Enhancing Micro-Tunnelling Activity in Infrastructure Construction Adopting Hybrid Lean Approaches: A Case Study

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Abstract

Micro-tunnelling Shaft Excavation (MTSE) is a major part in the development of infrastructure networks in Public Works Authority (ASHGHAL) projects in the State of Qatar. Despite the importance of this activity there has been minimal improvement to the existing methodology. Traditional methods are producing large amount of operational waste such as extra manhours, over-excavation and excess of backfilling materials used. Using collaborative pull planning, a system involving key stakeholders and last planners have been developed to streamline the micro-tunnelling activity. Using a panoply of lean tools, data collection and analysis, MTSE was monitored and evaluated through the Plan, DO, Check and Act (PDCA) cycle that led to around 60% of time saving. The paper summarises the process improvement using collaborative pull planning and applying PDCA with project stakeholders' engagement.

Keywords: Lean Construction; Collaborative Pull Planning; Last Planner System; Micro-Tunnelling; PDCA

1 Introduction

Micro-tunnelling (MT) techniques became necessary as the demand for utility service lines with minimal surface disruption increased. MT is "a trenchless construction method for installing pipelines with all of the following features: remote-controlled from a control panel on the ground surface, laser-guided, pipe sections jacked simultaneously as soil is excavated, with continuous support at the face of the excavation" (Moharrami et al., 2021). MT is a term used to describe remotely controlled pipe jacking operations.

Construction planning for MT projects is a complex process, leading activity and it is considered usually in the critical path for an infrastructure project. Therefore, delay in the construction of MT will lead to delay in project delivery (Moharrami et al., 2021). Despite the importance of this activity, the employed methodology has undergone minimal improvement. Traditional methods generate a substantial amount of operational waste, such as additional labour hours, over-excavation, and excess backfilling materials (Jain et al., 2022). As a framework for directing future research to improve MT operations, Jain et al. (2022) interpreted the impact factors that are affecting the productivity of MT. Then, they argued that empirical and practical studies to improve the conventional MT method are lacking in the existing literature. Therefore, this paper is developed to answer the research questions, "How can the traditional processes of existing methodologies be enhanced?" and "What tools can be used to enhance these endeavours?"

ASHGHAL has recently introduced the enhanced infrastructure project framework to maximize customer's value and minimize non-value activities (Aslam et al., 2020). Lean Construction is a set of ideas that are practiced by individuals in the infrastructure construction industry (Habibi et al., 2022). These ideas are based on the holistic pursuit of continuous improvements (Malinova et al., 2022) that are aimed at minimising costs and maximising value to clients in all dimensions of the built and natural environment, including planning, design, construction, activation, operations, maintenance, salvaging, and recycling. Lean Construction is also known as "just-in-time" construction (Gunduz & Naser, 2017).

The purpose of this research is to customise a set of improvement tools based on a case study in order to improve the MT process.

2 Methodology

The authors followed the case study methodology in developing this research paper, case studies are suitable for studying phenomena in their real-life contexts where researchers have not previously studied (Naji et al., 2022). ASHGHAL introduced Lean Construction to enhance infrastructure projects performance and delivery. Accordingly, to fulfil the enhanced contract requirements, multiple stages of improvement has been performed. This paper was developed to study the enhanced MT activity as a case study in construction of infrastructure and deep utility.

2.1 First Stage of Improvement – Collaborative Target Planning

A kick-off meeting was held at the beginning of the project with all of the key parties involved in MT activities. The purpose of the meeting was to review the overall scope of the project and to prepare the required data for the subsequent session, which will utilize Collaborative Target Planning (CTP), Pull Planning, Last Planner System (LPS), and Make Ready Plan:

- Collaborative Target Planning (CTP): A workshop held at least six weeks prior to the commencement of the planned works and involving representatives from all key parties (client, consultant, designer, contractor, and subcontractors) with the objective of establishing and update a 12 weeks schedule.
- Pull Planning: A collaborative approach to project scheduling that reverses the sequencing process. This entails gathering team members in order to identify and isolate important project milestones. The team then works backwards to add all required details and specifications.
- Last Planner System: is project production system that encourages the development of a predictable workflow between various parties in order to produce reliable results.
- Make Ready Planning: Ensures the planned work can occur by removing constraints in advance. These constraints are defined using an acronym of DRAMPPSS (i.e., Design, Resource, Access, Materials, Plant, Permits, Safety, and Shared Understanding).

