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LEAN CONTRACT, COLLABORATIVE POWER: ACCELERATING DELIVERY IN UNDERGROUND METRO PROJECT

Prabhu P[1], Nalin M[2], Ashwetha U[3], Aravind V[4] and Jayarama H[5]

ABSTRACT

This paper examines the practical implementation of lean principles in the contract management and operations of the TU 02 underground metro project in Chennai City, India. The project, a crucial component of Chennai Metro Rail Limited's Phase 2 development spanning 116 km, stands out for its intricate collaboration with multiple contractors. Despite its scale and complexity, CMRL TU 02 project team has embraced lean management principles since its inception. The project encountered about 24-months of delay due to the unavailability of shafts for lowering and retrieving TBMs. This paper provides a detailed analysis of the lean principles applied in Contracts Management to reduce this delay from 24 months to 18 months. The collaborative approach to lean management with clients and General consultants not only mitigated the schedule delay but also minimized TBM idle time, a critical aspect with high risks. Additionally, process optimization techniques, such as Value Stream Mapping (VSM) in the precast yard and TBM lowering cycle time reduction at the project site, are explored, showcasing the effectiveness of lean concepts in complex construction projects.

KEYWORDS

Lean construction, Lean Contract Management, Enhancing project efficiency, Value Stream Mapping (VSM), Big Room Planning and Collaborative Planning.

INTRODUCTION

Chennai, the bustling capital city of Tamil Nadu state in India, is undergoing a transformative phase in Infrastructure upgradation with the ongoing expansion of its metro rail network through CMRL's Phase 2 corridors. The TU 02 project, a significant segment of this expansion, involves the construction of 12 kilometers of twin bored tunnels and key underground station structures critical for enhancing urban connectivity and reducing traffic congestion. It encompasses the construction of diaphragm walls and entry/exit structures for 4 key stations

1 Assistant Manager, Planning, CMRL TU02 Project, Larsen & Toubro Construction, Chennai, India, 7305097121, prabhu.p1@lntecc.com

2 Manager, Planning, CMRL Projects, Larsen & Toubro Construction, Chennai, India, 9840684003, nalinm@lntecc.com

3 Construction Manager, TFL, CMRL Projects, Larsen & Toubro Construction, Chennai, India, 9500812844, ashwethakumar@lntecc.com

4 Senior Planning Engineer, TU02 Project, CMRL Projects, Larsen & Toubro Construction, Chennai, India, 9487450657, aravind.v@lntecc.com

5 Vice President, Project Director, CMRL Projects, Larsen & Toubro Construction, Chennai, India, 9819436227, h-jayarama@lntecc.com

namely Chetpet, Royapettah Government Hospital, Thiruvanmiyur, and Greenways Road. The scope of project is summarised in table 1.

Table 1: Scope of the project

Sl. No.	Description	UOM	Total Scope
1	Diaphragm wall	RM	2,757
2	Shaft Excavation	cum	70,352
3	Ring Casting & Erection	Nos	18,366
4	TBM Tunnelling	RM	25,000

The deployment of 8 state-of-the-art Tunnel Boring Machines (TBMs) underscores the project's technological advancement and its role in shaping the city's infrastructure landscape. However, like many mega construction projects, TU 02 faced challenges, including a notable 24-months delay in interface contracts, which necessitated innovative approaches rooted in lean principles for effective contract management and project operation.

COMPLEXITY IN PROJECT

A notable aspect of the CMRL TU 02 project is the execution of 4 launches for each of the 8 TBMs, totalling to 32 drives. The total of 32 launches and 32 retrievals needs to be taken up from total of 16 stations along the alignment. Out of the 32 shafts, 8 shafts are in the scope of Tunnelling Contractor. The balance 24 shafts are in the scope of Interface Station Contractor. The scope of Tunnelling and Station works are depicted in Figure 1.

