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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

SARA7403 - LEAN CONSTRUCTION MANAGEMENT

SYLLABUS

SARA7403	LEAN CONSTRUCTION MANAGEMENT	L	T	P	Credits	Total Marks
		3	0	0	3	100

COURSE OBJECTIVES:

- To provide exposure to the students on the principles and techniques of lean construction.
- To enhance their skills by training in lean project management software.
- To appreciate Lean management and develop a lean culture.

UNIT 1	INTRODUCTION TO LEAN PRINCIPLES	9 Hrs

Introduction — productivity measurement in projects and work diagnostics; Mapping of lean principles into construction; Lean construction — fundamental concepts; Lean thinking and culture;

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UNIT 2	PROJECT LIFE CYCLE AND LEAN PROJECT DELIVERY SYSTEM	9 Hrs

Project life cycle and lean project delivery system; Lean tools, techniques and measures; Collaborative planning and last planner system; Location based management system;

UNIT 3	LEAN IN DESIGN AND LEAN TOOLS	12 Hrs

Lean in design and supply chain management; Lean enablers and integration; Application in lean project management software - Master planning; Value Stream Mapping, Visual Management, 5S

UNIT 4	PLANNING AND PROJECT PERFORMANCE	9 Hrs

Framework for pull planning and constraint analysis; Look ahead planning, weekly work plans , Standup Meetings, Learning PPP, Key performance indicators for plan reliability and project performance.

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UNIT 5	CONSTRUCTIVE ASSIGNMENTS	6 Hrs

Design of pull planning charts, weekly work plans and look ahead charts for display using a case study.

Max. 45 Hours

COURSE OUTCOMES

CO1	Develop lean thinking and map lean culture in project delivery.
CO2	Interpret the Lean delivery systems.
CO3	Demonstrate skill in applying Lean planning tools.
CO4	Develop pull planning and other visual charts for follow up of project schedules and targets.
CO5	Understand Lean in supply chain management.
CO6	Investigate the key performance indicators and analyze project performance after implementation of lean management techniques.

SCHOOL OF BUILDING AND ENVIRONMENT

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SARA7403 - LEAN CONSTRUCTION MANAGEMENT

UNIT – I – INTRODUCTION TO LEAN PRINCIPLES

1. INTRODUCTION TO LEAN PRINCIPLES

- Lean is a philosophy, and it allows for the interweaving of the fields of those who create the built environment.
- Building stakeholders include owners, architects, engineers, contractors, trade partners, lawyers, financiers, vendors, and even those who teach construction.
- To make a construction project successful, there needs to be substantial shared understanding from those with disparate levels of education and desires.
- Developing a deep understanding in the art of collaboration lies at the very heart of lean construction.
- Serious games and simulations play an important role in helping stakeholders with this shared understanding.

Lean is about doing more with less. The objective of Lean is to create more value for customers, while at the same time reduce the resources required. It focuses on elimination/ reduction of waste, improving flow & velocity, reducing lead time.

Lean Principles

Value – Specify value from the point of view of the customer

Value stream – establish all the process steps in the value stream, and remove any step that does not create value

Flow – enable the remaining value-creating steps to occur in a very tight and integrated sequence so that the product or service can flow smoothly toward the customer.

Pull – As flow is introduced, let customers pull value from the next upstream activity.

Pursue perfection – As these steps lead to greater transparency, enabling further elimination of waste, pursue perfection through continuous improvement.

Lean Training

Range of Lean training areas alongside Lean journey are:

- Lean Transformation Program
- Lean Strategy & Roadmap Planning
- Lean Deployment & Implementation
- Lean Diagnostic Assessment / Diagnosis
- Lean Project Review & Coaching
- Lean Training

Comprehensive range of Lean Training is as follows:

- Lean Thinking Training
- Value Stream Mapping Training
- Lean Executive Training
- Lean Champion Training
- Lean Practitioner Certification Training
- Lean Expert Certification Training
- Lean Master Certification Training
- Lean for Service Training
- Lean for Office Training
- 5S Training

- Workplace Layout Training
- Poka Yoke Training
- TPM Training
- SMED Training
- Kanban Training
- Standardized Work Training
- TOC Training
- Lean Diagnostic
- Kaizen Event

Exploring the reach of lean philosophy in indian construction industry

Abstract
The construction industry has become synonymous with delays and cost overruns. Researchers and practitioners typically classify the delay and overrun causes into people, process, and technology dimensions. Lean construction philosophy promises to increase collaboration and communication amongst people and integrate them with process and technology, ultimately reducing the uncertainty caused by delay-inducing factors. Despite its potential advantages, the construction sector, at least in India, is on the back foot when implementing innovative concepts such as lean. Prior experience tells us about a trickledown effect in the construction industry, where advanced technology and managerial concepts have to be first adapted and implemented by the leading few construction companies spearheading the industry. Subsequently, such concepts make inroads into the rest of the industry comprising tier-2 and Small and Medium Enterprises (SMEs). With this premise, the study explores the reach of Lean philosophy in the leading construction companies in India.

Lean construction	Value addition	Integrated project delivery	Lean concepts / approach / principles	Quality	Action learning/research	Transparent/transparency
Last Planner	Flow	Change management	Logistics	Production planning	Target costing	Lookahead Planning
Lean implementation	Continuous improvement / kaizen	Lean	Lean implementation barriers	Cycle time	Productivity / efficiency	Integration
Lean culture	Visualization	Waste	Production management	Theory	Method	Early contractor involvement
Collaboration	Strategy	Value stream	Lean thinking	Organization	Learning	Cost management
Lean production	BIM	Project management	Transformation	Modularization / prefab	Construction Planning	Benchmarking/benchmark
Performance measurement / metric / indicator	Lean design management	Process map	Supply chain	Lean processes / techniques / practices	Target Value Design	Agile/agility

Figure 1: 49 'lean signs'

2. PRODUCTIVITY MEASUREMENT

The global construction industry, more specifically the Indian sector, has been facing challenges of low construction productivity, delays, cost overruns in project delivery, fragmentation of construction supply chain, and lack of trust among stakeholders.Lean construction has been promoted as an effective approach for improving productivity in construction through better project planning and collaboration. It is the application of lean thinking into construction projects, and essentially focuses on maximizing the performance and value for the customer and minimizing waste through increased transparency and trust between the project stakeholders.

In general, lean construction makes the project easier to manage, safer, complete earlier, cost less with better quality.

The key areas in project delivery at these times of the pandemic that needs to be specially handled through innovative project delivery methods are:

- Optimal manpower and resources planning for project execution to raise productivity
- Reliability and resilience against potential disruptions due to external factors
- Shortening of construction period

Creating everyday improvement: helping last planners and work teams improve productivity-*the change business- Alan Mossman*

- The purpose is to explore how enabling trade crews and their leaders to feel safe can help create everyday improvement in processes and productivity in design and construction.
- For many years the construction sector has relied on workers with little formal education or construction skill training who travel long distances to work on projects for months at a time.
- In this environment construction productivity is low, safety is poor, and so is product quality.
- Customers want quality products.
- It is the workers who create quality (value) for customers.
- Quality products are easier to produce in a factory but off-site fabrication needs reliable and predictable production on-site to realize the full benefits.
- Everyday learning can help deliver reliable and predictable on-site production.
- As part of the Last Planner System, it will do even more.
- In order to realize these benefits for their customers, project delivery teams need a new approach that treats all workers with respect and helps them to learn.
- For full benefits, the changes involved will be implemented at sectoral, corporate, and project levels to
    - understand the connection between psychological safety and learning; learning and improvement.
    - understand the difference between everyday learning and improvement and episodic learning.
    - be aware of the key structured conversations that are an integral part of LPS and how they work together to improve productivity.
    - understand how the promise cycle is critical to many of the structured conversations and how feeling psychologically safe is vital to making that work.