As explained earlier, MT is a leading activity and it is considered as a critical path for the project. A collaborative session was conducted between all the concerned parties: contractor key personnel, construction team, consultant, client, dewatering subcontractor, MT subcontractor and geotechnical subcontractor. The first step during the session was identifying the milestones from the original monitoring program baseline schedule. During the session, an effective pull planning took place. Moreover, during the session the team focussed on the productivity for equipment and the manpower, the handoffs between the activities, the flow of the work and identifying any constraints. Moreover, DRAMPPSS were discussed and recorded as a commitment with a dedicated individual responsible for the each identified constraint including completion dates and linked with the corresponding activity in the CTP. The practice of all above steps supports the Last Planner System (LPS) exercise.

2.2 Second Stage of Improvement - Direct Work Observation from GEMBA Walk

As part of monthly GEMBA audit, the process of demobilisation and mobilisation of the Micro tunnelling jack setup was observed and considerable waste was noticed, therefore a direct work observation has been performed to verify and enhance the duration of time and productivity for machines and manpower that were discussed in the CTP. Performing the Direct Work Observation is essential in any enhanced project as it provides a clear indication of the Value Adding (VA) activities and Non-Value Adding (NVA) activities and a clear vision on how to improve the process (Gunduz & Naser, 2019):

- GEMBA: is a Japanese term meaning "the real place." It is a practice of physically walking to the site construction location where value is generated to discover opportunities for improvement in a Lean Construction process.
- Value adding (VA): activities that transform the production or delivery of something that generate value to the customer or next activity; it needs to be maximized.
- Non-Value Adding (NVA): activities that are sheer waste but essential to perform VA activities; it needs to be minimized.
- Waste (W): Anything that consumes time, resources, or space without adding value to the customer's given goods or services; it needs to be eliminated.
- Direct Work Observation: collecting VA, NVA, and W, which are then analyzed and studied to determine how to improve the process.

The paper examines MT network including around 8.5 km of utilities network and 90 connection shafts. During the site visit and data analysis with the last-planners, it was observed that demobilisation and mobilisation of the tunnel boring machine and its jacking setup is a non-added value activity that should be minimised in order to maximise added value in the micro tunnelling process.

The MT contractor has agreed to increase the number of jacking setups so that each tunnelling machine will operate with two jacking setups. This helped to maximise the utilisation of the tunnelling machine (one to be used with the machine and the other one to be ready for usage once first drive is completed). This will allow overlap in the procedure, allowing for more efficient use of tunnel-boring machines.

2.3 Third Stage of Improvement - Process Continuous Improvement using PDCA

The shaft excavation phase is the first and most critical step in the MT process. Any delay in the excavation plan will have a significant influence on all subsequent activities, the critical path would be derailed eventually. Utilising continuous improvement approach, the traditional excavation method has been run through two PDCA cycles, each having its own impact and improvement as it will be demonstrated later:

- Continuous Improvement: is an ongoing effort to improve products, services, or processes. These efforts can seek "incremental" improvement over time or a "breakthrough" improvement all at once.
- PDCA cycle: (Plan, Do, Check, Act) is an improvement cycle based on the scientific method of proposing a change in a process, implementing the change, measuring the results, and taking appropriate action.

Traditional Excavation Method

The traditional and basic method to excavate a shaft, requires a regular jackhammer excavator of 20 tons, and a ramp system as an access to excavate reaching a depth more than 5 meters, as it can be seen in Figure 1. This method was used at the initial period of the project to expedite shaft excavation date but was generating a great number of operational wastes that can easily be avoided.

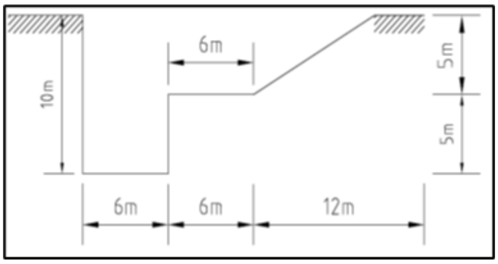

Fig. 1: Traditional Ramp shaft dimensions

First PDCA Cycle: Shaft excavation using Long Boom

The first PDCA cycle preformed to the shaft excavation process. After a thorough process analysis and discussion, the construction team decided to eliminate the use of ramps as it showed it can be improved with the replacement of regular jackhammers of 20 tons by long-boom jackhammers. The discussion revealed that the depth of 10 meters can be reached without the need of using a ramp as shown in Figure 2.

