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Application of Value Stream Mapping for Identification and Reduction of Construction Delays: A Case Study in Building Construction

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ABSTRACT

Time overruns in construction projects in India have always been a result of inadequate coordination, supply chain problems, manpower issues, and unnoticed non-value-adding (NVA) activities. In this study, Value Stream Mapping (VSM), one of the most important techniques of lean construction, is used to identify, measure, and eliminate factors that cause delays in column steel reinforcement for a mixed-use building construction, namely the Orchid Gold Project, Tower B, Ahmedabad, Gujarat. The on-site study was complemented with a structured survey questionnaire answered by 82 construction workers comprising site engineers, project managers, planning engineers, and supervisors. The responses were analyzed using the Relative Importance Index (RII) method, resulting in an RII value of 0.890, a high figure indeed. Current State the VSM analysis found that the total lead time was 51.00 hours, out of which 18.00 hours (35.29%) involved value-added work. However, 20.17 hours (39.5%) were spent in waiting. With lean improvement tools such as pre-scheduling for purchasing, parallel activities, zone binding, and inspection staggering, the Future State VSM was able to cut down waiting time by 93.80%, lead time by 37.10%, and process cycle efficiency (PCE) improved from 35.29% to 56.11%. This illustrates how VSM can be effectively used as a low-cost lean method to identify and address inefficiencies in construction process workflows.

Keywords:- Value Stream Mapping (VSM); Construction Delays; Lean Construction; Work flow Optimization; Process Cycle Efficiency; Non-Value-Added Activities; Relative Importance Index (RII)

INTRODUCTION

Time management is an essential part of a successful construction project completion process. There are various reasons for delivery delays, such as material delivery issues, labour mobility problems, lack of equipment, and insufficient cooperation between tradespeople. The combination of all of these causes when it comes to repetitive construction processes contributes greatly to extending project time frames and increasing costs.

The construction sector plays an important role in infrastructure development in India, but at the same time, it suffers from inefficiency and bad work processes management. Some of the main causes of delay are improper planning, delayed materials supply, contractors' financial problems, lack of qualified workforce, and ineffective project monitoring.

The first problem with inefficiencies is that they become apparent only when the delay has already occurred because there is no way to predict and measure the NVA tasks before a critical path delay occurs. Value Stream Mapping (VSM), which is a lean manufacturing system adjusted to the construction industry, could help to overcome this problem by mapping the whole process and differentiating between VA tasks and NNVA/NVA tasks.

Categorize and identify the key reasons for delays in construction processes.
Monitoring and measurement of lead time, cycle time, waiting time, and Process Cycle Efficiency (PCE), Create a current state value stream map, Create a future state value stream map using lean concepts, Comparison between current state and future state value stream maps.
The research will be confined to the process of structural reinforcement in a mixed-use building under construction in Ahmedabad, Gujarat. The focus on a narrow area allows deep analysis of the problem in hand despite the limited scope of the research.

LITERATURE REVIEW

Numerous studies have shown that construction delays are a worldwide problem and one which affects Indian projects to a great extent. This literature review will summarise major findings from different strands of studies:

A. Construction Delay Studies

Desai and Bhatt analyzed the residential building projects in central Gujarat and found that improper site management, delayed material supply, contractor's financial problems, and poor planning were the major sources of delays. The same factors were also found by Daba and Pitroda in Vadodara. They suggested earned value management and modern scheduling techniques to overcome the problem of delay. Mansuri and Patel investigated highway projects and concluded that improper client-contractor coordination and lack of financial stability led to increased delays.

B. VSM Application in Construction

Similarly, Agrawal and Sharda adopted VSM in a construction site in Indore, proving that traditional practices lead to considerable waste due to delay, waiting, and extra motions. In this regard, the visual aspect of VSM made the identification of the problems easier. According to Desai and Shelat, VSM helped reduce the duration of the project, increase resource utilisation, and enhance productivity by removing the non-value-added tasks. Barathwaj, Singh, and Gunarani combined VSM with real-time monitoring in residential constructions in Tamil Nadu. They found that the application of lean concepts along with the use of digital monitoring results in better resource allocation and decision making. This finding was supported by Nair who found that real-time VSM monitoring enhances on-site productivity and cost management.

