CHAPTER 21

Assessing the Potential Lean in Megaprojects

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ABSTRACT

Megaprojects are the economic drivers of infrastructure development. The megaproject delivery is often faced with Challenges in lean megaprojects, including complex coordination of stakeholders, logistical complexities, resistance to change, underutilization or overproduction of resources, inconsistencies in quality control, increased safety risks, and schedule. Also delays, data integration problems, environmental impact management, and cost overruns. Strong control over time management, costs, and optimizing available resources are, however, key to achieving mega-infrastructure success. The principles of Lean Construction approach these issues using tools such as Value Stream Mapping (VSM) to remove waste, standardize processes, and optimize the use of resources. Techniques like Kanban and focus on the Seven Wastes of Lean, including overproduction, waiting, transportation, overprocessing, inventory, motion, and defects improve operational efficiency. These practices also enhance stakeholder communication, impose structured workflows for safety, and clarify project scopes. Lean methodologies optimize the bidding process, reduce ambiguity in contracts, and align the goals of the stakeholders, resulting in cost savings, safety, and improved project collaboration. Navi Mumbai International Airport is where the Lean principle comes alive. This mega-project with over $1 billion, having complex logistics and stakeholder coordination incorporates Lean to address NMIA's challenges. Designed for an initial capacity of 12 million passengers that can scale to 60 million passengers spread across 2,865 hectares, it uses meticulous planning and resource optimization to ensure efficient execution.

Keywords: Lean construction; Megaprojects; Navi Mumbai International Airport; Logistics complexities; Stakeholder coordination; Quality control; Resource optimization; Value stream mapping; Kanban; 7 wastes of lean; Safety management; Cost overruns.

1.0 Introduction

Megaprojects are the foundation of contemporary infrastructure, defining cities and economies. Yet, they tend to be plagued by cost overruns, delays, and inefficiencies because of their magnitude and complexity.

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To counter these issues, Lean Construction provides a more intelligent solution—eliminating waste, enhancing collaboration, and streamlining workflows to maximize overall efficiency. This research investigates the effects of Lean Construction in megaprojects based on a case study of the Navi Mumbai International Airport (NMIA). NMIA shows how lean methods such as Value Stream Mapping (VSM), Kanban, and the Last Planner System (LPS) make processes smooth, enhance decision-making, and foster sustainability. Through this observation, the research brings out how Lean Construction has the potential to transform big-ticket infrastructure projects so that they become more successful in the long term.

1.1 Research objectives

- To know the role of lean construction in megaprojects,
- To understand what are the benefits of Integrated Project Delivery (IPD)?
- To know how digital twins enhance decision-making in construction?
- To learn how does lean construction promote sustainability?
- To understand how the Last Planner System (LPS) improves workflow?

1.2 Scope of study

Lean construction maximizes project planning, supply chain, workflow, quality, and risk management by eliminating waste and enhancing efficiency. Collaboration with stakeholders earlier on reduces uncertainty, while lean supply chain minimizes material wastage and dependency. Non-value activities are removed to increase productivity, and a culture of improvement enhances quality control. Joint risk management responsibility fosters proactive solutions of issues. All these factors combined promote efficiency, cost savings, and sustainability in megaprojects.

1.3 Limitations of study

Although this study offers useful findings, it is mainly case studies and secondary data-based, thus being context-specific. The results, focused on the NMIA project, might not apply to all megaprojects. In addition, external variables like regulatory policies, economic environments, and unexpected risks might affect the efficacy of lean methodologies in practice. While these constraints exist, the research provides a good basis for understanding and applying Lean Construction principles across various project contexts.

2.0 Literature Review

Kemppainen *et al.* (2003) concluded that Lean principles for infrastructure projects minimized mass haul distances and material volume, and this produced cost savings and environmental advantages. Rad *et al.* (2010) discovered that Lean strategies such as JIT, VSM, and LPS enhanced disaster recovery by mitigating delays and improving stakeholder

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coordination. Maraqa *et al.* (2011) noted that combining BIM and Lean Construction reduced waste and enhanced sustainability through optimized use of resources. Nowotarski *et al.* (2012) indicated that Lean implementations in construction projects improved cost management, labor productivity, and scheduling effectiveness. Solaimani & Sedighi (2010) pointed out that Lean initiatives harmonize economic, environmental, and social considerations, enhancing safety and minimizing carbon footprint.