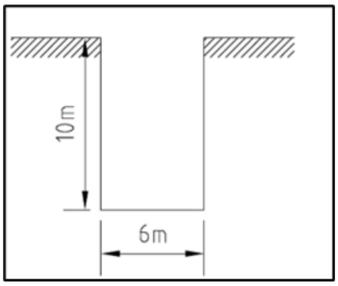

Fig. 2: Improved Shaft Dimensions

Second PDCA: Shaft Excavation using Long Boom Drum Cutter

Following the success of the first PDCA cycle and its implementation on site, a second PDCA cycle was performed. This cycle was supported by data analysis from direct work observations. Facts illustrated that the trimming process took a considerable amount of time. Therefore, the use of a drum cutter was proposed as it has better accuracy and shaft edges quality. The jackhammer tip was changed from pin head to a drum cutter head and which resulted in major improvements in the process that will be explained later.

3 Outcomes' Analysis

It is evident that performing three stages of improvement concurrently on the MT activity have yielded in beneficial results.

First Enhancement: Collaborative Target Planning

As result of implementing the first stage Collaborative Target Plan (Figure 3), a change into the final plan from the baseline was done, and numerous decisions were made based on the outcomes of the session. Table 1 displays the contrasts between the two planning methods:

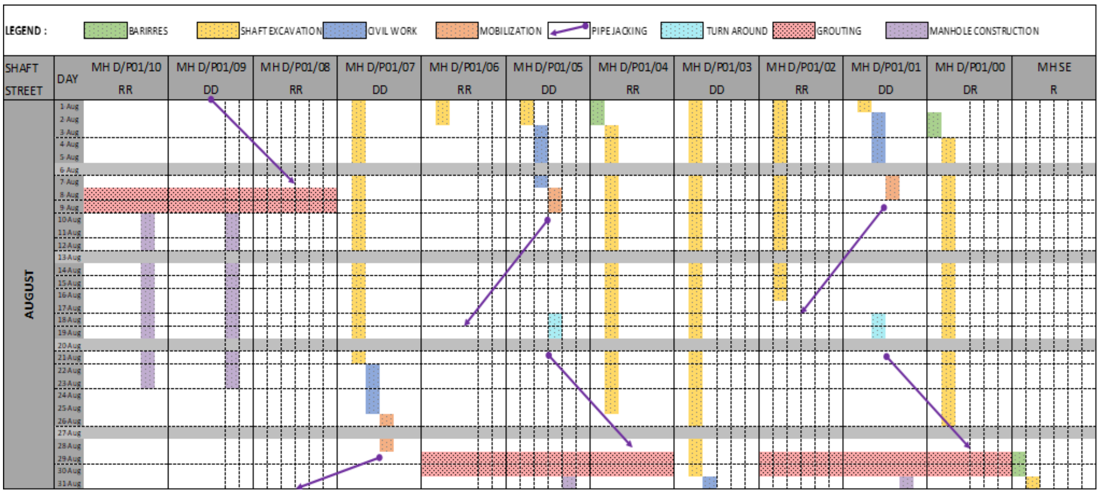

Fig. 3: Final Product of Collaborative Target Planning

Table 1: Comparison between the Baseline Schedule (original Plan) and Pull planning schedule

	Pull Planning Schedule	**Baseline Schedule**
Starting date	18th May 2021 (3 months ahead of Baseline schedule)	1st August 2021 (Project's Original Starting Date)
Slurry Lagoon	Size, Capacity and Possible locations were identified and shared	No common understanding of slurry lagoon details.
Storage Area	Storage Area required for Subcontractors identified	No allocated area
Pre-requisites	Materials, Resources, manpower, permits required were identified before commencement of work. Allowing more time to resolve the requirements	No record of requirements were recorded ahead of time
TBM Machine Numbers	1 TBM machine (Less resources and equipment required to operate at the same time)	3 TBM machine
Dewatering system	Schedule for the system route, sequence, pumps required during the upcoming MT activities	No clear indication on the requirements to operate the system
Dewatering capacity	Municipality have been contacted ahead of time to increase the number of Deep wells from 1 no. to 2.5 nos. Based on the site requirements and geotechnical report	Shortage in capacity would have occurred as only one Deep Well was dedicated to the project
Shaft Excavation sequence	Sequence has been modified to give priority and a head start for shafts that are above the water table	No criteria to decide sequence of the shaft

Second Enhancement: Direct Work Observation from GEMBA Audit

Applying this tool to the MT would potentially save about 120 days of mobilization and demobilization (Figure 4), in addition enabling the team to capture and rectify any issue before shifting the MT boring machine to the next shaft. Further, it allows early detection and resolution of issues faced when setting up the jacking system.

