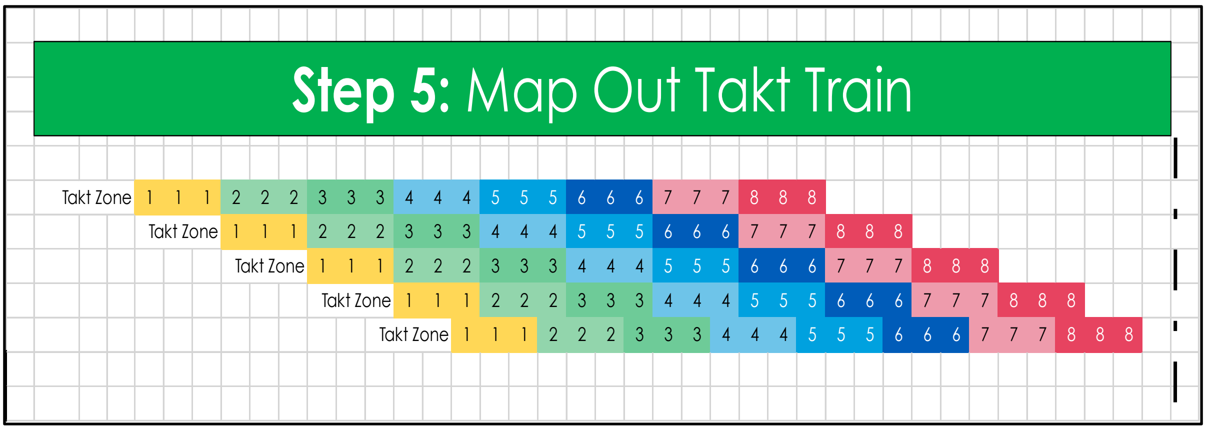
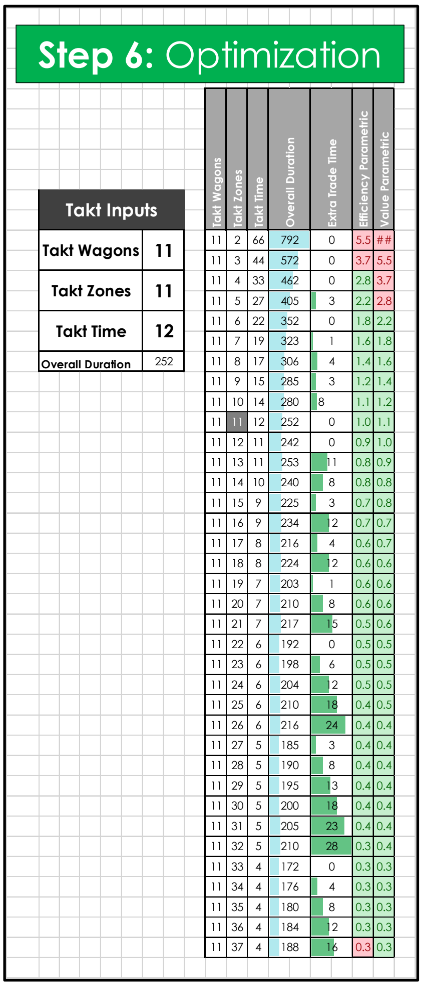


Figure 4: Preliminary TAKT Zones (Schroeder, 2023)

The work density method (WDM) employed for TP (Tommelein, 2022) to evaluate the optimal number of zones as an output, along with takt time, takt wagons, and overall duration as inputs. WDM is utilised to empirically assess the productive efficiency of decision-making.