Gaoa *et al.* (2015) discovered that Lean-based safety management systems, such as digital monitoring and 5S methodology, greatly minimized on-site risks. Jagannathan *et al.* (2013) recognized major hindrances to Lean implementation in India, highlighting policy reforms and training programs for successful implementation. Shaqour (2011) concluded that Lean initiatives such as LPS and 5S enhanced productivity and resource utilization in Egypt's construction sector. Singh *et al.* (2018) noted that developed economies have embraced Lean Construction extensively, while emerging economies require tailored Lean models for enhanced implementation.

Smalla *et al.* (2012) concluded that institutional resistance, absence of professional experts, and initial high costs were major deterrents to the adoption of Lean in Dubai, recommending policy incentives and training as remedies. According to the literature review carried out, it has been noted that a majority of studies on applying Lean Construction to transport infrastructure depend on surveys as opposed to live site applications, especially in India. This research will aim at addressing the site element, the application of Lean tools and techniques to overcome waste production, and comparison between traditional construction methods and Lean methods in Indian megaprojects.

3.0 Methodology

3.1 Data collection

Megaprojects are instrumental in designing contemporary cities and economies, yet they are frequently plagued by cost overruns, delays, and inefficiencies. Their enormity and complexity require creative solutions to guarantee successful implementation. Lean Construction provides the answer by reducing waste, promoting collaboration, and optimizing workflows to improve efficiency.

This research examines the influence of Lean Construction in megaprojects, using the Navi Mumbai International Airport (NMIA) as the subject of focus. Spread over 2,865 hectares, NMIA is planned to decongest Chhatrapati Shivaji Maharaj International Airport (CSMIA) in Mumbai. This $5.63 billion PPP project incorporates Lean practices like Value Stream Mapping (VSM), Kanban, and the Last Planner System (LPS) to enhance efficiency and sustainability. Through the study of NMIA, this study illustrates how Lean Construction can transform mega-scale infrastructure projects to deliver improved results and long-term success.

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Table 1: Project Description

Project	**Navi Mumbai International Airport**
location	Panvel, Navi Mumbai, Maharashtra, India
Total area	~1,160 hectares (2,870 acres)
Estimated cost	₹16,000 crore (US$1.9 billion
Capacity	Initial Phase: 20 million passengers per annum (MPPA) Final Phase: 90 MPPA (by 2040)
Runways	Two parallel runways (3,700m & 3,800m)
Developer	City and Industrial Development Corporation (CIDCO) & Adani Group

Project execution and major contractors

- Design & Master Plan: Developed by Louis Berger-INECO-RITES consortium.
- Terminal Architecture: By Zaha Hadid Architects.
- EPC Contractor: Larsen & Toubro (L&T) Construction.
- Environmental Impact Study: Prepared by Bombay Natural History Society (BNHS).
- Financial nb & Legal Advisory: SBI Capital Markets and Cyril Amarchand Mangaldas.

Figure 1: Navi Mumbai International Airport Futuristic Planning

Source: Global Coastal Cities Summit 202, CIDCO

NMIA is planned to cater to the increasing air traffic needs of the Mumbai Metropolitan Region (MMR). Passenger capacity will be expanded in phases, beginning with 10