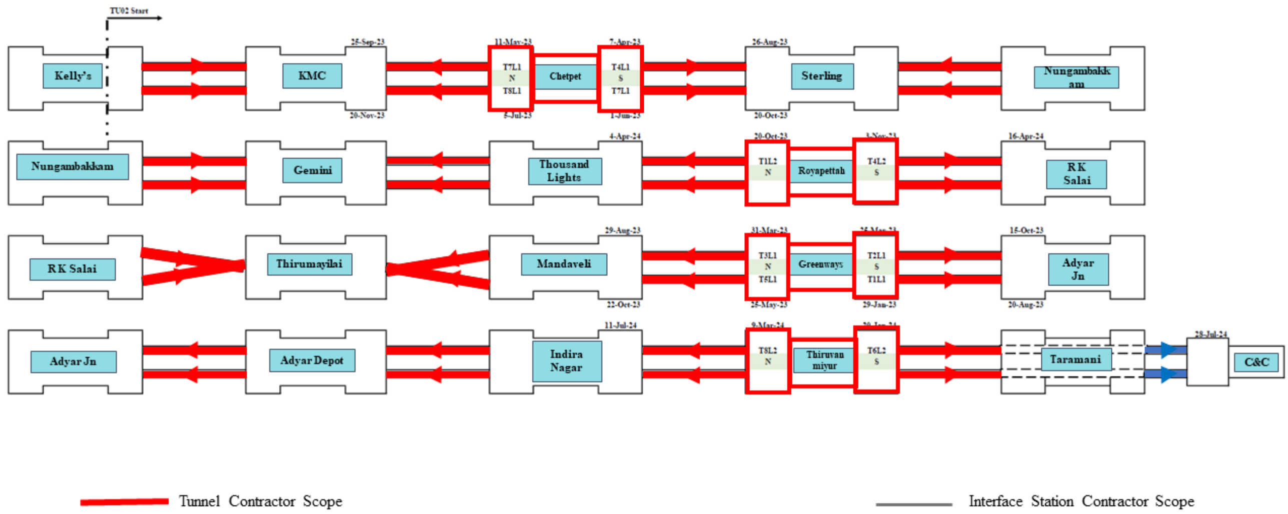

Figure 1: CMRL Phase 2 Corridor 3 – Kellys to Taramani Alignment

However, the complexity of the project was exacerbated by a 24-months impact on project schedule in the interface contract, stemming from various delays with the client. This delay posed a formidable challenge, leading to the postponement of TBM launches and a subsequent ripple effect on both cost and timelines.

To overcome these challenges and optimize project progress, lean initiatives were adopted, necessitating the resequencing of TBM launches and innovative approaches to contract management. This paper delves into the dynamic application of lean contract management principles in the context of CMRL TU 02, exploring strategies employed to minimize TBM idleness, renegotiate contracts, and propel the project forward. Our journey involves reshaping traditional approaches, resequencing TBMs, and converting setbacks into opportunities for efficiency enhancement and collaboration. The overarching goal is to not only highlight the practical solutions implemented but also to contribute valuable insights to the broader field of metro construction project management. Also, this paper explores the implementation of Value Stream Mapping in Precast Yard of the same project to reduce the cycle time of precasting of tunnel rings. As we embark on this exploration, the title encapsulates the essence of our endeavours. The paper describes the intricacies, challenges, and triumphs of CMRL TU 02, as we showcase how a lean approach can truly optimize progress in the dynamic landscape of underground metro construction.

NEED FOR LEAN IN CONTRACT MANAGEMENT

The complexities of modern construction projects, including tight schedules, fluctuating budgets, and multiple stakeholders, underscore the need for lean principles in contract management. Traditional approaches often fall short in meeting the dynamic demands of such projects, leading to inefficiencies, delays, and disputes. Contract documents for construction projects are traditionally prepared to manage conflicts rather than collaboration (Skinnarland and Yndesdal 2010). Lean principles offer a holistic approach to addressing these challenges by emphasizing continuous improvement, collaboration, and adaptability. By integrating lean principles into contract management processes, construction projects can achieve greater efficiency, transparency, and stakeholder satisfaction. Contracts can be structured to exploit the tremendous opportunities for performance improvement (Miles and Ballard 1997).