Step 6: Optimization

Takt Inputs	
Takt Wagons	11
Takt Zones	11
Takt Time	12
Overall Duration	252

Takt Wagons	Takt Zones	Takt Time	Overall Duration	Extra Trade Time	Efficiency Parametric	Value Parametric
11	2	66	792	0	5.5	##
11	3	44	572	0	3.7	5.5
11	4	33	462	0	2.8	3.7
11	5	27	405	3	2.2	2.8
11	6	22	352	0	1.8	2.2
11	7	19	323	1	1.6	1.8
11	8	17	306	4	1.4	1.6
11	9	15	285	3	1.2	1.4
11	10	14	280	8	1.1	1.2
11	11	12	252	0	1.0	1.1
11	12	11	242	0	0.9	1.0
11	13	11	253	11	0.8	0.9
11	14	10	240	8	0.8	0.8
11	15	9	225	3	0.7	0.8
11	16	9	234	12	0.7	0.7
11	17	8	216	4	0.6	0.7
11	18	8	224	12	0.6	0.6
11	19	7	203	1	0.6	0.6
11	20	7	210	8	0.6	0.6
11	21	7	217	15	0.5	0.6
11	22	6	192	0	0.5	0.5
11	23	6	198	6	0.5	0.5
11	24	6	204	12	0.5	0.5
11	25	6	210	18	0.4	0.5
11	26	6	216	24	0.4	0.4
11	27	5	185	3	0.4	0.4
11	28	5	190	8	0.4	0.4
11	29	5	195	13	0.4	0.4
11	30	5	200	18	0.4	0.4
11	31	5	205	23	0.4	0.4
11	32	5	210	28	0.3	0.4
11	33	4	172	0	0.3	0.3
11	34	4	176	4	0.3	0.3
11	35	4	180	8	0.3	0.3
11	36	4	184	12	0.3	0.3
11	37	4	188	16	0.3	0.3

Figure 5: Takt Optimization (Schroeder, 2023)

While WDM is closely associated with production theory in economics, it is also employed for benchmarking in operations management, where a selection of metrics is utilised to evaluate the performance of manufacturing and service operations (Tommelein, 2022). The analysis of the collected data indicates that the ideal number of zones is 11. Furthermore, the calculated efficiency is 1, signifying the optimal ZDTP.

It is unwise for any schedule to anticipate complete productivity or efficiency. This indicates our intention to advance with construction without deviation, which would be deemed irresponsible (Russell et al., 2012). Consequently, the plan must incorporate buffers. In Takt plans, three categories of buffers can be employed (Russell et al., 2012): material inventory, capacity, and time. Without buffers, we face a scenario of relentless pressure, leading to failure marked by overwhelming workload, imbalance, and inefficiency, ultimately causing a waste of time. With a sufficient provision of buffers, teams can reliably sustain a state of flow. Utilising buffers efficiently conserves time, whereas their absence results in time wastage.

Results

Execution strategies were generated through the takt analysis and subsequently assessed for effectiveness. Crew requirements, identified constraints, takt targets for each phase, and the number of zones per phase were all defined by the strategies. The team investigated the escalating trade-offs between processes in order to reduce resource utilization at the site and expedite the installation process. This would allow for additional time to make decisions that would subsequently impact operations in the ZDTP. Every step within a designated process and area, linked to a particular trade, carries a workload (Singh et al., 2020). The uneven distribution of tasks will result in varying workloads across different stages and areas. Implementing workload leveling to alleviate such variation should yield the following benefits:

- Reducing the workload peak enables the selection of a lower takt, potentially leading to a decreased process duration D [Eq. (2)].
- Minimizing the variability of workloads at specific steps within a designated zone enhances the flow of process location in that area.
- Minimizing the variability of a trade's workloads for a specific step across zones enhances trade location flow, potentially aiding in the maintenance of a stable crew size and increasing productivity.
- Enhancing the capacity to assess the appropriate level of underloading, thereby bolstering crew confidence in their ability to complete tasks within the designated timeframe while maintaining productivity.
- Underloading refers to the strategic planning of workloads to remain below the takt time, thereby providing trades with an intentional capacity buffer to facilitate timely transitions.
- Following the implementation of ZDTP, the total project duration was reduced by 36 days. Moreover, 52 buffer days were effectively administered and maintained during the trade transitions both intra- and inter-zonal.