In addition, Ramani and Lingan used lean VSM in Mumbai, which resulted in reduced construction time and cost by removing the idle time, transportation, and rework wastes. Similarly, Pancholi et al. (ILCC 2021) showed the application of VSM in various Indian construction activities. They mapped the flow of the processes and identified bottlenecks in the process. Layeequddin and Khatoon also used VSM in infrastructure construction projects in Hyderabad. They observed that VSM led to shorter durations of the projects and better stakeholder coordination. Moreover, Pothen and Ramalingam used VSM along with work sampling to measure the idle time and inefficiencies in labor in industrial construction projects.

METHODOLOGY

A mixed methods research approach was used, which involved using a primary quantitative survey along with a secondary qualitative case study conducted on the basis of the VSM model.

A. Questionnaire Survey Design

A questionnaire was constructed, which was administered to construction professionals in the city of Ahmedabad through Google Forms. Purposeful sampling was done to select those professionals who are involved in planning,implementation, management, and supervision of construction. A total number of 82 responses were collected, which included people having the following positions: Site Engineers, Planning Engineers, Project Managers, SupervisorsThe responses were collected using the five point Likert scale (1=Strongly Disagree to 5=Strongly Agree). The questionnaire had six parts, namely: (A) Knowledge about VSM, (B) Reasons for delays, (C) VSM for identifying delays, (D) VSM for reducing delays, (E) Issues with VSM, and, (F) Site condition and operations.

B. Relative Importance Index (RII)

The Relative Importance Index was used to rank the significance of delay factors and validate industry perception of VSM effectiveness. It is calculated as:

RII = ΣW / (A × N)

Where: ΣW = sum of all respondent weights; A = maximum Likert weight (5); N = total respondents (82). Higher RII values indicate greater consensus on the factor's importance.

C. Case Study Data Collection

Quantitative process data were collected through the following primary methods:

Direct Observation & Time Study: Manual recording of activity durations for all 13 reinforcement sub-activities.

Daily Progress Reports (DPR): Site-level records of actual progress versus planned progress, identifying delays and their causes.

Structured Interviews: Discussions with site engineers, supervisors, and labourers to identify root causes of operational delays.

The process metrics measured were Cycle Time (C/T), Lead Time (L/T), Waiting Time (W/T), Changeover Time (C/O), and equipment utilisation. The non-value-added tasks were categorised based on the TIMWOOD lean waste categories as follows: Transportation, Inventory, Motion, Waiting, Over-processing, Over-production, and Defects.

D. VSM Construction

Current State VSM was developed through the identification of all 13 activities performed within the column reinforcement process flow, including their cycle time, waiting time, activity classification (VA, NNVA, NVA), and manpower requirement. Overall Process Cycle Efficiency was computed using:

PCE = (VA Time / Lead Time) × 100

Future State VSM was subsequently formulated based on the implementation of lean techniques to minimise or eliminate NVA activities, overlapping of subsequent activities, synchronization of material flow, and planning for inspection approvals.

RESULTS AND DISCUSSION

A. Questionnaire Survey Results

The reliability index of the questionnaire overall is 0.890, which shows that there is extremely high consistency among all respondents on the relevance and effectiveness of VSM in managing construction delays.

Table I: Section-wise RII Results VSM

Section	RII
A: Awareness of Value Stream Mapping	**0.900**
B: Causes of Delays in Construction	0.880
C: VSM for Delay Identification	**0.890**
D: VSM for Delay Reduction	0.880
E: Challenges in Implementing VSM	0.890
F: Site Conditions & Workflow	0.870
Overall RII	**0.890**