LEAN AWARENESS LEVEL IN PROJECT

CMRL TU02 is already a lean-managed project where a lean culture was inculcated into the root level of the team. Initiating a culture of lean practices within a construction site required a fundamental shift in mindset and a deep-rooted understanding of lean principles among the project team. At the heart of the project's lean journey was the recognition of the importance of motivating the project team to embrace lean practices. This motivation was cultivated by providing tangible evidence of the benefits of lean through data-driven insights from lean tools such as Work Sampling, Foreman Delay Survey (FDS), and Value Stream Mapping (VSM). Under the guidance of the project director, a dedicated lean implementation team was formed to spearhead the initiative, laying the groundwork for lean practices to permeate throughout the project, including contract management processes. The effectiveness of the lean tools was evident through the improved customer focus and eliminating waste (Refer to Mastroianni and Abdelhamid 2003).

IMPLEMENTATION

A structured approach was adopted to implement lean practices, starting with a focused drive to kickstart the journey. Below (Figure-2) is the Lean Organogram of the project framed to cultivate lean culture in project. Simulations help Lean learners evaluate from a flow- and efficiency- perspective how project team members are managing production system design and control (Tsao and Howell 2022) Lean culture was developed by organizing meetings and training sessions directly at the project site, providing an immersive learning experience for team members. Real-world case studies and interactive lean games (e.g., Airplane game) were utilized to impart hands-on knowledge of lean principles, ensuring that team members were equipped with the skills needed to embrace lean practices in their respective roles, including contract management. Training sessions were conducted extensively across various departments, equipping team members with the skills and knowledge needed to integrate lean principles into all aspects of project management, with a specific focus on contract management.

Approximately 80 team members underwent training, ensuring that lean principles were fully integrated into daily operations, including contract negotiation, execution, and evaluation.

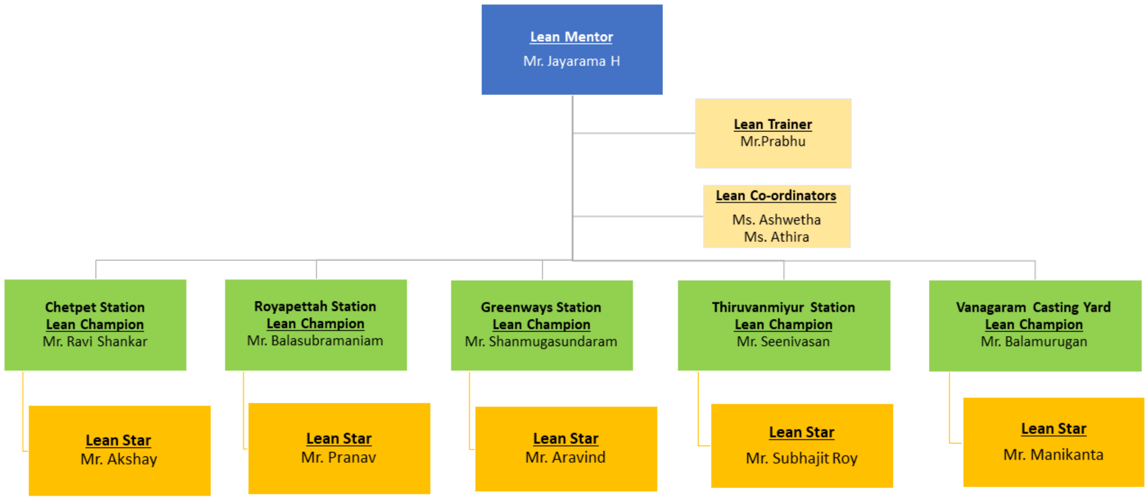

Figure 2: Project Lean Organogram

Consistent weekly review meetings played a crucial role in maintaining momentum and assessing progress. These meetings provided a platform for team members to review Planned Percentage Completion (PPC) achievements, identify constraints, and conduct root cause analysis, fostering a culture of continuous improvement and accountability in contract management processes.

PROBLEM STATEMENT

The project faced significant challenges during its implementation. One of the foremost obstacles was the 24-month delay in the interface contract, which had cascading effects on project timelines and costs. This delay led to the postponement of Tunnel Boring Machine (TBM) launches and subsequent disruptions in construction activities. The level of technical and commercial risk anticipated because of the delay was very high. Additionally, the complexity of the project, compounded by its underground nature and urban setting, posed unique challenges in resource management, stakeholder coordination, fulfilling the contractual requirement, collaborative work with the CMRL contractors, and risk mitigation.