3. CONSTRUCTION PRODUCTIVITY

- (CP) is an important indicator followed globally to monitor waste reduction during the construction.
- CP continues to remain important parameter along with other traditional method in construction sector.
- For improving CP, various aspects can be investigated such as reducing rework, wastage, and over processing for the project.
- The objective of this study is to improve CP thereby enhancing efficiency through the application of lean tools.
- To achieve the above aim, a detailed literature review is carried out to identify the variables affecting CP followed by an exploratory factor analysis of the identified attributes to be grouped into factors.
- In addition to the above, the critical lean tools that are appropriate for CP improvement are identified through the questionnaire survey.
- The study identified 19 attributes affecting the CP and they are grouped into four critical factors using exploratory factor analysis.
- There are 11 lean tools identified in the study and Continuous improvement, BIM, Just in time, 5S, Visual Management, and PDCA have emerged as the important practices followed in industry to improve CP.
- This study contributes to the identification of prominent lean tools linking to the CP and the industry professionals could use them to improve the CP.
- The projects in the construction industry ranging from real estate to infrastructure projects, needs to be completed effectively and efficiently in terms of time, cost, and quality to reach the customer value. The CP is one of the aspects that needs to be investigated as a part of the construction practices to reach the project value efficiently.
- The Indian construction sector faces a lot of challenges and one of them is the CP. Labor, equipment, and material are the three main components of CP. In the construction practices, the construction management techniques and waste management are the two major issues found during the construction phase due to poor practices and it is necessary to adopt advanced construction management techniques/framework and practices to take up the downfall of the CP M.P & Natarajan P.S (2019). The CP is more important to the construction companies handling the project and to the country's economic development Dixit et al. (2019). CP plays a major role in better project performance. The CP efficiency is not consistent over the past decades and overtime period of the project there are a lot of issues related reasons such as improper planning, poor construction management techniques, poor framework related aspect, tools usage, labor handling, competences, skills are few aspects. Improving the CP which helps in saving cost, reduce waste, and increase profit for the project execution Dixit et al. (2019). CP might differ in each phase of the project, one of the facts from the article published by Jones (2019) that 77% of people agree that there is a need for improving the productivity of the construction sector. Keeping this in mind that there is a need for some possible alternative research to try improving CP

4. WORK DIAGNOSTICS.

Is Your Lean Implementation Effective?

- A Lean Diagnostic is a useful tool to measure an organization's Lean performance. A Lean

Diagnostic assessment is an evaluation of an organization's current status of Lean implementation.

- The Lean Diagnostic assessment provides a useful platform for an organisation to identify waste or non-value added activities, current strengths and weaknesses, and improvement opportunities. The assessment will also facilitate the development of a Lean implementation strategy and action plan to fully integrate Lean principles into the organisation.
- The scope of the Lean Diagnostic assessment will be customized in accordance to the organisation's needs. It could include the following:

    - Review of the Current Status of Lean implementation
    - Review of Lean Performance Metrics
    - Review of existing Lean practices

Deliverables

A comprehensive Lean Diagnostic Assessment Report will be provided upon completion of the assessment. Depending on the scope of the assessment, the report could include the following areas:

1. Current Lean implementation status of the organization
2. Review of Lean Performance Metrics
3. Review of existing Lean practices
4. The elements of Lean that have yet to be addressed
5. Recommendations on improvement opportunities
6. Recommended strategy and action to fully integrate Lean into the organization

For the Lean approach of your company to be successful and installed in the long term, you need to structure your project and Lean diagnosis is the essential tool.
Indeed, establishing a Lean diagnosis will allow you to realize and share the initial state of your performance, identify potential improvements to be made, and target your objectives.

Why carry out a diagnosis?

Imagine yourself in the context of a medical consultation, the doctor is trying to understand your condition, so his research will be based on consultation and listening to the patient and then supplemented by targeted analysis, without following this process your doctor will be unable to know what disease is gnawing at you. Performing a diagnosis within your organization to initiate your Lean approach follows the same logic as the example mentioned above.
The reasons for carrying out a diagnosis can be multiple. Here is a non-exhaustive list:

- The client's need is not satisfied
- Your sector of activity pushes you to evolve and adapt quickly
- Your performance is low
- Growth and/or acquisitions cause malfunctions
- Deterioration of communication between and among clients
- Observation of back-pedaling on the actions put in place
- No guidelines for managing your priorities
- No involvement.

Principle of the approach

- The Lean diagnosis is a prerequisite to your Lean approach, it is an initial inventory based on figures, interviews and observations. It provides a basis for work and for deciding on priority actions and then proposing a roadmap over several months.
- The results will then be shared with management, middle management and the field teams concerned.
- Its realization is based on collaborative work.

The steps of the diagnosis, in 4 key stages

Preparation of the Lean diagnosis: Understanding of the context and objectives, definition of the scope, segmentation, people to be audited, calendar, appointment scheduling.

Conducting the diagnosis: This phase takes place in the field with operational managers and process pilots, through interviews and visits to Lean sites completed or in progress. Data is being collected.

Elaboration of the diagnosis: Elaborate a synthesis which indicates the situation of the company on each axis of analysis. This synthesis is established on each predefined sector of the company.

Roadmap presentation: Awareness of Lean methods, work streams and planning. Definition of priority projects, management methods, resources, etc.

5. MAPPING OF LEAN PRINCIPLES INTO CONSTRUCTION

The Construction industry has turned from an industry dominated by a few, to a highly competitive market in the last decade and this competition is felt the most in the residential sector. Any issue leads to a hunt for solutions. In such a competitive environment, utilization of Lean tools in the projects can provide an extra edge to the contractors, by reducing time & Cost of the project. The Prestige Finsbury Park Project, Bengaluru has utilized the Collaborative Lean tools to improve the Slab Cycle time & productivity through Look ahead planning, Constraint Analysis, Big Room Meetings, Cycle Time Analysis & various workmen appreciation methods to boost morale & increased involvement of the workmen for the benefit of the project.

Introduction

Prestige Finsbury Park Project, Bengaluru is a cluster of high-rise residential buildings consisting of 18 towers with 2B+G+19/20/21 Floors. With a total of 283 floors to cast in superstructure, it became critical for the project team to ensure the structure completes well within the scheduled end date. In order to ensure the timely completion, multiple lean tools were implemented at site with the focus of reducing the slab cycle time & subsequently improving the productivity in each tower. Weekly sub-contractor meetings & workmen appreciation methods were implemented at site to understand the problems faced by the last man executing the job at site and provide solution at the earliest.

Need For Study

Residential building with typical floors have a common issue with persistently increased cycle time if not monitored regularly. Construction projects tend to have unforeseeable delays, Lean practices provided chance to take command of these delays - control them, reduce time wastage & improve productivity.

Objectives

- To identify the constraints in advance & mitigate them.
- To reduce slab cycle time in typical floors.
- To get feedback from all the hierarchy of people and act upon them.
- To boost confidence of all stakeholders.

Methods

- Big Room Meetings with engineers & sub-contractors
- Cycle time tracking & analysis
- Constraint analysis
- Appreciation System for Staff & Workmen.

Fig 1 – Big Room Meetings with subcontractors

• All constraints/issues faced were recorded in constraint analysis register and assigned to the concerned person to resolve it within target date.
• These meetings also helped to improve co-ordination between subcontractors.

