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TAKT PLANNING EFFECTIVENESS INTO ONE BILLION DOLLARS PROJECTS

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ABSTRACT

Takt Planning (TP) is a prominent Lean tool that is gaining wide applicability on construction projects; it helps assess project progress status from the beginning of a project until the end. TP techniques pinpoint the weaknesses in a project's scope of work and assist in identifying appropriate ways to integrate resources into any given project. The approach has been thoroughly studied in building projects but not on infrastructure ones, and little empirical results have been reported. Hence, this paper presents results from a case study of applying TP in mega infrastructure projects in Qatar. The paper showcases issues faced by teams during the execution of work, their TP approach to remedy the situation, their approach for integrating TP into the existing system, and the corresponding outcomes. Results show that adoption of TP helped the construction team to properly control, organize, and place resources into projects to achieve desired goals. This study is an accurate example of how TP technique can resolve project problems and provide a clear 'X-ray' to scan large projects.

KEYWORDS

Takt Planning, Infrastructure Projects, Lean tools.

INTRODUCTION

TP aims at creating flow; flow is a basic Lean management principle that allows efficient execution of construction processes (Binninger et al., 2019). Takt is a German word that means beat; Takt time is the time unit required to produce a product in a way to match demand rate of the product (Frandson et al., 2014). The concept originated in Lean manufacturing to achieve the goal of meeting customer demand (Seppänen, 2013). Put simply, in construction Takt means creating a balance between work activities' rates to ensure they advance at similar beats around similar time units to prevent waste. Implementing TP into processes results in prevention of overproduction, reduction in lead times, stability of work processes, reduction in inventory and waiting times, continuity of flow, and increase in production capacity (Haghsheno et al., 2016). Consequently, Takt time planning offers the opportunity of exposing problems, helping thereby teams to

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identify breakdowns in other processes such as identifying and removing constraints (Linnik et al., 2013).

In theory, implementing TP steps sounds manageable, but the real challenge is how to apply them successfully to a specific project which has unique characteristics. It has been observed that previous TP studies focused on building projects, and empirical results of implementing TP have been little reported (Heinonen & Seppänen, 2016). However, applying TP to infrastructure projects is more challenging because such projects are different in terms of risk and crew distribution. Unlike building projects that have mainly static work locations, infrastructure projects' work locations are dynamic, and these projects face continuous and unforeseen risks. Implementing TP into these projects requires a smooth approach to avoid disrupting the existing system. Therefore, this study presents empirical results from case studies of implementing TP in infrastructure projects. It also presents a systematic approach to integrate TP into a company's system in a way to create a harmonized holistic system of different Lean tools. The novel contribution of this study lies in applying TP to infrastructure projects, considering TP as a problem-solving tool, and presenting an approach for integrating TP with other Lean tools such as the Last Planner System (LPS). The case studies illustrate the problems faced by teams on infrastructure projects, their TP approach to remedy the situation, their approach to integrate TP into the existing company system, and corresponding results. The next sections describe previous state-of-art, present the case studies, carry on discussion, and present conclusions and future recommendations.

LITERATURE REVIEW

TP gained wide applicability in construction over the past years. For instance, Yassine et al. (2014) presented a method to align production rates and accordingly calculate Takt time. Their results proved that Takt time enhances construction workflow. Heinonen and Seppänen (2016) presented empirical results from applying TP on a cruise ship cabin refurbishment case study. A 380% increase in productivity, 99% decrease in Work In Progress (WIP), 99% decrease in quality defect, and 73% decrease in project lead time were reported as a result of implementing Takt time method. Binninger et al. (2017) described the development of a simulation game to support teaching participants about abstract Lean concepts and TP. The game proved efficiency when teaching employees in companies about Takt. Another study is the one done by Lehtovaara et al. (2019) who conducted 14 interviews and collected site data in order to assess suitability of applying TP for residential projects. Their results revealed that TP indeed shortened project duration however they listed some barriers and enablers in planning and control phases that might be embraced as basis for continuous improvement. Haugen et al. (2020) contributed to identifying general challenges anticipated during execution of TP, and highlighting Takt performance indicators which expose these challenges. Results from a preliminary study conducted showed that 16 general challenges for execution stages were linked to 4 Takt components and 5 adjustment mechanisms. The performance indicators that were used are manhours and staffing, overtime, additional choices, returns, perfect handovers, and PPC. Singh et al. (2020) developed an interactive tool for visual management that is based on work density to support TP. The tool showcases potential value of having readily available work density data to support what-if type of analysis in assessing if desired Takt time can be met given certain production rates, zoning, and other considerations. Another study done by Slosharek et al. (2021) went further into integrating TP with sustainability of construction processes. They established a conceptual framework that helps assessing the environmental aspect of construction processes through an interdisciplinary approach using Life Cycle Assessment (LCA) and TP. It is stated that this method forms a starting point into a holistic approach for assessing sustainability of construction processes.