STRATEGIES OF LEAN CONTRACT MANAGEMENT ADOPTED

Lean Contract Management was chosen as a tool to mitigate the challenges faced in the project in terms of delay in time and cost impact from same. Below are the step-by-step lean strategies adopted in the project.

1. Proactive delay notification
2. Establishing the Pull
3. Big Room Planning
   - Phase 1: Initial Level
   - Phase 2: Core Level
   - Phase 3: Senior Management Level
4. Incorporation of Results in Contract

PROACTIVE DELAY NOTIFICATION

Effective communication with the client is paramount in managing mega projects successfully. Letters, emails, and monthly reports uploaded in Project Management Interface System forms part of official communication of project as per contract. As a first step, the Tunnel Contractor prepared the project schedule incorporating the delays as on date and submitted the same to client. The baseline schedule of 54 months got extended by 24 months. The other interface contracts were not awarded to contractors from Client, and it created a huge impact in timeline of tunnelling contract. The technical risk arising out of idling of TBMs under the ground of 15-18m for months is also notified. By systematically documenting and communicating these potential delays, we ensured transparency and facilitated collaborative problem-solving with all stakeholders.

ESTABLISHING THE PULL

The tunnelling contractor established the Lean Concept of Pull in the System (PMI 2017) with Client by exercising on the Key Milestone Dates of Shaft Handover in Contract. The communication was submitted for seeking of Shaft Handover dates (especially retrieval shafts) from client. This established the pull and underscored the gravity of situation to act immediately.

BIG ROOM PLANNING

Lean principles of collaboration and risk assessment were integral in reducing delay. Upon aligning the Contractor, General Consultant and Client on the criticality of the delay, the Contractor implemented the Lean Practice of Big Room Planning. Big Room Planning is a tool that increases the joint work and ownership of all stakeholders and develops mutual trust and respect (Başağa et al. 2019). A Big Room Planning workshop was initiated with all stakeholders to collaboratively discuss and plan to find all measures to reduce the impact of delay. Big Room Planning was taken up at different phases to mitigate delay to the maximum extent. The different phases are explained in detail as below:

Phase 1: Initial level

As a first step, technical representatives from all stakeholders, namely Tunnelling contractor, General Consultant and Client were part of the Initial Big Room Planning. The Handover dates of shafts as per Contract were analyzed and the plan for revised Handover dates were devised. The plan for revised Handover dates were to be derived by resequencing the entire TBM drives, considering different geologies and machine types as the very fundamental factors.

Phase 2: Core level

The stakeholders engaged in rigorous Big Room Planning exercise for second time to finalize the TBM drives and the Hand over dates. Through rigorous permutation and combination calculations, different schedules were arrived and the optimum sequence with less number of idling time is chosen. In addition to resequencing, methodological changes were also proposed to reduce the time of construction. Table 1 describes the comparison of first and second drives of all 8 TBMs.

Phase 3: Senior Management Level

The senior management of all stakeholders sat down for final discussion in concluding the entire resequencing plan, thereby finalizing the schedule. This open collaborative discussion of Big Room Planning reduced the anticipated 24-months delay to 18 months, agreed upon by all stakeholders. This resequencing resulted in a 30% reduction in TBM idle time.

Addressing critical delays

Despite resequencing activities, inevitable delays were foreseen for 4 TBMs starting from 2 stations. To mitigate this, the contractor renegotiated to commence the execution of retrieval shafts in 2 locations, implementing effective risk mitigation measures in contract management. This measure not only reduced TBM idle time but also prevented losses to the contractor. By proactively addressing critical delays, we demonstrated our commitment to efficient project management and stakeholder satisfaction.

Table 2: TBM Mining as per contract vs revised.