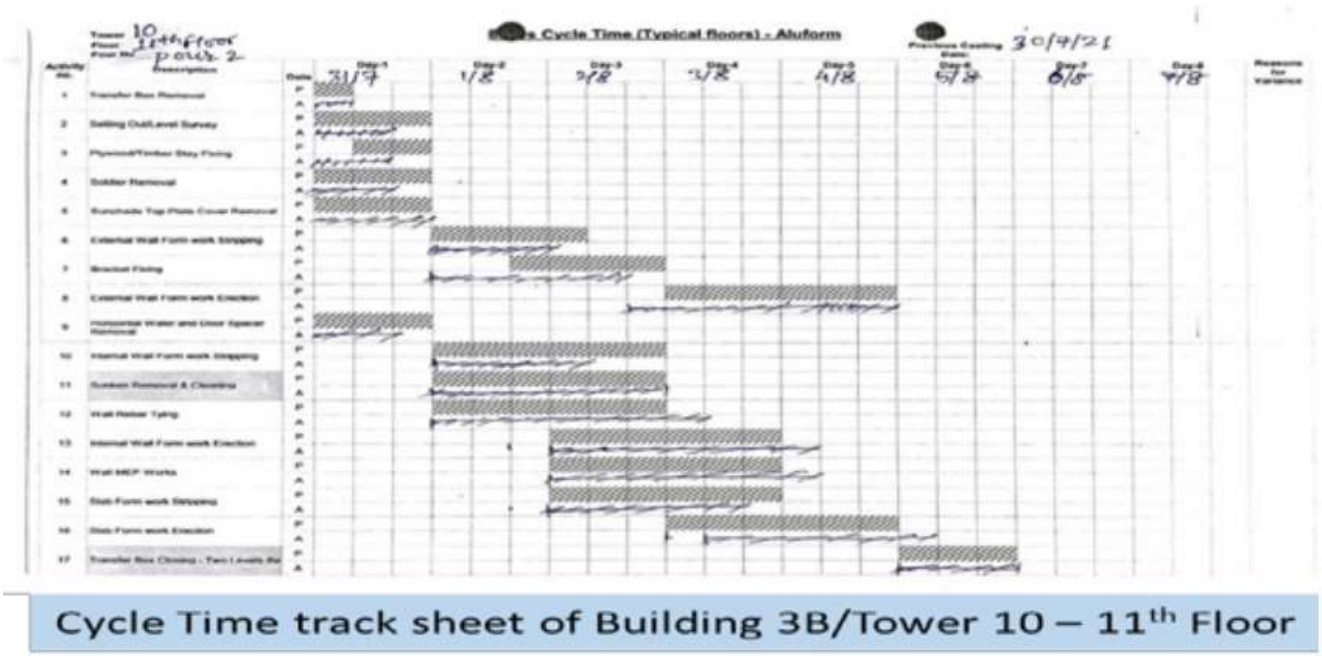


Fig- Slab Cycle time Tracking

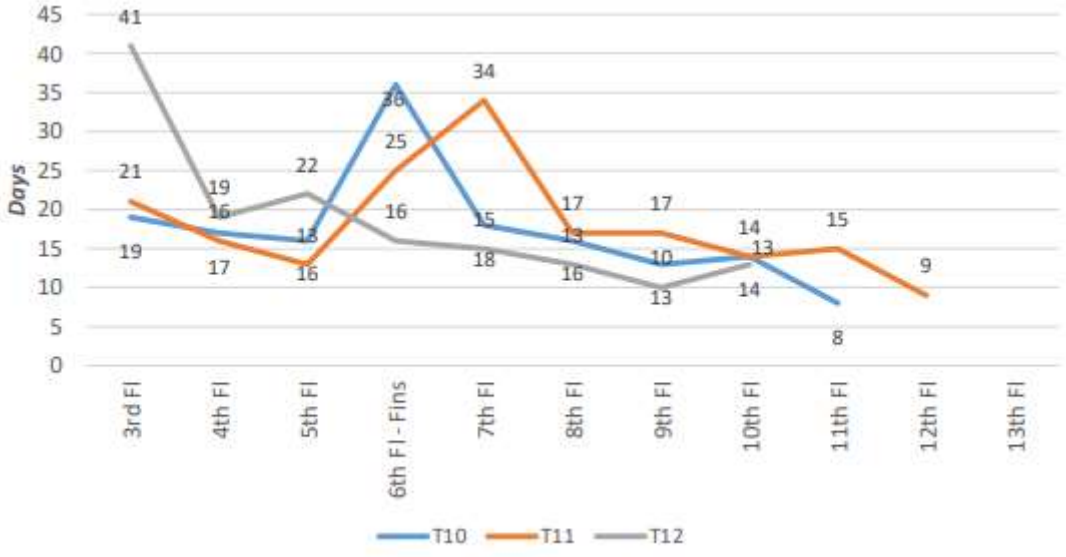
• Daily afternoon meeting with Tower in charges & Project Manager with reference to Cycle time track sheets. • All constraints & reasons for delays (if any) discussed during the meeting.
• Cycle time reduced to 8 days from earlier average of 17 days.

• Appreciation system for achievements of staff & workmen.
• Achievements were highlighted on Project office notice boards & WhatsApp group to share with all members of the Project.

Results

•Cycle time track sheet for all towers prepared and tracked on daily basis, which helped in identification of issues pertaining to each tower.

•Each tower in-charges were supported, to counter these issues and it helped in reducing the slab cycle time from average 16 days to 9 days (minimum 8 days cycle time).



Cycle Time Improvements

• Improvements were observed in productivity of shuttering (23%) & reinforcement (10%) activity in Typical floor towers.

Productivity Improvements

• Regular interaction with engineers & sub-contractors, allowed the management at site with details of constraints faced by them and immediate resolutions were provided. Conclusions

• Utilization of collaborative lean tools helped improve the project outputs in multiple areas i.e. Cycle Time, Productivity, workmen morale.

•Additionally, implementation of 5S along with these initiatives provides an overall improvement and efficiency in the working environment at project sites.

6. FUNDAMENTAL CONCEPTS

Lean implementation at construction projects helps all stakeholders such as customers, management ,vendors ,suppliers and most importantly the project teams made up of engineers, safety officers, supervisors, and workmen who toil relentlessly with the single-minded goal of getting the project completed as per customer committed timelines, zero safety, quality and statutory non compliances.

Need For Study

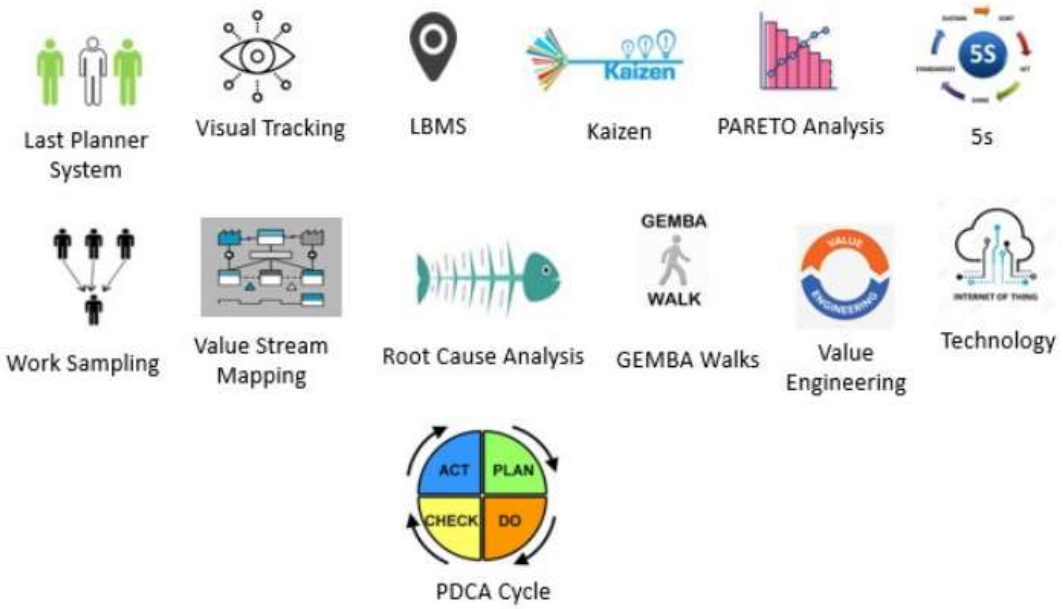
• Low labour productivity in all trades of construction which was very challenging due to high percentage of nonvalue added activities, waiting, transportation etc. • High percentage of wastes generated during construction putting tremendous pressure on natural and human resources due to rework, coordination issues, extra processing etc. • Time & Cost Overruns due to delayed decisions, quality non-conformances, change in specifications, high overheads, rework costs etc hence affecting customer deliverables and project profitability. • Inconsistency in processes for execution causing additional costs impacting the top line and bottom line. • Coordination Issues and conflicts between various stakeholders involved in the project such as management, Engineers, Contractors, Suppliers, Workmen etc. causing stress and delays

Objectives A well-defined methodology with various tools which could be deployed to mitigate project related challenges, and motivate all the stakeholders to convey their issues and find solutions to complex project problems which were risk to effective project delivery to customers, without any Quality, Safety, Statutory non compliances, non-conformances etc.