RESEARCH METHOD

Dlouhy et al. (2018) described construction work content through distinguishing three detail levels namely macro, norm, and micro-level. As the name signifies, macro-level entails minimized detail depth, and it is used for decision and communication basis. The norm-level entails coordinating construction processes with an average detail degree. As for micro-level, it is the lowest, most detailed level that represents actual progress of construction processes, and where work packages are itemized (Dlouhy et al., 2018). Since the knowledge acquired at micro-level transfers automatically to norm-level, impacting future planning, and norm-level responds to findings at micro-level through harmonizing workloads (Dlouhy et al., 2018), this paper poses the question of whether TP should be implemented simultaneously on both micro and macro-levels. And if so, what would be the correct steps for proper TP implementation and integration with existing systems. The study adopts a case study research method that is analogues to the one by Hartmann et al. (2008) to aggregate results from a case study in answering the posed question. The unit of analysis is the detail level of construction work content. The adopted method differs from traditional multiple case design method proposed by Yin (2003) in that it advocates summarizing findings from different cases, offering a broad overview of actual state of TP implementation, instead of replicating multiple cases' findings. A TP approach that is based on previous studies is amended and adopted throughout the study. Research is carried out with applying TP at micro-level (stage one), applying TP at macro-level (stage two), aggregating results, deducing conclusions, and presenting a proper way of integrating TP with existing systems.

CASE STUDY

BACKGROUND

This study intends to show how TP method is tested by application, and its positive impact on the delivery of multiple large-scale infrastructure projects. The company handles multiple large infrastructure projects simultaneously. Generally, when work commences on multiple projects, the project team only applies common Lean tools and concepts such as LPS system, four weeks look ahead, and PPC. However, couple of months into execution, some projects faced a slow flow of activities, and the construction teams couldn't successfully implement appropriate rhythms for major project activities. The teams found that some activities were absorbing their full efforts and substantial project resources, constituting a noticeable bottleneck.

In the projects undertaken to test this study's hypotheses, the team started executing infrastructure projects by applying traditional planning tools such as master scheduling, then adding Lean tools and technique like LPS, collaborative meetings, 5S techniques, and measuring PPC. The results were not satisfactory, and the Lean team, as well as the construction team, found that a significant part of the process was missing because they didn't get the desired flow of activities. Moreover, LPS couldn't help to control and accomplish contractor's and consultant's goals because after applying the above techniques for months, many problems surfaced such as absence of resources, and inability of teams to meet their goals. Applying Lean tools to the project was perceived as more of an information-gathering exercise than a contributing factor to the project outcome.

Addressing the situation required a solution from Lean perspective, that would align the activities' rhythm or 'beat' by implementing TP time and techniques. At that time, the project team was looking for a serious solution or additional tools to help in finding a proper solution. Project team could not simply eliminate Master Planning, LPS, and PPC and just implement TP as an absolute solution in order to resolve the problems due to many contractual factors.

TP APPROACH

The TP method employed in this study is based on the one by Frandson et al. (2013). The method consists of five applicable phases or steps for TP, whose implementation on a project requires iteration. The steps are 1) collecting information, 2) defining work zones/areas and time requirements, 3) identifying and understanding trade sequence and trade durations, 4) balancing plan and workflow, and 5) establishing and finalizing the production plan and schedule. On the other hand, later studies by Dlouhy et al. (2018) considered TP a separate entity and tool that is applicable to projects. They adopted a three-level tiered flexible system and noted that the knowledge gained at the micro-level will automatically transfer to the norm-level and will influence planning in the future.