TBM No	As per Contract		Revised Sequence	
	1st Drive	2nd Drive	1st Drive	2nd Drive
TBM 1	Chetpet metro to Sterling Road junction	Chetpet metro to KMC	Chetpet metro to Sterling Road junction	Royapettah Govt Hospital – Crossover – to Thousand lights
TBM 2	Chetpet metro to Sterling Road junction	Chetpet metro to KMC	Chetpet metro to Sterling Road junction	Nungambakkam to Gemini
TBM 3	Royapettah Govt Hospital – Crossover – to Thousand lights	Royapettah Govt Hospital – Crossover – to Thousand lights	Greenways road metro to Mandaiveli	Royapettah Govt Hospital to RK salai Jn
TBM 4	Royapettah Govt Hospital to RK salai Jn	Royapettah Govt Hospital to RK salai Jn	Greenways road metro to Mandaiveli	Nungambakkam to Sterling
TBM 5	Greenways road metro to Adyar Jn	Greenways road metro to Mandaiveli	Greenways road metro to Adyar Jn	Mandaiveli to Thirumayilai
TBM 6	Greenways road metro to Adyar Jn	Greenways road metro to Mandaiveli	Greenways road metro to Adyar Jn	Kellys to KMC
TBM 7	Thiruvanmiyur metro to Taramani Cut&Cover tunnel	Thiruvanmiyur metro to Taramani Cut&Cover tunnel	Chetpet metro to KMC	Thiruvanmiyur metro to Taramani Cut&Cover tunnel
TBM 8	Thiruvanmiyur metro to Indira nagar	Thiruvanmiyur metro to Indira nagar	Chetpet metro to KMC	Thiruvanmiyur metro to Indira nagar

INCORPORATION OF RESULTS IN CONTRACT

There were two major changes contractually because of Lean Strategy Implementation.

1. *Changes in the Interface Contract*: The mutually agreed sequence of construction with Tunnelling Contractor has been finally effected in the Interface Contract of other contractors and Client. Collaboration with senior management led to the modification of interface handover dates of underground station contractors to align with the resequenced dates, thereby revising the project's baseline schedule. The final revised TBM sequence is represented in figure 3 and in table 2.

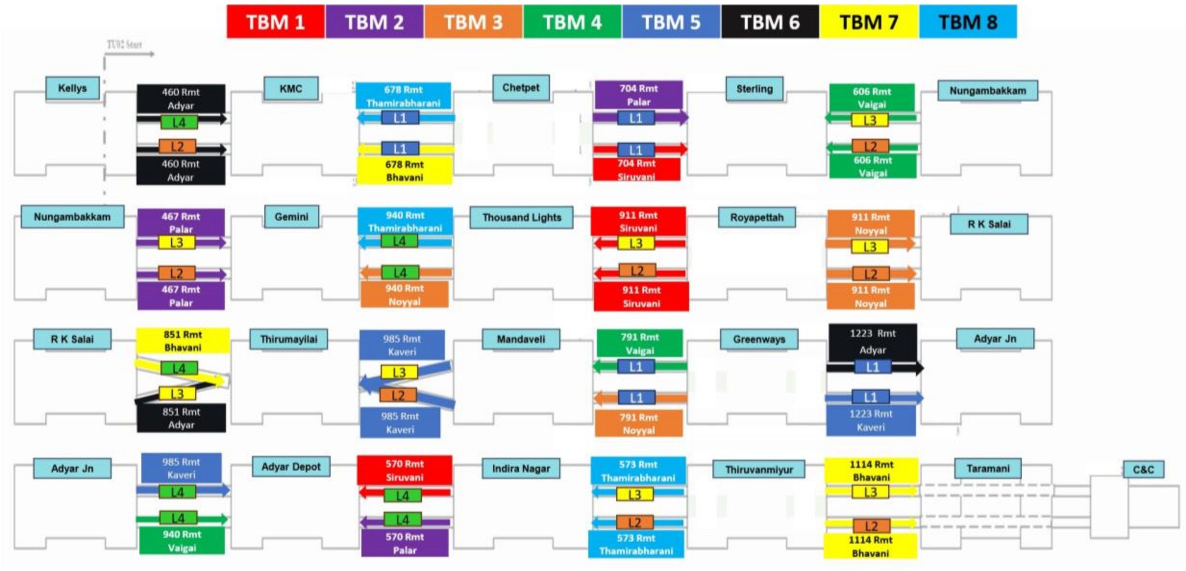

Figure 3: Revised TBM launching sequence.