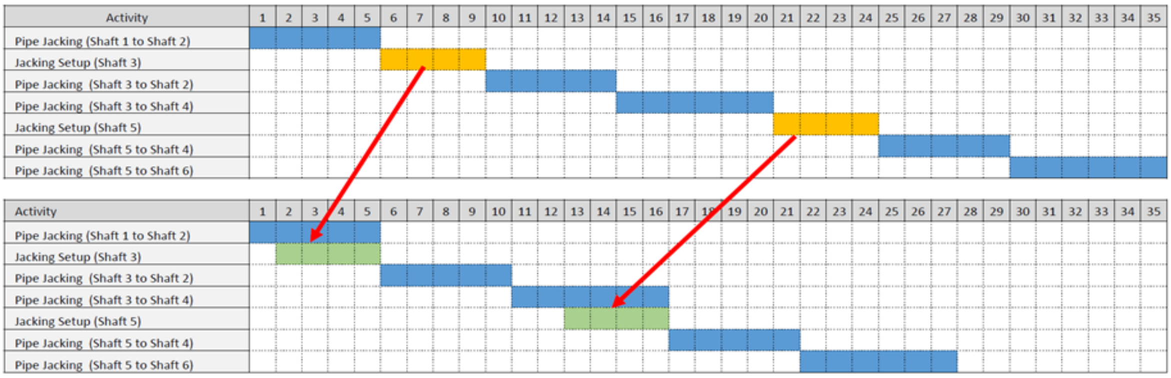

Fig. 4: Optimisation of NVA (Yellow) in MTSE to be Performed Concurrently with Other Tasks

Third Enhancement: Process Continuous Improvement using PDCA cycle

As indicated in Tables 2 and 3, the quantity of excavation material decreased by 63%, excavation time decreased by 33%, shaft working space decreased by 44%, and around 60% of trimming time saved.

Using the final approach with Long-Boom Drum cutters, Table 4 summarizes the considerable reduction in manhours needed to dig the shaft while the size remained unchanged. As trimming is eliminated, shaft excavation duration is optimised by 27%.

Table 2: Size and Time required to Excavate and Trim the Shafts Using the Traditional Method

Traditional Method: Excavation Ramp		
Type of Shaft	Shaft Excavation volume	Ramp Excavation Volume
Jacking	6x6x10= 360 m3	(12x6x5)/2=180m3
Receiving	6x6x10= 360 m3	(12x6x5)/2=180m3
Total Volume Excavated	1080 m3	
Excavation Time needed	120 Manhours	
Trimming Time needed	120 Manhours	
Total Hours needed	240 Manhours	

Table 3: Size and Time required to Excavate and Trim the Shafts using the Long-Boom method

First PDCA cycle: Long-Boom Jackhammers		
Type of Shaft	Shaft Excavation Volume	Ramp Excavation Volume
Jacking	6x4x10= 240 m3	N/A
Receiving	4x4x10= 160 m3	N/A
Total Volume Excavated	400 m3	
Excavation Time needed	112 Manhours	
Trimming Time needed	48 Manhours	
Total Hours needed	160 Manhours	

Table 4: Size and Time required to Excavate and Trim the Shafts using the Long-Boom Drum cutter

2nd PDCA Cycle: Long Boom Drum cutter		
Type of Shaft	Shaft Excavation Volume	Ramp Excavation Volume
Jacking	6x4x10= 240 m3	N/A
Receiving	4x4x10= 160 m3	N/A
Total Volume Excavated	400 m3	
Excavation Time needed	64 Manhours	
Trimming Time needed	N/A	
Total Hours needed	64 Manhours	

MTSE Enhancement benefits

Benefits of this process improvements can be summarized in a quantitative and qualitative comparison, as shown in Table 5. Figures 5 and 6 illustrate the considerable optimisations realized.