To expand this research and knowledge, it is argued that TP must be considered and applied as part of the whole system, from the beginning of projects and maintained until completion. Having mentioned in the previous sub-section all such issues facing the projects, and failure of segregated techniques, the best solution for the company was to integrate TP as an advanced technique into the current planning systems and control process, instead of dealing with it as a separate entity. This was done in two stages, leading to progressive resolution of all major problems. Many issues were captured at stage one which required the team to mobilize resources and adopt techniques in order to prevent the rock encountered from affecting the flow. To do so, a continuous flow was sought, allowing further issues to be captured and resolved in advance. Practically, prior to starting implementation of TP properly, the project team has to fully understand the specific nature of the project, including all major project activities. The second step in the process focuses on creating an appropriate and measurable rhythm for activities, through identifying Takt time. TP was integrated into the system in two stages. Table 1 presents sequential steps which the teams took in order to implement and integrate TP into the existing process.

Table 1: Sequence of Steps to implement TP

Step	Phase	Stage
1	Master Plan	Case Study for Stage One
2	LPS System for a three months period	
3	TP analysis for activities (defining wagon)	
4	PPC	
5	TP for entire project	Case Study for Stage Two
6	Update LPS System for the three months period	
7	Update TP for entire project	

Implementing the above method requires that TP including LPS, must be implemented in a continuous cycle as depicted in Figure 1 in order to ensure smooth flow and sequencing of activities, proper rhythm, and proper project control. TP appears to be a systemic set of steps in theory; however, during implementation, teams find that continuous TP needs to be maintained for success, which is not always an easy task. The use of TP is like getting an X-ray of the project's entire zones; it identifies the problems on the whole project. Therefore, it must be applied continuously to prevent errors during project execution. The following sub-sections detail stage one case study followed by stage two case study.

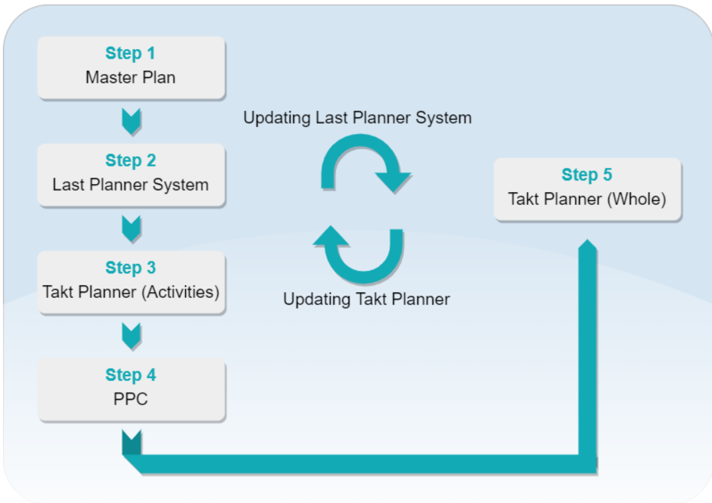


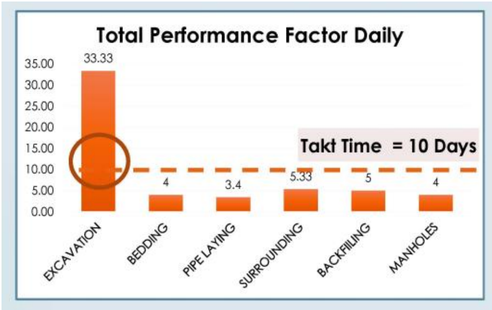
Figure 1: Integration of TP into the Existing Process

CASE STUDY RESULTS

STAGE ONE - APPLYING TP AT MICRO-LEVEL

Stage one was undertaken as a pilot project to investigate possible efficiency gains at the micro-level, from site excavation works. This micro assessment was undertaken to ensure efficiency improvements were possible and then obtain buy-in to implement TP project-wide, on a macro-scale. According to Binninger et al. (2016), levelling of activities in construction processes is done by defining Takt units and then matching the required workload to the available workforce. If some activities take longer than others, their durations can be optimized according to the selected Takt time. The Lean team started applying this method to a local road project in Qatar with a total cost of 800 million dollar. Figures 2(a) and 2(b) show that there is a bottleneck and unbalance in activities' rates.