The organisation partnered with IIT-M and IIT-B as knowledge partners for technical Lean trainings for all their employees (Execution, Design, Procurement, Planning & HR) Deployment of tools for Productivity Improvement and waste reduction such as LPS/CPS (Last Planner System / Collaborative Planning System), Big room Meetings(Physical & Virtual), LBMS (Location Based Management System), VSM (Value Stream Mapping), 5S, Visual Controls, Work sampling etc

Training by Knowledge Partners IITM & IITB

Collaborative Planning at Site



Deployment of various Lean Tools

Results

• Reduction in Construction time by 10% compared to previous towers which has helped to deliver their project 9 months earlier than the customer committed date despite the COVID lockdown and restrictions.

• Rework percentage has reduced by 25% due to good coordination between various functions and trades, early detection of issues and transparency among all project stakeholders

• Third party Customer Satisfaction, Vendor satisfaction and Employee Satisfaction Surveys indicate that they have also been able to meet most of their stakeholder expectations.

• Improved transparency and morale between all project stakeholders.

• The Safety performance has improved and there have been no reportable accidents or major safety and quality non-conformances. Zero COVID cases with 150 labours working in situ. Zero lost manhours due to accidents.

• Just in Time (JIT) Approach – for Ready Made Steel assisted in Zero Steel wastage and better 5s at site

• Kaizens helped drive improvement culture based on focus theme in line with desired business results

Results achieved

Conclusions & Sustenance Plan

• All the Lean practices deployed on 28 storied high-rise tower have been documented converted into SOPs and deployed on upcoming projects of similar nature as well as industrial building, office buildings etc.

7. LEAN THINKING

Handling Differing Site Conditions Through Lean Thinking

A case study on encountering changed soil conditions at site and solving through Lean thinking for a Warehouse construction project at Bangalore, India-*Kavinkumar Shanmugam*

Abstract
Construction projects encounter many risks during execution. One of the major risks is the Differing Site Conditions or Changed Site Conditions. Differing Site Conditions hereinafter referred to as DSC is a condition that the contractor experiences at the site that differs materially from any of the conditions indicated in the contract that has entered into with the owner of the project or from what can be normally expected on the site are called a Differing Site Condition (DSC). The DSC significantly affects the work plan and results in time delays and cost overruns. Overcoming the DSC is highly challenging as it involves resolving the increase in project cost and time delays between the owner and the contractor. Most of the project time is lost in contractual interpretation and fixing the blame on one party. The lack of a systematic approach for problem identification and development of solutions for DSC is affecting many construction projects in India and as well as in global construction projects. This paper presents a case study of a warehouse construction project of 10,000 m2 at Bangalore for SS Logistics. EPMCR (P) L was the project management consultant and implemented Lean Construction in this project. The case study is about the encountered changed soil condition (high expansive clay) at the site during the excavation, handling DSC, and the solution developed to resume the foundation work. The foundation design was done based on the soil test report and the changed soil condition encountered during the excavation affected the proposed foundation system while also inflicting time delay and cost overrun to the owner and the contractor. The paper presents the usage of various lean tools like Human Centered Design Thinking, A3 sheets for problem-solving, Last Planner System, Plan Percentage Complete, and Value stream mapping. The paper's finding is that Lean thinking significantly improves stakeholder participation in developing a solution model and implementation for Differing Site Conditions, reduces contractual conflicts, generates out of the box solutions from the last level resources, develops continuous improvement culture and was successful in handling Differing Site Conditions.

Keywords Lean construction, Last Planner System, Collaboration, Workflow, Continuous Improvement

Lean tools
The Last Planner® System was developed by Lean Construction Institute which allows a team to create and maintain reliable workflow on construction projects.

The Last Planner system includes five phases: 1. Master Planning

2. Pull Planning

3. Make Work Ready Planning

4. Weekly work planning and

5. Learning.

Figure 1 Lean Tool Implementation

The minimum weekly output requirements are

1. Percent Plan Complete chart

2. Pareto variance chart and

3. Constraint logs.

- The Big room, where all stakeholders meet allows to review PPC and constraint logs and make conducive decisions to move the project forward.

- PPC measures the extent to which the front line supervisor's commitment (WILL) was realized (Ballard 2000).

- PPC measures whether the planning system is able to reliably anticipate what will actually be done.

8. LEAN CULTURE

Enabling Lean Culture in Indian Construction Project "Construction of Post Graduate Institute and Super Speciality Hospital at Rourkela, Odisha, India" by URC Construction (P) Ltd.

- It covers the way of implementation of major lean tool like Last Planner System and minor tool like Value Stream Mapping.
- Variability between planned target and achievement is quite common thing in construction industry.

- To bridge the gap between plan vs achievement, to figure out the issues which pulls back the project progress and to streamline the project flow, Last Planner System was followed in the site.
- LPS is a construction planning, control and monitoring tool developed in response to the high levels of production variability found in construction industry.
- LPS involves four levels of planning:
  - Master Scheduling
  - Phase Scheduling
  - Look Ahead Plan
  - Weekly Work Plan

MASTER SCHEDULING

Master Scheduling, also called as Milestone Scheduling, made based on the milestones that should be met as per the decision of the top-level management in the company or the contract with the client (Tommelein and Ballard 1997). So, according to the milestones given in the contract agreement, the milestone schedule was prepared and followed.

The figure of milestone schedule prepared in the project is provided below.

PHASE SCHEDULING

A collaborative scheduling technique that involves scheduling in the reverse order from the milestones, identifying the interdependencies between activities, and program compression by means of negotiations. (Ballard and Howell 2003; Mossman 2013). So, considering the milestones given in our contract, reverse planning was done, and the reverse phase schedule was prepared and followed.

- It helps to locate our current phase of project and give focus on particular phase.
- It helps to integrate and coordinate various phase operations.
- It leads to develop Look Ahead Plan.

LOOK AHEAD PLAN

A mean of production control which involves planning for the week that is four to six weeks from the current week. The work that can be done is made ready by means of analyzing constraints, assigning tasks to respective parties to eliminate the constraints over the Look Ahead period and designing the operations. (Ballard 1997; Hamzeh and Langerud 2011; Hamzeh et al. 2012; Mossman 2013).

Basically, LAP helps to

- Analyze constraints.
- Assign tasks to respective parties.
- Eliminate the constraints over the Look Ahead period.
- Design the operations.
- Create the flow.

WEEKLY WORK PLAN

It involves production evaluation of the previous week: calculating Percentage Promises Complete (PPC), analyzing reasons (Root Causes) for non-100% PPC and learning from previous week's experience; and proposing the production plan for the work that will be done in the following week and catch-up plan for previous week's backlogs. (Ballard and Howell 2003; Ballard 2000; Hamzeh and Langerud 2011; Mossman 2013). So, every week all the frontline engineers will have constraints free targets and have a clear mindset about their weekly/daily targets. Then, achievements against their targets gets recorded and monitored daily. Based on which daily PPC and weekly PPC were recorded. Weekly Review Meetings were conducted throughout the process. During the meetings, Root Causes for non-achievement of targets were recorded and taken remedial action to not repeat in future which will emphasize the project to catch up the flow and to meet out the milestone targets as per the schedule. The sample formats of weekly work plan and root cause analysis chart followed in the project are provided below.

References

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4. *A case study on encountering changed soil conditions at site and solving through Lean thinking for a Warehouse construction project at Bangalore, India- Kavinkumar Shanmugam.*
5. *Exploring the reach of lean philosophy in indian construction industry - Debopam Roy1 and Murali Jagannathan*

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DEPARTMENT OF ARCHITECTURE

SARA7403 - LEAN CONSTRUCTION MANAGEMENT

UNIT – II – PROJECT LIFE CYCLE AND LEAN PROJECT DELIVERY SYSTEM

PROJECT LIFE CYCLE AND LEAN PROJECT DELIVERY SYSTEM

1. PROJECT LIFE CYCLE

The increased construction activity and its associated operations have been notorious for significant waste generation and consumption of natural resources. On these lines, the recent traction of Circular Economy (CE) with its concepts of 'reduce', 'reuse', and 'recover', facilitates a restorative economy through a closed-loop material system. Typically, CE promulgates preserving a system's materials, parts, and products and enables maximum utility extraction. Thus, the concept of Circular Economic plays a promising role in achieving multiple Sustainable Development Goals (SDG). Also, the Lean tenets and its allied tools enabled value optimization through effective mapping of non–value-added processes and minimizing wasteful aspects. While there seem to be synergies between the concepts of Lean and CE, the construction management research fraternity has not fully tapped the huge research potential in this domain. To address this gap, a two-phased exploratory qualitative research design is proposed. The first stage involves mapping lean tools with ten dimensions of CE in the context of the built environment sector through content analysis and expert validation (n=3). "Continuous Improvement" and "Added Value" tools of lean attained maximum realization of CE dimensions. The second phase involves semi-structured interviews of experts (n=9) on an understanding of the synergies between Lean and CE through thematic analysis (TA). Thus, this study identifies predominant lean tools that realize CE dimensions and develops a conceptual model of Lean driven Circular Economy (LdCE) framework for the construction project.