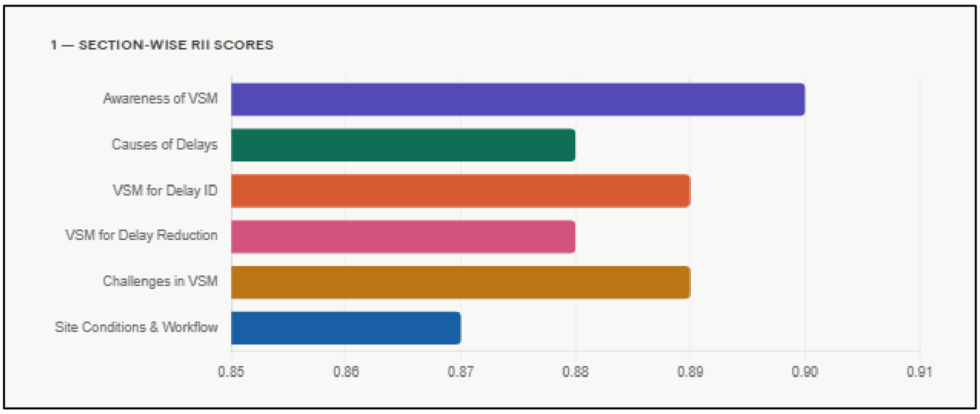

Figure I: VSM Questionnaire Section-wise RII Score

The highest score was achieved by Section A (Awareness of VSM, RII = 0.900), which proves that construction workers in Ahmedabad have a good knowledge of lean construction practices and the VSM method. This is a necessary condition for proper implementation. The confidence in the effectiveness of VSM in detecting delays and adapting to difficult on-site conditions was proved by Sections C and E (RII = 0.890). The lowest score, RII = 0.870, was achieved by Section F (Site Conditions).

Table II: Designation-wise RII Results VSM

Section	Project Manager	Planning Eng.	Site Eng.	Supervisor
Overall	0.84	0.88	**0.90**	0.88
Section A	**0.92**	0.90	**0.93**	0.86
Section B	0.90	0.89	0.89	0.87
Section C	0.88	0.90	**0.92**	0.86
Section D	0.80	0.88	0.89	0.88
Section E	0.82	0.86	**0.93**	0.89
Section F	0.80	0.86	0.89	0.88

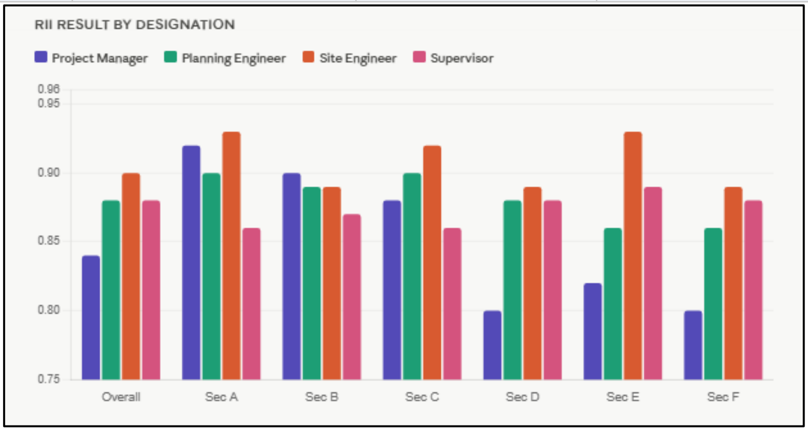

Figure II: VSM Questionnaire Designation-wise RII Score

Site Engineers showed the highest RII score overall (0.90), due to the fact that they were directly involved with site issues and experienced how the activities of NVA affected their processes. They showed the highest results in Sections A (0.93) and E (0.93). The lowest RII score overall was demonstrated by Project Managers (0.84) as well as the lowest scores in Sections D and F.

B. Current State VSM Activity Analysis

Table III: Current State Value Stream Mapping Column Reinforcement

Sr.	Activity	CT (hrs)	WT (hrs)	Type	Manpower
1	Preparation of Bar Bending Schedule (BBS)	1.00	—	NNVA	—
2	Steel Procurement & Delivery	—	8.00	NNVA	—
3	Steel Storage & Yard Issuance	0.50	1.00	NNVA	2
4	Steel Cutting & Bending (Yard)	10.00	1.00	VA	4
5	Scaffolding Material Shifting	1.00	1.00	NNVA	2
6	Shifting Reinforcement Bars to Work Front (15 loads)	4.00	1.00	NNVA	2
7	Scaffolding Erection	2.00	1.00	NNVA	4
8	Waiting (Dependency before Binding)	—	3.00	NVA	—
9	Column Reinforcement Binding (12 Nos.)	8.00	1.00	VA	18
10	Scaffolding Dismantling	1.50	—	NNVA	3
11	Internal Site Engineer Check	1.50	1.00	NNVA	2
12	Rectification Work	0.33	0.17	**NVA**	2
13	Client Inspection	1.00	2.00	NNVA	1

Table III presents the Current State VSM for column steel reinforcement work. Activities were classified as Value-Added (VA), Necessary Non-Value-Added (NNVA), or Non-Value-Added (NVA).