The first step carried out by the Lean team includes analysing and balancing activities; by doing so, they were able to determine takt time, identify bottlenecks that occurred within the existing process, and then resolve them. Takt rhythm includes deployment of resources in a proper way to avoid waiting and to eliminate waste. As Figure 3 shows, excavation activity length now matches takt time. The activity time has been manipulated, so the work performed aligns with the work gang size.



(a)

Trade Sequence	Total Performance Factor Daily	Gang
EXCAVATION	10.00	10
BEDDING	4	4
PIPE LAYING	3.4	5
SURROUNDING	2.67	6
Backfilling	5	5
MANHOLES	4	4

(b)

Figure 2: Current Project Status (a) Total Performance Factor Chart, (b) Trade Sequence

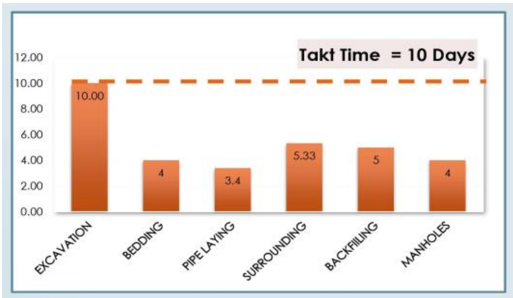
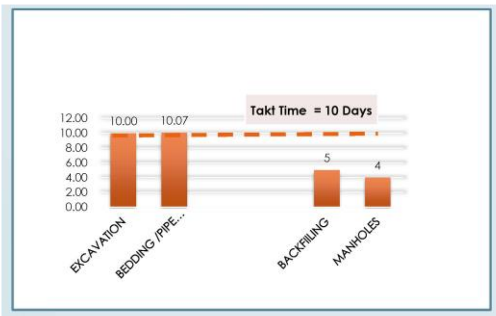


Figure 3: Harmonizing the Work - Improving

Moreover, activities are merged and optimized as shown in Figure 4(a). Levelling is performed where activities durations are optimized as work gangs are deployed to a resource plan aligned with the activity's Takt time as displayed in Figure 4(b). Also, different work packages were combined to create efficiencies as to how time was allocated to work gangs. Planning Results were adopted and implemented gradually; the construction team started rectifying their way of managing the project, considering fast activities.

Hence, it is shown that applying TP techniques helped to improve outputs, create harmony between activities, and balance them together. Table 2 summarizes the three different states of the project.



(a)

Trade Sequance	Total Performance Factor Daily
EXCAVATION	10.00
BEDDING /PIPE laying / SOUROUNDING	10.07
BACKFIILING	5
MANHOLES	4

(b)

Figure 4: Harmonizing the work (a) Combining Activities, (b) Levelling Activities

Table 2: Summary Comparison of Different Project States

Current Status	Improving Status	Combining and Leveling Status
Unbalanced activities No proper sequence of activities No proper deployment of resources	Matching excavation activity length to Takt time Altering working group sizes to match Takt time	Merging activities Combining different work packages to make up a single time slot, such as the surrounding gang

As can be seen from the site pictures in Figure 5, the construction team used TP to resolve bottleneck issues, as well as to balance overall activities in a different way.