Table 2: Lean Construction Practices for O&M Stage

S. No.	Lean Construction Practices	Description
1	Last Planner System (LPS)	LPS is a construction monitoring tool that employs master planning, phase planning, look ahead planning, and weekly planning so as to control the project.
2	Integrated Project Delivery (IPD)	It involves a formal contract between the client and key designers, contractors, and other project participants.
3	Virtual Design construction (VDC)	To create computer-aided designs (CAD) and simulations for checking defects in designs and models before sending them to production or prefabrication.
4	Value based management (VBM) or value stream mapping (VSM)	For detecting non-value-adding construction activities so that value can be maximized and supplied to the client.

2. LEAN TOOLS

a) Big Room Meetings
b) Constraint Analysis
c) Last Planner System
d) Ppc And Variance Analysis

Big Room Meetings

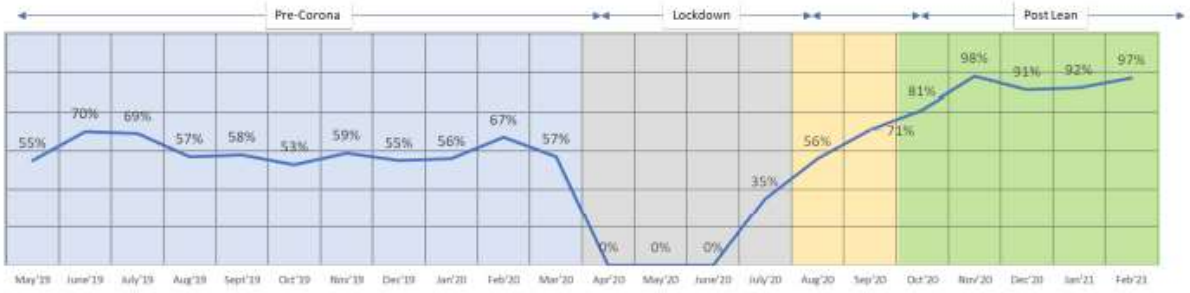
The Big room is where all the stake holders of the project are brought together to bring the project design to life through target value delivery by creating plans to deliver the project. The purpose of the Big Room meeting is to drive collaborative decision making in the presence of all the necessary stake holders. This ensures the potential errors arising due to lack of communication and ensures seamless flow of information to everyone involved. All the

departments of project execution team like Project Managers, Quality team, Planning team, Safety Team, Site Engineers, Sub-contractors, Supervisors, etc. are involved in Big Room meetings which are planned every week to understand and discuss the status of work done, to plan for the next day, and to mobilize resources according to the daily plan. Weekly and monthly look ahead plans are decided in the Big Room by collaborative planning between the Execution team and Planning team. This ensures "We plan, we execute" instead of "You plan, they execute". Big room meetings also offer an opportunity to check the compliance of the weekly plan and identify the reasons of noncompliance. The weekly results are published in the Big Room Meetings indicating the performance of each staff/team for each task implicated. This publicity of results is a key factor to reinforce commitment of the Last planners.

Constraint Analysis Constraint Analysis is performed for all the activities that are coming up in the next look ahead plan period (4-6 weeks). All the constraints are listed during the Big Room Meetings. Then various plans and ways of solving the constraints are identified to ensure that execution can happen smoothly without any interruption. This tool helps in finding the bottlenecks which represent obstacles that will hinder the optimization of output and profitability. These constraints cause delay in construction and is costly for the company if not resolved.

- Last Planner system is used to analyze and increase workmen productivity and accountability on daily basis. This tool is used to monitor the daily planned and achieved productivity of every workman gang.
- PPC AND VARIANCE ANALYSIS PPC – Planned percentage Complete is an indicator of the reliability of the weekly and monthly plan. Since the reliability of the plan is directly related to productivity, PPC analysis provides deep insights on the shortfalls, reasons for non-compliance to avoid them in future.

$$\text{PPC Score (\%)} = \frac{\text{No of completed activities}}{\text{No of planned activities}} \times 100$$



(Monthly PPC Analysis of International Guest House part of IIT Hyderabad Ph 2 project)

PPC Analysis is done for all the activities planned for the week and month in the Big Room Meetings and Variance Analysis is done for activities which do not have a 100% PPC Score. Variance Analysis helps us identify and understand the causes of delay which are affecting the PPC Values.

CONSTRAINT ANALYSIS FOR FINISHING ACTIVITES IN TRP BUILDING, IIT HYDERABAD PHASE II (L&T)

Item	UoM	Total Qty	Completed Qty	Balance Qty	% Comple	Vendor	Constraints	Remedial Action	Person Res
Terrace Water Proofing (PU)	SqM	2548	1886	662	74%	Sanjay Water Proofing	Block H and F Balance, workmen not available	Workmen to be mobilized	Mr. Tharg
Terrace Screed Flooring (1st Screed)	SqM	2548	1886	662	74%	Sanjay Water Proofing	Block H and F Balance, workmen not available	Workmen to be mobilized	Mr. Tharg
Puff Insulation	SqM	2548	0	2548	0%	Sanjay Water Proofing	Material Not available. PRISM has to decide rate revision.	follow up to be done with PRISM to decide revised rate	Mr. Charles T
UGWT Ceramic Work	SqM	268	190	78	71%	Geet Contractor	Irrigation tank balance, Workfront not available	waterproofing to be completed by 01 July 2021	Mr. Tharg
OHWT Ceramic Work	SqM	268	0	268	0%	Geet Contractor	Workfront not available as water proofing not completed	waterproofing to be completed by 01 July 2021	Mr. Krishn
Gypsum ceiling (B,H,K,L blocks)	SqM	1508	0	1508	0%	MECH FAB	Material Not available	Materials to be procured to site by 15 July 2021	Mr. Chir
Grid Ceiling (Calcium Silicate + mineral Fiber)	SqM	940	0	940	0%	MECH FAB			Mr. Chir
Expanded Metal Ceiling	Sqm	3500	0	3500	0%	Laseena	1000 Sqm available, balance 2500 sqm to be received.	Balance material to be procured & trasnported to site by 10 July 2021	Mr. Chir
Non Fire rated Doors	Nos	26	0	26	0%	Shakthi Horman	Material Available, w/m not available	Workmen to be mobilized	Mr. Krishn
Fire Rated Doors	Nos	47	0	47	0%	I Clean	Material Available, w/m not available	Workmen to be mobilized	Mr. Krishn
Laminated flush Doors	Nos	330	0	330	0%	Alu MS + Gayatri	Door Frames available. w/m not available. Door Shutters Status - 122 nos shutters received. Balance material after release of payment	Workmen to be mobilized & payment to be concluded at the earliest	Mr. Krishna P Charles Th
Shaft Metal Doors	Nos	366	0	366	0%	Iclean	material not available	Materials procurred. Delivery of materials to be followed up and endured by 03 July 2021.	Mr. Chir
Aluminium Windows	Nos	1050	0	1050	0%	Green build Koncept	material not reached site,	Vendor payment issue to be resolved	Mr. Charles T
Expansion Joints	Rmt	434	0	434	0%	Kanta Flex	client approval for material pending	Mockup to be done & client approval to be got by 7 July	Mr. Maria
Tensile Fabric Structure work	MT	6.50	6.5	0	100%	Sky Shade	Fabric Material Available , but it is last activity	Workfront to be provided by Structural team	Mr. Srikar
Fabric Cloth Fixing	Sqm	185	0	185	0%			Workfront to be provided by Structural team	Mr. Srikar
External C-Pink River Wash Granite Flooring Work	Sqm	2042	0	2042	0%	Stone Zebero, Ricardo	Material not available	Materials to be procured.	Mr. Chir
Rendering Works - Internal	Sqm	-	-	-	0%	Boom Lift	Boom Lift not available.	Boom lift to be diverted from MSME & BTBM building. Follow up to be done by P&M team for releasing Boom lift.	Mr. Sund
Rendering Works - External	Sqm	-	-	-	0%				
DI Manhole covers	-	-	-	-	0%	Crescent Foundary	Material Available but workfront not available	Workfront to be provided by Civil team	Mr. Tharg