Table 3: Results of Big Room planning Resequencing - Delay and Idle time reduction

S.no	Description	Project Start	Project End	Duration (In Days)	Duration (In Months)
1	Original Contract duration	09-06-2021	05-11-2025	1610	54
2	Revised duration without Resequencing	09-06-2021	16-10-2027	2320	77
3	Revised duration with Resequencing	09-06-2021	01-05-2027	2152	72

2. *Issuance of Variation Order*: Two number of critical shafts for retrieval were descoped from the Interface Contract and added to the scope of Tunnelling Contractor as a variation order in Contract. Also, it helped the tunnelling contractor to generate more revenue with the existing resources. Hence, the risk was converted into a revenue generating opportunity.

The collaborative nature of Big Room Planning taken up systematically ensured that diverse perspectives were considered, leading to innovative solutions and improved project outcomes.

CONTINUOUS IMPROVEMENT IN TIMELINE

Even after the underground contractors commenced execution at different stations, the contractor ensured further optimization of the schedule by rescheduling within the interface contractor's dates, further minimizing project idle time. This ongoing focus on continuous improvement underscores team's dedication to maximizing project efficiency and delivering value to all stakeholders. Central to the success of TU 02 was the cultivation of a culture of continuous improvement. The project team encouraged feedback and suggestions from all stakeholders, fostering a collaborative environment where innovative ideas were welcomed and implemented. Regular review meetings and performance evaluations helped identify areas for improvement and drive ongoing enhancements in project execution.

IMPLEMENTATION OF VALUE STREAM MAPPING IN CASTING YARD

The precast yard for tunnel segment manufacturing is located at 20 km from project alignment. The project requires production of 18366 rings from the casting yard. The total cycle time of production of a ring was 16 hours 5 min.

To reduce the cycle time, Value Stream Mapping (VSM) was chosen as the lean tool to evaluate the present cycle time in detail and reduce the Lean Waste (Vilasini and Gamage 2010).

Initial State of VSM

The different activities in production of a tunnel ring are listed and the time taken for each activity is recorded for a continuous 12 days and the VSM is generated as per the figure-4 given below:

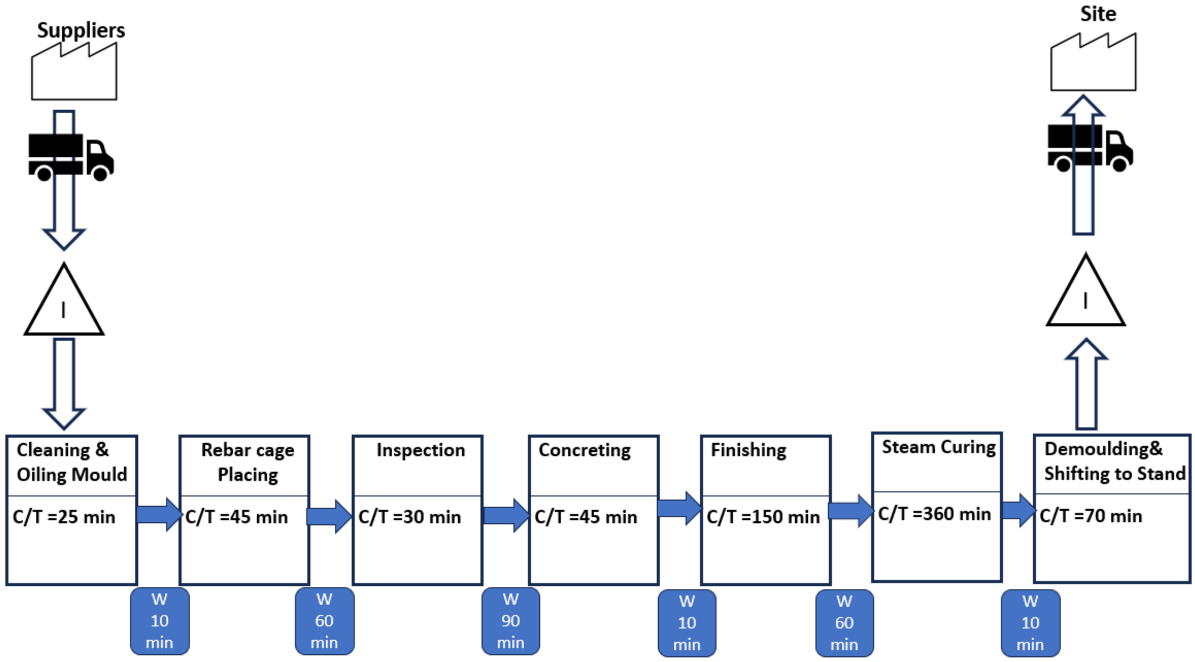

Figure 4: Segment Ring Casting VSM-Initial State.

The total cycle time is 16 hours 5 minutes with the bifurcation of Value Added -12 hours 5 minutes and Non-Value Added- 4 hours.

By collaborative discussion with construction managers, the below measures were taken at each step to reduce the Waiting and Idling time to completely reduce the Non Value-Added time to zero.

1. Increase of rebar crew from 10 to 15 numbers to remove the waiting time of 10 min.
2. Client approval was sought for each ring instead of 3-4 rings together to remove the waiting time of 60 min.
3. Ordering for concrete when the inspection is called for to reduce the 90 min of waiting of concrete.
4. Increase the crew size of finishing from 2 to 6 numbers to reduce the time of finishing from 150 min to 120 min.
5. Increase of one more stand to reduce waiting time for lifting of segment from mould by 10 min.

Below Figure 5 is the future state VSM that was envisaged and later achieved at site. The cycle time has been reduced to 11 hours 15 minutes.

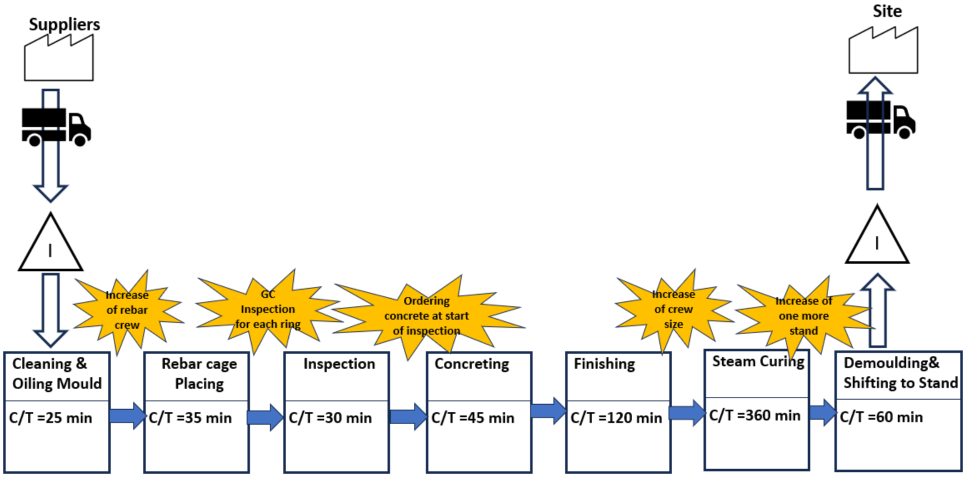

Figure 5: Segment Ring Casting VSM- Future State.

IMPLEMENTATION OF BIG ROOM PLANNING FOR TBM LOWERING ACTIVITY

In the context of tunnelling projects, particularly in densely populated urban areas, the process of TBM lowering and assembly emerges as a pivotal and intricate process. The spatial constraints inherent to urban settings necessitate meticulous planning and synchronization of various resources. It becomes imperative to organize the logistics, deployment of lifting machinery, and assembly teams in a manner that minimizes any downtime for these critical resources. Previously, the assembly of two TBM units consumed a substantial period, stretching over a duration of fourteen days. In response to this, a challenging internal target was set: the goal was to complete the lowering and assembly of two TBM units per shaft within ten days, ultimately achieving the ambitious milestone of four TBM assemblies within a span of twenty days. To accomplish this formidable task, it was imperative to foster collaboration (Rothman 2016) among a multitude of stakeholders.