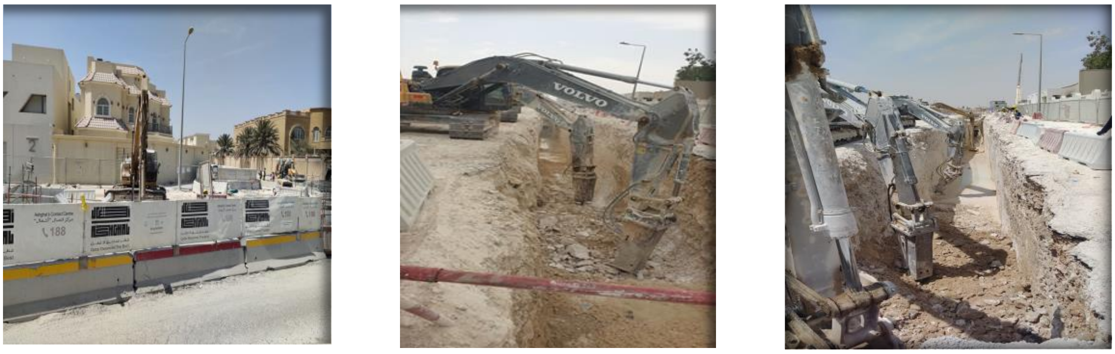


Figure 5: Case Study Stage One Site Impact

STAGE TWO - APPLYING TP AT MACRO-LEVEL

After successfully implementing the first stage analysis in the project, the Lean team wanted to utilize the preliminary TP results from case study stage one to the next level and apply them to the whole project's zones in a more accurate and practical manner. The Lean Team began by analysing the project status, identifying the bottlenecks and major challenges to progressing the works expeditiously and in a consistent manner. Five major challenges were identified and resolved as part of this stage. Figure 6 depicts how TP was applied fully in the entire project's zones. This provided an X-ray view of the project which enabled the analysis of the project status, at the resource level, providing information relating to timing, activities gaps, and waste. Five major bottlenecks were identified as a result of applying stage two analysis. These are 1) gaps between activities, 2) critical activities to be considered for further analysis, 3) congestion of the schedule, 4) resources distribution, and 5) milestone alert. After running TP stage two for a couple of months, we observed that smoothness of activities appears visually in the plan and better resources deployment which became visually apparent in the plan at the macro-level as shown in Figures 7(a) and 7(b).

DISCUSSION

This study showcases how TP was implemented in two stages at two different levels. Stage one began with a method for calculating Takt time, which led to a preliminary theoretical Takt Plan depicted in Figure 8. By utilizing this method, the team avoided delays and mitigated project risks, leading to more accurate work execution, and avoiding delays. Additionally, it helped the project team understand the nature of the project and deploy appropriate resources. Generally, TP is seen in many projects as a complex and very rigid process where trades are optimized individually (Dlouhy et al., 2018). However, proper, and gradual TP implementation can be less rigid, and this is reflected in the study' results such as achieving milestones more smoothly, having more accurate deliverables, and attaining easier project control. Moreover, applying Takt Planning to mega infrastructure works at a macro-level is risky, yet necessary to improve the efficiency rate of the project delivery (Binninger et al., 2016). Nonetheless, this case study demonstrates that TP helped teams to pinpoint micro-level issues that delayed an infrastructure project, and it explains how random distribution of resources led to an unsound investment for the company owner, as well as shortages of material and other resources. After analysing TP, managers understood exactly the problem and took appropriate steps to implement a proper solution; case study number one analysis was applicable at the micro-level.

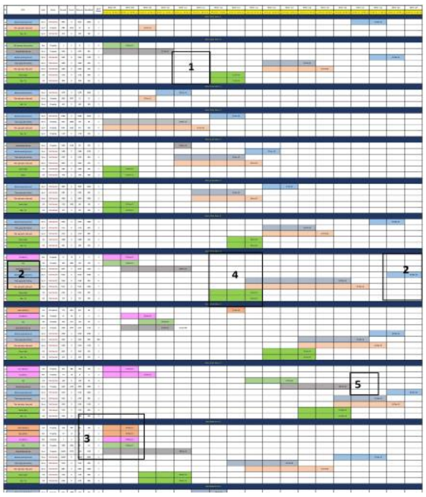
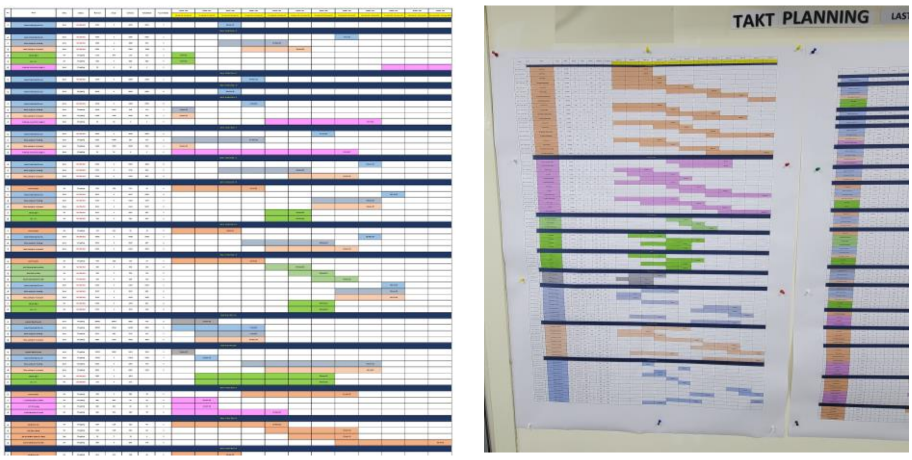