3. COLLABORATIVE PLANNING

Collaborative approach with business partners during pandemic to drive the business continuity

Abstract

COVID-19 situation has placed pressure on conventional procurement practices and tempted organization to drive the Sustainable Collaborative Partnership with its key Business Partners to maintain the Business Continuity. Enhance Credit terms, Proactive communications, Risk Mitigation, new way of working, Value Engineering, Labor Shortages, Cash flow Management, Cost Reduction etc. becomes critical and required to be addressed efficiently. Enhancement in credit terms was one of the major activities initiated by the Organization with its active Business Partners to ensure to manage its cash flows and payment commitments in the COVID-19 challenging time. The organization has always valued its business partners and manage relationships with them and believe that they are their greatest asset. The organization leveraged effective communication channels to proactively maintain transparency amongst all its Business Partners through official platforms and ensured that their expectations are met. As a result, they reciprocated to the change positively and supported the organization to make the association sustainable and move ahead to next level in a New Normal era. The initiative has helped organization to

manage its cash flows efficiently wherein weighted average credit terms improved by almost 50% as against pre-COVID scenario. Business Partners Demonstrated values such as trust, fairness, ethics. During that period the team worked collaboratively with the Finance team to ensure payments are made on time by implementing various innovative solutions such as online trackers, digital approval systems etc. Also, the organization has come out with the initiative of Vendor Financing to its Business Partners to support them for early payment with nominal rate of charge. The paper portrays how the Organization and its Business Partners have built a resilient association by multiple collaborative efforts and continued to support each other to ensure business sustenance and stress-free dealings.

KEYWORDS Supply Chain Management, COVID-19 pandemic, Collaborative Partnership, Effective communication, Trust.

Introduction

As a typical "black swan" event, COVID-19 took the world by complete surprise. The focus of most businesses was on protecting employees, understanding the risks to their business, and managing the supply chain disruptions caused by the efforts to contain the spread of COVID-19. Supply chain disruptions have cash flow implications across the extended supply chain that can't be underestimated. The crisis has demonstrated that forging collaborative partnerships with its Business Partners is a better long-term strategy for ensuring success across the ecosystem than taking a zero-sum-game approach. The Company has made immediate payments to smaller Business Partners to relieve their cash-flow problems, for instance. This new level of collaboration opens the door to better partnerships that will build resilience for the ecosystem in the long term. Company segments its active Business Partners base by using Kraljic Portfolio Purchasing Model, wherein Business Partners are segmented based on their perceived impact on business versus Company's ability to influence them and regularly evaluates their performance on price, lead time, quality, and code of conduct. Accordingly, Business Partners are classified into Strategic/Key Business Partners (most important for Business Purpose, Vision and Strategy execution), Leverage (Enable Business to be Competitive), Bottleneck (Low impact but essential) and Routine (providers of low value goods and services). Procurement strategy and approaches differs for each one of them.

Approach and analysis cash is always king — especially in troubling times. Cash flow

management has always been an integral part of a company's overall risk assessment. With the disruption in the market, businesses that have a favorable cash position relative to competition will be viewed as more stable and balanced. This might be the difference between a minor crisis and major crisis for the board. To improve operating cash flow in this difficult economic condition, Organization has evaluated following four key tactical areas to concentrate in coming financial quarters. • Ensure Supply of required Raw Materials and services for Uninterrupted Business operations in high Demand • Reduce Purchasing Cost • Optimize/Enhance Business Partner's Payment terms • Evaluate converting fixed cost to Variable cost and reduce Variable cost Procurement function has worked closely to coordinate with Business and finance team to define and finalize the approach to be adopted with Business Partners for Optimize/enhanced credit terms.

Challenges

The organization has revealed key constraint and challenges before taking decisions on Enhanced credit terms. Those are as follows,

• Reluctance of Business Partners acceptance on enhanced credit terms

- Govt. Rules and Regulations for SME vendors
- Payment to contract labors as per government notifications
- Maintain supply of critical materials and services
- Increase in cost of material and services
- Morale of contract workers / daily wage workers during Lockdown
- Late deliveries and quality problems
- Issues of Bottleneck/monopolistic vendors
- Can erode supplier goodwill, slower responses to queries and more onerous payment terms
- Claims and disputes to make up for delayed payments.

The above-mentioned challenges are enlisted (but not limited) based on interaction with key Internal Stakeholders, Corporate functions, Industry peer references and referring various published articles on cash flow management during COVID-19.

Methodology (key levers and best practices to address the challenges):

The organization adopted Industry best practice for effective payment terms enhancement. Best practices include components such as Analysis of requirement, Mandate, Communication, Execution, and relationship management activities to foster the payment term enhancement activity. Strategic Analysis approach, the organization took an initiative to implement systematically credit term enhancement activity across the active vendor base. A Charter being prepared with 52-week plan to execute the enhance credit terms of Business partners.

Early Communication is always more welcome than suddenly reaching out in an emergency. The organization initiated the proactive communication with its Business Partners to ensure that their acceptance in supporting enhanced credit terms for Sustainable Partnership in crisis.

Execution Post email communications, all the buyers interacted with existing business partners to work upon enhanced credit terms and status being monitored weekly basis. New Business partners were strictly onboarded with enhanced credit term. During the initiative execution phase Procurement team worked collaboratively with various internal stakeholders such as Finance, HR, Business teams, and Sr Management to mitigate the issues of supply continuity and cash flow management.

Team has put in efforts to streamline the payment process through optimized approval processes, changes in system, Early labor payments, Various approval notes and Justifications for making payment in exception basis, status updation of business partner conversion to enhanced credit terms, opportunities for enhanced business to Key partners etc. with the coordination and collaboration with Internal stakeholders. Business Partner Relationship Management. The Organization initiated supplier relief activities to boost the credit term enhancement.

Adopting more robust governance practices, which can reduce the risk of manual error and strengthen internal controls around accounts payable processing, and contract review. Strengthening purchasing approval processes by defining the level of management authority required to make various-sized purchases.

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CHARTER

Initiative Name: Enhancement in Credit terms of Business Partners

Initiative Number: FY21-P&C-MI-A-09 **Initiative Type:** MI **Category : A**
Initiative Sponsor : APM **Owner:** SS **Crack Team Leader : RG**

Scope:
Enhancement in credit term for Material Suppliers by 90 days and for Service providers as per defined guidelines

Rationale (Reason for taking this initiative):
Support for G&B cash flow management in pandemic situation
Improvement in GC working capital

Success Factor(s) for Initiative:
1. Converting key Supplier's (accounting 70% of overall annual spend) payment term to 90 days
2. Converting all contractors/consultant payment as per guideline approved by GC Sr Management
3. Converting all SME vendors payment terms to 45 days
4. Improvement in Overall Weighted credit days at GC level, Material & Services as against FY20

Key Constraint(s) for owner/CTL:
1. Business Partners acceptance for enhanced credit terms
2. Support from Internal Stakeholders for credit terms guideline approval

Key Risk(s) for owner/CTL:
1. Business Continuity
2. Cash flow issue at Business Partners
3. Increase in product/service cost
4. Team support
5. Clarity of role

Key Assumptions(s) for owner/CTL:
1. Acceptance of revised credit term by key suppliers
2. Improvement in wtd avg credit terms w.r.t. pre covid

Key Dependencies:
☐ CFT's Initiative Top ☐ Mgmt ☐ Govt Norms ☑ Others (Pl. Specify) _____

Supporting Documents Attached
☑ Team Constitution ☑ Key Deliverables ☑ Key Considerations ☐ Milestone Plan ☐ – 12 Stages ☑ Others (Pl . Specify)

Start Date: 02-05-2020 **End Date: 31.03.2021** **Tracking Frequency** Weekly

Initiative Name & Number: Enhancement in Credit terms FY21-P&C-MI-A-09 — Key Deliverables