The different teams involved in this highly critical activity include:

- Specialized Transporters
- Plant & Machinery department.
- Specialized Assembly Team
- Procurement team
- Safety team
- Quality Assurance team
- Administrative team
- General Chennai Corporation (GCC)
- Traffic Police Department
- General Consultant (GC) and
- Customer

The cohesive synergy between all teams was achieved through the implementation of Big Room planning. Within the Big Room planning exercise, a granular examination of the project was conducted. This entailed scrutinizing micro-level plans, proactively identifying potential constraints, and formulating precise action plans. It was during this collaborative process that several previously unrecognized, although crucial, minor activities came to light. The constraints identified and the action measures taken as output of Big Room Planning are summarized in Table 4.

Table 4: Constraints and Action Measures Implemented from Big Room Planning

S No	Constraint Identified	Action Taken
1	The shortage of Umbilical Hoses required for TBM Initial Drive has been identified as the same earlier planned quantity has been engaged in TBM 1 & 2	Immediate procurement order was finalized
2	Traffic Police Approval required from two different jurisdiction is identified	Admin team person in charge is allocated and both approvals were processed in parallel
3	Cutter Protection walls which were required in present shaft and not required in previous shafts was identified	Civil team has been engaged to take up this activity before TBM lowering
4	Crane Positioning: As per crane positioning and lifting sequence, the outrigger of 700T crane needs to be placed on D-wall panel. However, the same panel has been proposed for rectification measures already.	The entire micro schedule has been planned after completion of rectification of D wall
5	Route survey: The activity of joint route survey along with GC was missed in program	The same has been incorporated in program with duration of 2 days

The 700T and 300T cranes being the critical equipment driving the entire task of 7 days, rigorous microlevel planning was done to achieve the Just in Time lowering activity. To ensure the seamless execution of these preparatory tasks, resources such as boom lifts, specialized lifting tools, and scaffolding were meticulously organized and delivered promptly. These concerted efforts, guided by meticulous planning and precise execution, culminated in the remarkable achievement of completing the lowering and assembly of all four TBM units within a commendable twenty-day timeframe. This achievement underscores the effectiveness of a collaborative and detail-oriented approach to construction planning, demonstrating how meticulous coordination and proactive problem-solving can lead to significant gains in project efficiency and ultimately pave the way for the successful realization of complex construction objectives.

Figure-6: Big Room planning at TU02 project site.

RESULTS AND DISCUSSION

1. The adoption of lean principle – Big Room Planning in Contract Management in the CMRL TU 02 project yielded significant results, including:
    a. **Reduction in TBM Idle Time:** By resequencing TBM launches and implementing innovative contract management strategies, we were able to reduce TBM idle time by 30%, minimizing the impact of delays on project progress and cost.
    b. **Optimum Resource Utilization:** Collaborative planning and risk assessment enabled the efficient allocation of resources, ensuring optimal productivity and cost-effectiveness throughout the project lifecycle.
    c. **Timely Project Completion:** Despite the initial delay in the interface contract, the project has been rescheduled within 72 months, meeting client expectations and demonstrating our commitment to delivering quality infrastructure on time and within budget.
2. The adoption of lean principle - Value Stream Mapping in Casting Yard reduced the cycle time of precasting activity from 16 hours 5 minutes to 11 hours 15 minutes. Total time savings of 5.5 months. These improvements in the precast production also directly benefit construction projects by reducing expenses and increasing delivery. (Deffense and Cachadinha 2011)
3. The adoption of lean principle – Big Room Planning for critical activity of TBM Lowering enabled the project team to lift and lower 4 TBMs within a record time of 20 days and saving total of sixty days.

CONCLUSION

The CMRL TU 02 project serves as a compelling case study in the effective application of lean principles in underground metro construction. By embracing collaboration, proactive risk management, and continuous improvement, we were able to overcome significant challenges and deliver a successful project that enhances urban connectivity and fosters economic development. Our experience underscores the importance of lean practices in modern construction projects and highlights the value of collaborative problem-solving and stakeholder engagement in achieving project success. As the construction industry continues to evolve, the lessons learned from CMRL TU 02 will serve as valuable insights for future projects seeking to optimize efficiency, mitigate risks, and deliver sustainable infrastructure that meets the needs of communities around the world.

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