Figure 6: Stage Two TP for Full Zones

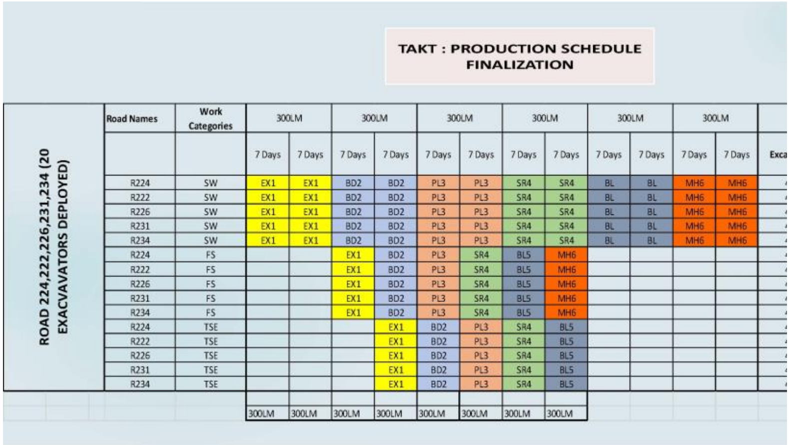


(a) (b)

Figure 7: TP Positive Impact at Macro-level

As a technique, TP analysis in stage one helped stakeholders capture major activities' bottlenecks. During the process, the size of main activities and the boundaries of Takt time wagons were measured. The outputs from TP's first step analysis led the construction team to change the project execution plan, following a TP rhythm; it was an important shift in the construction team's thinking. It also had a direct positive impact on project site activities. Lehtovaara et al. (2019) stated that planning TP wagons in more detail is regarded as an enabler for continuous improvement, along with a narrower collaboration among project participants. This confirms that micro-level TP implementation is essential for greater gains.

Upon receiving results of stage one study, the Lean team realized they needed to do more at a macro-level to control the entire project; consequently, they proceeded to put the outcome of stage one study into practice on a greater scale for the entire project to



TAKT : PRODUCTION SCHEDULE FINALIZATION

	Road Names	Work Categories	300LM		300LM		300LM		300LM		300LM		300LM		
			7 Days	7 Days	7 Days	7 Days	7 Days	7 Days	7 Days	7 Days	7 Days	7 Days	7 Days	7 Days	Exca
ROAD 224,222,226,231,234 (20 EXACVAVATORS DEPLOYED)	R224	SW	EX1	EX1	BD2	BD2	PL3	PL3	SR4	SR4	BL	BL	MH6	MH6	
	R222	SW	EX1	EX1	BD2	BD2	PL3	PL3	SR4	SR4	BL	BL	MH6	MH6	
	R226	SW	EX1	EX1	BD2	BD2	PL3	PL3	SR4	SR4	BL	BL	MH6	MH6	
	R231	SW	EX1	EX1	BD2	BD2	PL3	PL3	SR4	SR4	BL	BL	MH6	MH6	
	R234	SW	EX1	EX1	BD2	BD2	PL3	PL3	SR4	SR4	BL	BL	MH6	MH6	
	R224	FS			EX1	BD2	PL3	SR4	BL5	MH6					
	R222	FS			EX1	BD2	PL3	SR4	BL5	MH6					
	R226	FS			EX1	BD2	PL3	SR4	BL5	MH6					
	R231	FS			EX1	BD2	PL3	SR4	BL5	MH6					
	R234	FS			EX1	BD2	PL3	SR4	BL5	MH6					
	R224	TSE				EX1	BD2	PL3	SR4	BL5					
	R222	TSE				EX1	BD2	PL3	SR4	BL5					
	R226	TSE				EX1	BD2	PL3	SR4	BL5					
	R231	TSE				EX1	BD2	PL3	SR4	BL5					
	R234	TSE				EX1	BD2	PL3	SR4	BL5					
			300LM	300LM	300LM	300LM	300LM	300LM	300LM	300LM					