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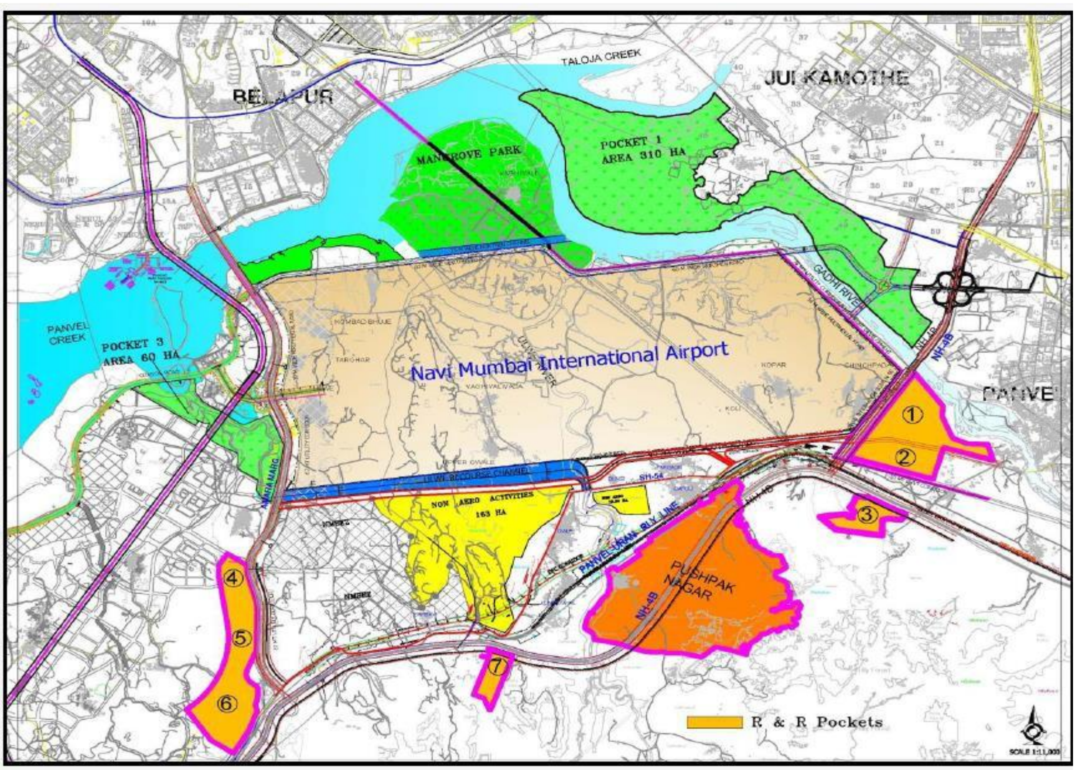
million passengers per year in 2024 and up to 60 million after 2032. The airport will have two parallel runways (3,700m each), three passenger terminals, and exclusive cargo terminals (23,700m² international, 33,000m² domestic). Further infrastructure consists of three aircraft hangars, a 151,000m² fuel farm, and 25,000m² for ground and catering services, providing smooth operations and future scalability. Sanctioned in 2008, NMIA is constructed in four phases on a DBFOT (Design-Build- Finance-Operate-Transfer) pattern with a concession period of 30 years. Although initially proposed to start operations in 2020, due to land acquisition problems, financial closures, and the COVID-19 pandemic, the schedule has been delayed. The first phase is now set to be completed by December 2024 with the help of a ₹127.7 billion ($1.67 billion) debt facility guaranteed by SBI.

Figure 2: **Environmental Sensitive Areas**



Source: Global Coastal Cities Summit 2023, CIDCO)

Also, NMIA incorporates Lean Construction concepts to increase efficiency and sustainability. Major applications involve Value Stream Mapping (VSM) for logistics optimization, Just-in-Time (JIT) Delivery for lowered storage costs, and Prefabrication &

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Modular Construction for quicker assembly. Digital Twin Technology & BIM facilitate real-time monitoring, while sustainable practices like green building certification, rainwater harvesting, and energy-efficient infrastructure minimize the carbon footprint. By embracing these practices, NMIA wants to provide a benchmark for efficient and sustainable megaproject development.

3.2 Data analysis

The Navi Mumbai International Airport (NMIA) encountered major challenges prior to breaking ground. Land acquisition and site clearing involved the relocation of 5.5 million cubic meters of soil, soil stabilization, and drainage planning because of soft clay and waterlogging close to Panvel Creek. Approvals from regulatory bodies were slow, especially because of environmental issues close to the Karnala Bird Sanctuary, necessitating clearances from several authorities. Financial issues were caused by changes in ownership from GVK to Adani Group, as well as increasing material prices impacting initial cost estimates.