Key Deliverables	Responsibility	Start Date	End Date	Key Success Factors
Initiating Communication to vendors on revised credit terms	RG, SS, PP	02/05/20	20/05/20	Communication to all existing vendors
Interaction with vendors by all purchasers	All P&C staff	21/05/20	15/06/20	Acceptance of vendors and mapping of data
Preparing report as per responses received from vendors for Sr. Mgmt. review	RG, SS, PP	16/06/20	22/06/20	Revised credit term guidelines, status of credit term enhancement impact
Approval of credit term guidelines from DMC members	RG, SS, PP	23/06/20	20/07/20	Revised Guideline approval
Credit term data monitoring for month of July	RG, SS, PP	20/07/20	03/08/20	Performance of New order released during July
Updation of Master database (vendor) with revised credit terms and guidelines	RG, SS, PP	03/08/20	31/08/20	Master database with credit terms enhancement & Overall report
Monthly credit terms data monitoring	RG, SS, PP	01/09/20	31/03/21	Report of weighted avg credit terms

Some of the relief activities are as under

- Setting up supplier portals – to track the status of GRN
- Vendor financing/Bill discounting
- Strategic interactions with Key Business Partners
- Early full/part payments in exceptional circumstances
- Extension of time for contract performance
- Revised milestones or delivery dates and/or
- reimbursement of wages to Contractors and Manpower Service Providers for lockdown period
- Immediate payment to labor suppliers (Daily Wages)

4. LAST PLANNER SYSTEM

Constraint Management and Production Planning – A Case Study

Abstract

Constraints are an essential aspect of the Last Planner® System (LPS) of production planning. LPS defines that constraints must be mapped during lookahead planning, and only constraint-free activities should be included in the production week. Conventional methods of constraint management have proven drawbacks with respect to their documentation and integration with production planning. Further, their impact on the master plan is rarely integrated to provide adequate insight into the achievement of key milestones. There exists a universal gap in efficient constraint management across the industry, for which different organizations are trying to adopt lean platforms to address this, with no evident success. This paper adopts a design science research approach on an infrastructure project case study to address this gap for improving the efficiency of constraint management. The paper first highlights the conventional methods, with a key focus on the challenges faced by the project team. Following that, the paper elaborates on the transformation of the process through the deployment of a digital tool developed on lean workflows. The paper concludes with defining the key aspects of this production control system for efficient constraint management, which has helped improve the constraint mapping, assignment, and tracking process significantly on this project

KEYWORDS Lean construction, Constraint Analysis, Constraint Management, Last Planner® System.

Introduction

LPS has a proven track record of being rather effective in making the production process lean, despite the inherent variability in the process. The term "last planner" refers to the individuals in the team responsible for making the final assignment of work to specific performers and ensuring they have the materials, equipment, space, design, and information available to complete their assignments (Ballard & Tommelein, 2016). One of the most critical factors to minimizing wastes is early identification, realization, and elimination of constraints and variances (Rahman, 1998). Constraints, in the production and workflow control in LPS (Ballard, 2000), are one of the prominent root causes or reasons for the failure of weekly work plans (Mossman, 2009). An important parameter for successful completion of weekly work plans is the compliance of all the prerequisites and ensuring the availability of required resources (Perez and Ghosh, 2018).

Constraint analysis is an essential part of LPS that is applied as a proactive way to map and solve potential problems as a team (Porwal et al., 2010). In fact, proactive constraint identification and removal is teamwork and a continuous process throughout the production management. The key is to ensure ownership of the constraint so the responsible actor can take necessary actions to clear the constraints and comply with the prerequisites (Seppänen et al., 2015). Accordingly, to understand the notion of constraints, Theory of Constraints (TOC) has been explored here first. Goldratt (1988) summarizes the concept of TOC as: Every system must have at least one constraint. If it were not true, then a real system such as a profit-making organization would make limitless profit. A constraint, therefore, "is anything that limits a system from achieving higher performance versus its goal". The amalgamation of schedules and constraints, from a point of view of production planning, is a significant, yet complex process, for any project team (Kalsaas et al., 2014). The amount of time and effort required by project teams to keep the process active is found to be a major barrier in the successful implementation of this approach (Ballard, 2008). There is a need in the industry for a production management system which can drive the production planning along with proactive constraint mapping for projects (Herroelen, 2005). A lean tool developed on the Last Planner® System for collaborative planning can potentially help improve the efficiency of the process, by providing an environment that can host discussions, make-ready process, and finally, production control, to help teams in driving efficiency in production.

Literature Review

Prof. Lauri Koskela has done extensive work in defining the theory of production, driven by three different conceptualizations: the Transformation, Flow, and Value theories define the critical aspects of a successful production management model (Koskela, 2000). While Transformation helps breakdown the scope in a structured manner, the concept of Flow stems from the making the transformation more efficient by minimizing wastes in the process and reducing cycle time. The goal is to reduce variability through a commitment-based approach, thereby balancing the push and pull between the release of work and the ability of the team to execute it realistically onsite (Koskela, 1999). It is important to note that production control is different from project control; while the latter is driven by replanning when the execution varies, the former is driven by an approach to planning right in the first place by ensuring the accurate flow of information, with the goal of generating value for the teams (Ballard, 2000). The difference in these approaches ties closely to the concept of push and pull in production. With high variability in the production flows, it is important to adopt an approach of clearing the preconditions for a construction task, i.e., Construction Design, Components and Materials, Workers, Equipment, Space, Connecting works, and External Conditions (Koskela, 1999). With a clear focus on reducing variability and driving a commitment-based approach to production planning, LPS is known to be the first and most famous Lean tool adopted by the construction industry (Dave et al. 2015). LPS and lean construction was developed in the wake of lean, inspired by Toyota, which first was developed for manufacturing (Ballard, 2000). Pull as a production logistical principle is central to lean manufacturing and is often associated with just-in-time production (Boyd & Gupta, 2004). With a focus on look-ahead planning, LPS defines what should be done in the upcoming weeks of the project. A critical aspect of this process is constraint mapping while pulling work between the trades to ensure activities are ready for production, and handovers between trades can then be made efficient and value-driven (Ballard, 2003). To keep prerequisites and constraints in check, LPS has a mandatory process called make-ready. Dave et al. (2015) discuss the shortcomings of LPS that emerge as major barriers of application of the system overall through a review of

multiple projects. It was observed that weekly planning was the widely applied aspect of LPS, while lookahead planning, constraint analysis, and continuous improvement proved to be a major challenge. Only two out of the five projects analyzed had constraints in the implementation of LPS. Lack of information management processes in tracking the root causes for plan failure is highlighted as a limitation to effective application of LPS. Learnings with respect to constraint management in the application of LPS in different case studies by Gupta (2003) highlights the importance of constraint analysis prior to the weekly coordination meetings. This approach reduced the time spent in collecting problem information, to rather focus on discussions on actual problem solving. Manual processes were set to maintain a constraint analysis form which was sent to every subcontractor to fill for the next lookaheads and ensure to proceed with the work only when all the constraints were removed. With extensive constraint analysis and subcontractor participation, the project was able to achieve a Percent Planned Complete (PPC) of 90% over the period of the study.

Research problem

Based on a cursory review, it has been found that the success stories depicted in these studies bring out the importance of constraint management, as well as the challenges to implementing it effectively in production management. However, little is conveyed about the processes involved in reaching the milestone. A lot of peripheral systems makes it unnecessarily complicated for the last planners to keep track of both the production plans, as well as the constraints. Eventually, this adds to confusion during progress review and look-ahead planning, leading to poor efficiency in the entire process. Further, the poor execution of a lean approach leads to demotivation amongst project teams towards continuous improvement. The paper here explores the success factors of an improved production planning process through efficient constraint management from the lens of people, process, and technology, through a design science approach. The scope of the study is limited to an Infrastructure Project Case Study to work out the best ways to improve existing constraint and production management processes.