Figure 8: Preliminary Theoretical TP

make sure all zones are controlled effectively. Stage two required the project team to dwell deep into the project detail at the macro-level. All project zones had to be considered and re-planned. The outcome of stage two helped to identify the location of key problems, as well as provide a visual X-ray of the project. This process helped the team to improve the plan for the whole project in a reliable way, smoothing activities, and solving critical activities and problem areas. The X-ray visual aid enabled the team to plan and then deploy resources in an effective and economical way that reduced waste.

The outcome of stage two case study was considered an extension of stage one. Both had improved the focus of the project team, enabling problems to be identified, allocated, and treated, which then improved the project throughout and output by avoiding disruption to work processes at the macro-level. TP makes it easier to detect errors and steer continuous production proactively. Although spotting and correcting daily errors is stressful, it prevents cascading delays which improves overall flow (Vatne & Drevland, 2016). Thus, gradual implementation of TP from micro to macro levels can improve overall flow. The pictures depicted in Figures 9(a) through 9(c) display teams applying TP on three different infrastructure projects; whose total cost was more than one billion dollars. The collected feedback from the team was that TP techniques added edges to them and helped them to accomplish and to plan future activities collaboratively and adequately. After applying TP and testing its capability, the teams agreed that is beneficial if it is integrated as part of the full project management and control process, and not as a separate entity. Also, it was shown that TP can be used successfully as a problem-solving tool on micro and macro-levels during project implementation. Although the production flow measurement technique from LPS method seems to be the most favourable for TP projects (Haugen et al., 2020), Lean tools including LPS couldn't deliver a full solution for the team and the project; adding TP helped noticeably in resolving many problems. Thus, integrating TP with other Lean tools is a must for successful realization of projects. Although TP was used in projects as a result of an emergency need, without knowing what the outcome would be and after tracking the results for a couple of months, it was revealed that TP helped to understand project critical issues in a better way. The team applied TP taking into consideration all stakeholder values and needs.

(a) Project 1 (b) Project 2 (c) Project 3

Figure 9 Deploying TP (a) Project 1, (b) Project 2, Project (3)

CONCLUSIONS

This study has outlined how TP has been applied to improve project tempo, setting the rhythm for major activities, both at micro and macro-levels. It has also highlighted the importance of adopting TP as an essential Lean tool that can be used to regain control of projects in crisis, where work waits on workers, workers are forced to wait on work, and waste impedes progress. TP was implemented in two stages, first at the micro-level and then at the macro-level. Stage one work balanced the outflow, work-worker allocation and distribution, and harmonized the pace of work. At stage two, TP was applied at the macro-level, streamlining the project delivery process. Implementing TP delivered an important missing part of the process, by identifying problems at both micro and macro-levels; it also helped project team to zoom into activities by creating a smooth flow of activities from beginning until completion; making it a tool that ensures project success.

The study shows that integrating TP into projects helps to identify the appropriate Lean plan for new and ongoing projects; the team called it an X-ray of the entire project. Applying TP clarifies the project scope of work in a precise way. The study considered that adoption of TP in addition to existing Lean tools such as LPS is essential, which differs from other studies that consider TP as a separate entity. Therefore, TP must be flexible, and a proper relationship between LPS and TP must exist and be adequately maintained to ensure effectiveness and smooth project control. The study shows in practical examples how TP can be selected as an essential tool in analysing project difficulties, such as gaps between activities, critical scope of work, milestones, deployment of resources, and time management at both micro and macro-level.

The article shows that TP is an essential addition to the existing process and can’t be considered a sole solution. Applying TP helps teams to clearly identify difference between the outputs they get from Master Planning, LPS, and TP. Master Planning gives a broad picture of project, whereas LPS scales that image in more specific details, and TP proves its success in accomplishing both benefits in more detail. Future studies should address digitizing TP, making it more reliable and user-friendly. Also, future research can tackle Takt production’s long-term effects over several projects, in addition to a more detailed comparison of various methods and implementations of Takt.

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