DISCUSSION

The benefits, as indicated in the literature (Tommelein & Lerche, 2023), that have been experiential with the implementation of the implementation framework of ZDTP are:

- Enhanced team organization is achieved by implementing effective layout, material management, optimized routes, and standardized work package. This includes conducting risk analysis of the layout, devising strategies for efficient storage and supply of materials, and establishing structured daily production routes and routines. Figure 3 (the "Work packages and Takt wagons" template) visually represents how activities are packaged and sequenced, which supports the idea of a structured work package.
- Improved transparency, achieved through the implementation of a visual board, as demonstrated in the defining the zonal delivery takt approach. Figures 2, 3, and 4 provide visual representations of the planning process, demonstrating the use of visual aids to improve transparency.
- Enhanced productivity was achieved by implementing a check-in/check-out routine, which streamlined the process of developing a prompt action plan to address any daily issues that arose. Figure 5 (the "Takt Optimization" template) shows how different parameters are analyzed to optimize the process, suggesting a proactive approach to problem-solving.
- Progress was made in determining the appropriate size of equipment and materials to meet the production demand specified by the Takt planning using the equipment and material drivers. The formula in Equation 2 shows how the duration of tasks is calculated based on the number of takt wagons, takt zones, and takt time, which would influence equipment and material needs.

- ZDTP is a highly beneficial tool and logistical framework that can be employed to establish the zonal delivery plan and monitor the progress and productivity by setting specific milestones. The entire methodology outlined in the paper, from data collection to optimization, demonstrates how ZDTP can be used to create and manage a detailed project plan with specific milestones.
- The noted enhancements – comprising a 36-day reduction in project duration, improved team organization, increased transparency, heightened productivity, and optimized material/equipment sizing – are directly linked to the comprehensive application of ZDTP strategies, which streamlined workflows, promoted collaboration, and facilitated data-driven decision-making throughout the project lifecycle.
- The 36-day reduction was a result of a combination of factors, including workload leveling, improved coordination, efficient buffer management, enhanced logistics, and data-driven decision-making. By implementing ZDTP, the project team was able to streamline the construction process, minimize waste, and achieve a significant reduction in project duration.

CONCLUSION AND FUTURE RECOMMENDATION

The paper defines and illustrates the influence of Zonal Delivery Takt Planning (ZDTP) on Lean Construction in the context of infrastructure. Through the integration of takt planning, zonal delivery, and a logistics framework, ZDTP reduces waste, enhances efficiency, and promotes continuous improvement, thereby addressing a deficiency in Lean implementation within road construction. A 36-day reduction in project duration, resulting from optimized workflows and expedited delivery. ZDTP improved team organization via standardized work packages, visual management, and collaborative pull planning, thereby enhancing coordination and communication. Effective buffer management, enabled by ZDTP, facilitated disruption mitigation and maintained a consistent work pace. The case study confirmed ZDTP as an effective logistical framework for developing zonal delivery plans and tracking progress. Subsequent research ought to broaden ZDTP's applicability to various construction endeavors, including high-rise buildings and renovations. Longitudinal studies are essential to evaluate ZDTP's enduring effects on project performance and Lean implementation. Incorporating risk management strategies into ZDTP can proactively mitigate disruptions. ZDTP provides a pragmatic methodology for the application of Lean principles such as takt time, workload levelling, and visual management in intricate settings. The framework establishes a basis for ongoing enhancement, allowing teams to detect and address bottlenecks, observe workflow fluctuations, and execute remedial actions. The integration of ZDTP as a core method within the Last Planner System (LPS) enhances efficiency in LPS implementation. Organizations ought to commence ZDTP implementation by initially structuring their production system according to Takt, subsequently designing their LPS implementation to maximize the benefits of production management and control. ZDTP should guide design and supply chain integration both operationally and strategically. Future advancements may incorporate cloud-based software and real-time data analytics can improve user interface and decision-making.

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