After the commencement of construction, runway and airside development needed high-load-bearing pavement and sophisticated navigation systems, but monsoons and unexpected delays hampered progress. The lotus-shaped terminal presented structural and engineering issues, while delays in importing major systems such as HVAC, baggage handling, and aerobridges further delayed completion. Issues related to utility, i.e., high water table levels, integration of solar power, and delayed waste management infrastructure, also affected timelines. Connectivity issues, including delays in projects like Mumbai Trans-Harbor Link, Sion-Panvel Expressway, and Metro Line 8, impacted access, while COVID-19 supply chain breakdowns delayed essential material and equipment. Shortages in labor in skilled fields such as BIM-based construction and AI-based airport systems further disrupted project advancement.

Even after initial build, testing and commissioning took longer because integration of ILS, radar, and ATC systems was delayed. Compliance with regulations also consumed more time and involved DGCA and AAI approvals, plus environmental audits to obtain green airport certification. Excess spending meant added financial burdens, with protracted timelines enhancing penalties and project costs overall.

4.0 Findings and Discussion

4.1 Pre-construction phase solutions

Even before construction had commenced, the Navi Mumbai International Airport had been through major hurdles, ranging from land acquisition through regulatory setbacks and financial uncertainty. In addressing these challenges, the team embraced Lean methods for better efficiency and coordination. The Last Planner System (LPS) ensured that all stakeholders were synchronized, minimizing miscommunication and maintaining site preparation on target. Value Stream Mapping (VSM) located inefficiencies in logistics so that operations could be smoother.

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Figure 3: Value Stream Mapping

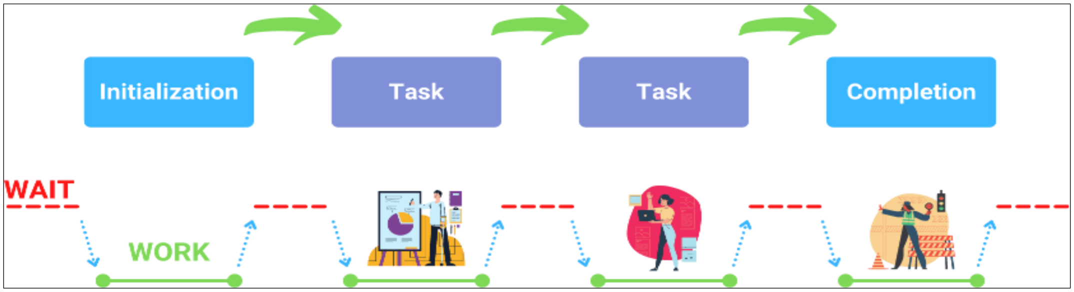
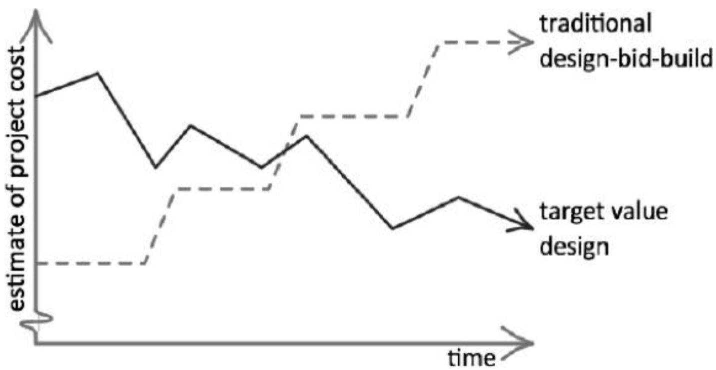


Figure 4: Target Value Design



Regulatory approvals were another significant hurdle, particularly with stringent environmental regulations. Integrated Project Delivery (IPD) facilitated early interaction with authorities, accelerating permits and minimizing bureaucratic delays. Digital Twin Technology offered real-time environmental simulations, guaranteeing regulatory compliance and avoiding last-minute surprises. Financially, Target Value Design (TVD) facilitated cost-effective choices, while Lean Accounting allowed real- time budget monitoring, avoiding overruns and smooth financial handovers.