Table 5: Qualitative and Quantitative Benefits

Quantitative	Qualitative
Foam Concrete required dropped by 56%	Eliminate Ramp
Shaft excavation area reduced by 44%	Less impact on other nearby trades as ramps are eliminated.
Excavation manhours required decreased to 27% of original time.	Less concrete barriers and edge protection is required to protect the shaft.
Trimming time reduced to 0%	Better utilization of manpower and equipment.
	Minimize disruption by reducing time required to backfill the shaft.
	Increase public satisfaction
	Noise Reduction

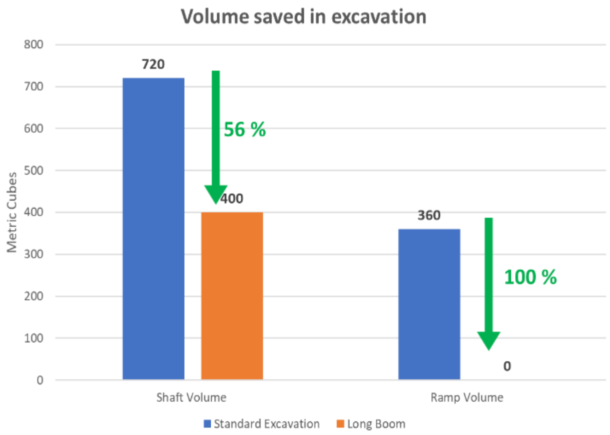

Fig. 5: Reduction in Excavation Volume

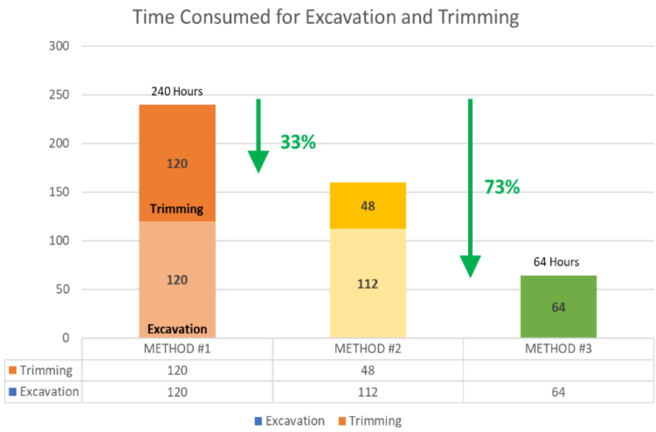

Fig. 6: Reduction in Excavation Time

4 Conclusion

Implementation of Lean tools in the construction industry has vital achievement to enhance the project delivery, mainly, in the construction of the infrastructure. This article demonstrates how the project has undergone three concurrent stages of improvement, with all stages interconnected to achieve the goal of delivering the final product with less waste and greater value.

CTP addresses the conventional planning approach failures in a lack of cooperation, communication, and transparency. All participants in the collaborative session agreed on the order in which the tasks were to be performed, the required mission for each individual present, the start and end dates, and the required manpower, equipment, and Tunnel Boring Machine (TBM) numbers, which strengthen accountability on the promises taken. In addition, DRAMPPSS identification supported mapping critical prerequisites and deliver accountability for fulfilment.

In addition, the GEMBA has resulted in the implementation of direct work observation, which is an effective method for monitoring an activity and identifying gaps directly. The improvement made to the MT jack setup is a practical example on the GEMBA importance to optimise processes and generate savings.

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List of Acronyms

ASHGHAL	: Public Works Authority
CTP	: Collaborative Target Planning
DRAMPPSS	: Design, Resources, Access, Materials, Plants, Permits, Safety, Shared Understanding
GEMBA	: Japanese term meaning "the real place."
Km	: kilo-meters
LPS	: Last Planner System
MT	: Micro-tunnelling
MTSE	: Micro-tunnelling Shaft Excavation

NVA	: Non-Value Adding
PDCA	: Plan, Do, Check and Act
TBM	: Tunnel Boring Machine
VA	: Value adding
W	: Waste

Cite as: Kamal A., Hakouz J., Zakaria Y., Shalabi M., Naser A. & Al-Tamimi S.A., "Enhancing Micro-Tunnelling Activity in Infrastructure Construction Adopting Hybrid Lean Approaches: A Case Study", *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0026