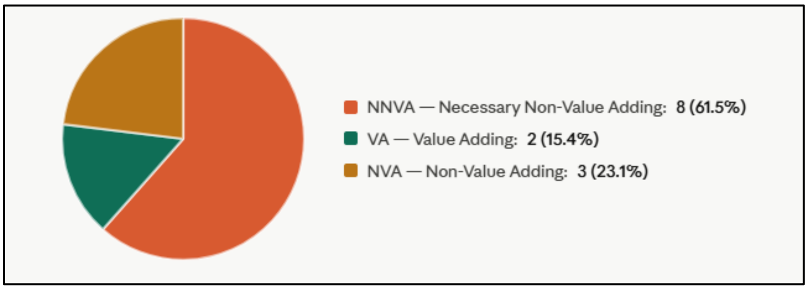

Figure III: Activity Classification into VA, NNVA, and NVA in Column Reinforcement Workflow (CSM)

C. Current State Mathematical Analysis

Based on the observed activities, the following performance metrics were computed:

Total Cycle Time (CT): Sum of all processing times = 1 + 0.5 + 10 + 1 + 4 + 2 + 8 + 1.5 + 1.5 + 0.33 + 1 = 30.83 hours

Total Waiting Time (WT): Sum of all buffer/idle times = 8 + 1 + 1 + 1 + 1 + 1 + 3 + 1 + 1 + 0.17 + 2 = 20.17 hours

Total Lead Time (LT): LT = CT + WT = 30.83 + 20.17 = 51.00 hours

Value-Added Time (VAT): Steel Cutting & Bending (10 hrs) + Column Binding (8 hrs) = 18.00 hours

Process Cycle Efficiency (PCE): PCE = (18.00 / 51.00) × 100 = 35.29%

PCE at the level of 35.29% implies that more than half, specifically two-thirds, of the entire process time (64.71%) will be wasted on unnecessary actions or waiting periods. The major factors that cause the process inefficiencies are: steel procurement waiting time (8 hours; 39.7% of total waiting), dependency waiting before binding (3 hours; 14.9%), customer inspection waiting period (2 hours; 9.9%).

D. Future State VSM (Lean Improvement Approach)

The Future State VSM is created based on the use of the following lean interventions:

Procurement prior planning: Procurement activities and preparations for BBS are done 1-2 days ahead, thereby eliminating an 8-hour delay for procurement.

Concurrent activity performance: Loading and unloading of scaffolding materials (5 loads) starts at the same time as cutting/bending in the yard.

Sequential binding in zones: Binding of reinforcement starts while scaffolding is being set in zone one.

Concurrent internal inspection: Inspection activities by the site engineer are performed simultaneously during the process of binding.

Scheduled client inspection: The approval from the client is scheduled in advance to avoid post completion delay.

Concurrent scaffold dismantling: Dismantling of the scaffold is conducted concurrently with client checking activities.

Table IV: Future State Value Stream Mapping Column Reinforcement

Sr.	Activity	CT (hrs)	WT (hrs)	Type	Manpower	Improvement
1	Preparation of BBS	1.00	—	NNVA	—	Pre-planned
2	Steel Procurement & Delivery	—	—	NNVA	—	Pre-planned procurement buffer
3	Steel Storage & Issuance	0.50	0.50	NNVA	2	Better planning
4	Steel Cutting & Bending	10.00	0.50	**VA**	4	Synced with site schedule
5	Scaffolding Material Shifting (5 loads)	1.00	0.17	NNVA	2	Parallel start with binding
6	Shifting Reinforcement Bars to Work Front	4.00	0.08	NNVA	4	Pre-planned crane schedule
7	Scaffolding Erection (Partial)	2.00	—	NNVA	4	Start in zones
8	Column Binding Zone-wise (12 Nos.)	8.00	—	**VA**	12–18	Continuous flow
9	Internal Engineer Check (Parallel)	1.50	—	NNVA	1	Overlapping with binding
10	Rectification Work	0.33	—	NVA	2	Binding/misc. cover

11	Client Inspection (Pre-informed)	1.00	—	NNVA	—	Reduced waiting
12	Scaffolding Dismantling (Staggered)	1.50	—	NNVA	3	Overlap with client check