4.2 Construction phase solutions

Construction of NMIA was enormous, but Lean Construction ensured the job remained on course. Just-in-Time (JIT) Delivery allowed materials to reach the site precisely when required, minimizing waste and excess storage. 5S methodology ensured work areas remained tidy, while BIM technology enabled real-time monitoring of runway alignment and drainage systems, reducing mistakes and rework.

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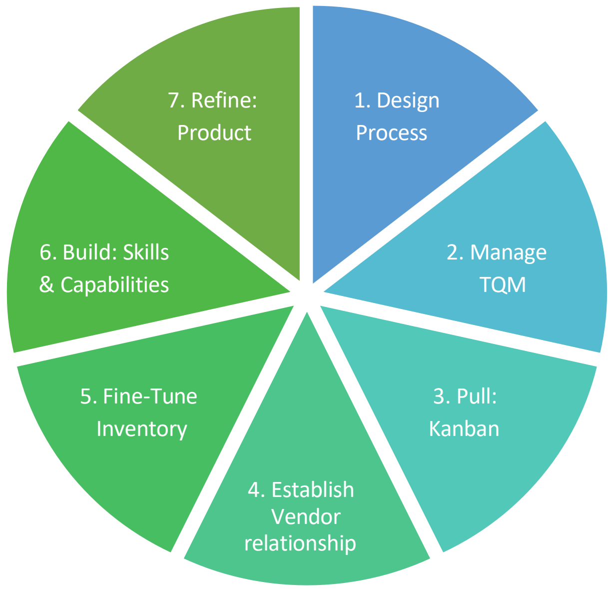
Figure 4: JIT Just-in-Time



Weather was another issue, particularly during monsoon months. Poka-Yoke (Error Proofing) and Lean Six Sigma maintained quality control to avoid material damage and construction flaws. To accelerate terminal construction, Prefabrication & Modular Construction facilitated large items such as HVAC equipment and baggage handling units to be constructed off-site and erected in a matter of weeks. Digital Twin Technology further improved scheduling and resource utilization.

Utility and infrastructure coordination was also intricate. Pull Planning coordinated utility work to correspond with other construction activities to prevent delays. Critical Chain Project Management (CCPM) coordinated dependent projects such as the Mumbai Trans-Harbor Link and Metro extensions to ensure airport connectivity readiness on schedule. In times of the COVID-19 pandemic that caused a global supply chain disruption, Lean Procurement Strategies and Multi-Sourcing allowed for alternative suppliers, avowing project delay.

4.3 Post-construction phase solutions

As NMIA approached completion, operationally smooth-running was a major priority. Standardized Work procedures optimized testing of navigation, security, and baggage systems, with Kaizen providing continuous improvement momentum. A3 Problem- Solving was used to speed up regulatory approvals, and Design for Maintainability (DfM) provided long-term reliability of essential systems. From a financial perspective, Earned Value Management (EVM) tracked costs, with TVD managing cost-effective facility upgrades so that the project remained financially viable.

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5.0 Conclusion

This Lean Construction research for megaprojects, case-study NMIA, depicts how Lean fundamentals overcome most daunting issues such as delays in acquiring land, administrative issues, inefficiencies in logistics, and money crunches. Value Stream Mapping (VSM), Just-in-Time (JIT), Building Information Modelling (BIM), Digital Twin Technology, and Prefabrication minimized process fragmentation, increased efficiency, and lowered wastage. Lean Construction was successful in cost management, schedule optimization, and sustainability, reducing environmental footprints while optimizing the use of resources. NMIA shows that early participation by stakeholders, cutting-edge technology, and proactive risk management prevent significant cost overruns and delays. In summary, the implementation of Lean principles results in effective project delivery, cost reduction, improved safety, and timely delivery. Nonetheless, there is a need to overcome change resistance, unawareness, and training deficiencies. Megaprojects in the future must undertake systematic Lean adoption by policy assistance and a continuous improvement culture for ensuring efficiency, sustainability, and long-term success in mega- infrastructure development.

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