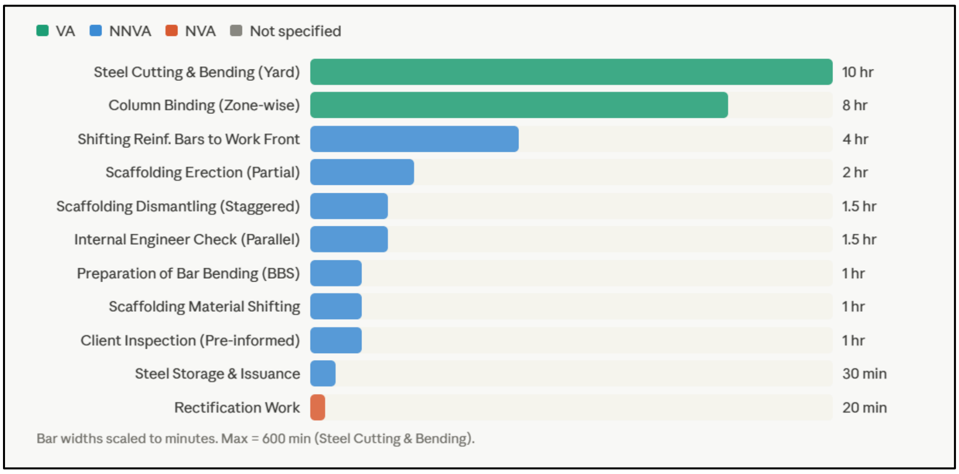

Figure IV: Process time by activity

E. Future State Mathematical Analysis

Total Cycle Time: 1 + 0.5 + 10 + 1 + 4 + 2 + 8 + 1.5 + 0.33 + 1 + 1.5 = 30.83 hours

Total Waiting Time: 0 + 0.5 + 0.5 + 0.17 + 0.08 + 0 + 0 + 0 + 0 + 0 + 0 = 1.25 hours

Total Lead Time: 30.83 + 1.25 = 32.08 hours

Value-Added Time: 18.00 hours

Process Cycle Efficiency: PCE = (18.00 / 32.08) × 100 = 56.11%

F. Comparative Improvement Summary

Table VI presents a consolidated comparison of current and future state performance metrics.

Table V: Comparative Performance Current vs. Future State

Metric	Current State	Future State	Improvement
Total Cycle Time (hrs)	30.83	30.83	No change
Total Waiting Time (hrs)	**20.17**	**1.25**	↓ **93.80%**
Total Lead Time (hrs)	**51.00**	**32.08**	↓ **37.10%**
Value-Added Time (hrs)	18.00	18.00	No change
Process Cycle Efficiency	**35.29%**	**56.11%**	↑ **20.82 pts**

The findings clearly show a remarkable enhancement in all major lean performance indicators. In particular, the 93.80% reduction in waiting time, measured in going down from 20.17 hours to 1.25 hours, seems to be the most impressive achievement, implying that most of the construction delays occurring in the current state are not intrinsic to the actual construction process but rather are due to inefficient planning and coordination. Moreover, a 37.10% decrease in lead time will positively influence floor cycle times, concrete pouring dates, and the overall pace of construction projects completion. Additionally, Increasing PCE from 35.29% to 56.11%, or a difference of 20.82 percentage points, suggests that more productive time was spent than before. Although it cannot be classified as a world-class figure (80%+), this result should be regarded as quite satisfactory, given the nature of construction processes that do not allow much more room for improvement when it comes to eliminating waste.

CONCLUSION

From this research work, it can be conclusively stated that the analysis of questionnaire surveys along with VSM at site level makes the tool a very effective instrument for identifying, measuring, and removing construction flow delays.

From the questionnaire surveys that were conducted among 82 professionals in the city of Ahmedabad, the overall result achieved was the RII value of 0.890. In this regard, the highest score was recorded for VSM Awareness (0.900) and VSM for Delay Identification (0.890). It was seen that Site Engineers showed the highest RII value in all sections indicating that they recognize the practical relevance of VSM.

From the Current State VSM carried out regarding the reinforcement of steel columns in the Orchid Gold Project, a PCE value of just 35.29% was recorded. From the total number of 20.17 hours (representing 39.5% of lead time), 3 were purely consumed on wasteful activities. In terms of waste time, 64% of the total time comes from three major areas that include procurement buffer, waiting dependency, and client inspections.

Based on the findings presented, the study shows that VSM has potential value as a lean construction tool that could be used to detect and eliminate workflow disruptions in construction processes. In the conducted survey among 82 construction experts, VSM received a very high relative importance index of 0.890, indicating its suitability and relevance as a lean construction tool for detecting and addressing workflow disruptions. Analysis of operations using current state VSM identified several problems that characterized inefficient workflow management, where much of the lead time was wasted on various non-value-added activities.

The application of lean techniques using future state VSM brought about some considerable improvements in workflow management, with significant reductions in total waiting time (by 93.80%) and lead time (by 37.10%), alongside a marked increase in PCE from 35.29% to 56.11%.

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