Case study briefing

The case study is a new railroad development project in Norway (EU). The project's construction work began in the last quarter of 2019 and is expected to be completed by 2025. The project is being constructed by a joint venture between two leading contractors of the region, with whom the authors have been working with since the last quarter of 2020 on this project. This infrastructure project has been chosen as the case study for the immense number of constraints arising out of the sheer complexity of this project, which can potentially have a significant impact on the project timeline and cost. The project in reference has partially mature implementation of Lean Production Management, driven by the Last Planner® approach for collaborative planning. The components involved in implementing LPS have majorly been achieved during the Master Scheduling, Phase Scheduling, Lookahead Planning, and Commitment Planning Stage. The main challenge has been the manual intervention and physical communication required by the Planners to proceed through each step, leading to confusion and stress on the implementation of LPS. The learning phase also gets skipped as the Planners are constantly time bound with hours spent to gather past data for evaluation, which is a challenging act in itself. In the pursuit of achieving excellence in their collaborative planning practices, the project team participated in the exercise of building a more efficient and advanced constraint management solution. Accordingly, the before and after implementation of solution processes have been documented and analyzed here.

5. LOCATION BASED MANAGEMENT SYSTEM

Site information

The project is exactly located at Satyanagar, Unit- IX, Bhubaneswar. It is an EPC mode project of cost Rs. 73, 30, 20,000/- under Bhubaneswar Smart City Limited surveillance. The project duration was bound to 24 months. The area allotted is 4.2 acres.

Job-sequencing location based management

Location based management system was adopted promptly for toilet completion schedules. In the building they had two common core toilets in east and west side of the building excluding some individual toilets. They focused on completion of toilets floor wise so that it would become easier for them to progress fast towards the completion of project. Theye followed tabulation where they mentioned each activity succeeding for completion of a toilet including MEP works. It started from de-shuttering, handing over for brick work till final handover including cleaning and painting.

References

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3. Synergies between circular economy and lean practices in built environment Vijayeta Malla, 1 Murali Jagannathan, 2 and Venkata Santosh Kumar Delhi

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

SARA7403 - LEAN CONSTRUCTION MANAGEMENT

UNIT – III – LEAN IN DESIGN AND LEAN TOOLS

LEAN IN DESIGN AND LEAN TOOLS

1. Lean in design, process flow and supply chain management
2. Lean enablers and integration
3. Value Stream Mapping -244
4. 5S

1. LEAN IN DESIGN, PROCESS FLOW & AND SUPPLY CHAIN MANAGEMENT

Cost-benefit analysis of structural activities in residential projects

Abstract
Construction industry plays a significant role in the country's development. Yet, the projects are found to be unprofitable and labor intensive. Among these, a multitude of projects are residential which are less complex to construct with visible scope for improvement during project execution. 'Lean construction' with its philosophy on eliminating waste during project execution enhance the value generation. Based on this insight, an experimental study was conducted, wherein major structural activities of residential projects were observed and analyzed by the project team. With emphasis on the process rather than the product, a flow diagram was initially prepared for several activities. These diagrams were subsequently analyzed to identify and eliminate the nonvalue-added tasks using an action-based methodology. Activities were compared and analyzed with alternative plans through cost-benefit analysis and the waste laden activities were eliminated. Alternative plans were determined cautiously considering the market conditions, local availability, and practical constraints. Improvement methods included: introducing new machines, new systems, materials, and improved execution plans which showed profitable results compared to conventional methods. The study demonstrated that continuous improvement methods and possible automation could help projects to be economically viable and efficient in the construction sector.

Keywords Process improvement, Non-value added tasks, Cost-benefit analysis, Action research, Lean construction.

Introduction

Construction sector has a major role in the socio-economic development of a country. In general, residential projects have a set of construction activities which are common and repetitive across projects such as shuttering and plastering that provide scope for improvement. Adopting a Lean philosophy, an attempt was made to foremost identify Non-Value Added tasks (NVA) in residential projects in Kerala and further, improvise the system by proposing alternative methods or material and by conducting a Cost benefit-Analysis (CBA) to validate the decision. The inferences from the study are preliminary and context specific that can be further validated in other projects across the country. The scope of the study was limited to identifying NVA for 4 major structural activities that include: shuttering, column footing, masonry and plastering works and further validating through CBA. The study is unique as it takes a step forward beyond conventional identification of NVA tasks alone in construction projects. The following sections discuss a review of literature, identified gaps, data collection, analysis methodology and the inferences drawn from the study.

Literature review

A review of literature on lean adaptation in construction showed that by eliminating waste, lean construction excelled in managing the construction process and achieving the project's purpose (Apradh and Minde 2020). Similarly, Lekan and Segunfunmi (2018) observed that 'Lean thinking' emphasized on the removal of waste and non-value adding activities in order to increase customer value. Lean tools and techniques aim to improve efficiency, reduce cost and time over-run and addresses issues like low productivity by focusing on the process rather than on the product. Tools like Value Stream Mapping and flow charts are some of the common tools used to understand and simplify complex processes. For instance, Shakil et al. (2013) noted that a process flow chart was used to communicate how processes work as well as to create and document complex processes or programs. A flowchart is a simple mapping tool that displays the sequence of steps in a process in an easy-to-understand format. According to Ismail and Yusof (2016), the waste during construction process is termed as non-value added activities. Activities that converted materials or information towards what is required by the customers were value added. These researchers suggested that traditional management, improper process during design, errors, and machine breakdown also contributed to non-value added activities.

They came to the conclusion that minimizing flaws and waiting time during structural and architectural construction had a significant impact on the project's schedule, cost, quality and productivity. A review of literature in this direction showed that conventional and traditional construction practices had to be critically examined to find ways to improve. According to Prajapati et al. (2014), plastic formwork had distinct features which included cost effectiveness, easy handling, eco-friendliness, low maintenance and reusability for more than 100 times. Also, smooth finish was achieved using this formwork. According to Vatin and Gamayunova (2014), wall plastering activity was time consuming and labor intensive and used more manual methods in traditional construction. As an improvisation, the introduction of spray plastering machine into construction helped in reduction of time and increased productivity. Similarly, tying of rebars is a labor intensive, expensive and also time-consuming activity. According to Safal et al. (2016), Rebar tying guns were more efficient in sites when compared to traditional tying method and it helped in reducing man-hours, total cost, and increased productivity. However, choosing the appropriate method and technique will require an analysis with respect to cost and its benefits. A cost-benefit analysis is a systematic method for calculating and comparing the total costs and total expected rewards of a project or investment.

It helps to analyze whether the benefits would outweigh the cost and if so, by what profit margin? Thus, the decision should be made if the benefits greatly outweigh the costs; otherwise, it should be avoided. CBA can support dual purpose: a. to compare various alternatives, b. to serve as a baseline information for future works. The costs could include direct and indirect cost, opportunity costs, socio-economic costs, and market risks. Benefits could include components such as direct and tangible benefits or intangible benefits such as increased productivity and cost savings (Campbell and Brown, 2003; Prest and Turvey, 1996). Gaining insight from the literature review, two aspects were evident. Within India, few leaders have tried to adopt Lean techniques in their projects. However, case examples in specific states such as from Kerala are limited. Second, while there are studies that highlight Value-added and Non-value added activities and their proportion in projects, there are limited evidences that discuss alternate methods and their cost-benefits.

There is literature mentioning lean improvement plans, yet region specific application of local materials and methods for improvement are limited. To this end, this study addresses two research

questions:

a) What are the non-value added activities in residential construction projects and what approaches can minimize process waste?

b) How can CBA help to select viable solutions?

Methodology

The study adopted an action-based research methodology, wherein a team of experts working on the project along with external researchers were actively involved to address the set research question of the study. In action research, the team diagnoses a problem and develops solutions, implements the solutions and observes the results in order to either standardize or improve the solutions (Bell et al. 2018). The approach involved both qualitative and quantitative collection and analysis of data, which in turn has made the study robust. Site visits were done to five different sites by the Project Management Consultant (PMC) team – BuildNext Construction Solutions Private Limited, to observe the tasks involved in residential construction projects. The overall processes with sequence were mapped using process flowchart (Shakil et al. 2013). These process flowcharts helped to analyze and identify the NVA activities. Further steps were to either eliminate the NVA activities or to convert it into valueadded (VA) activity, wherever possible. The selection of a viable solution for improvement was aided by performing a CBA. This was done by collecting data from various material manufacturing firms like Nova formworks, Prince TMT, Magicrete building solutions etc. Through the information and data gathered, CBA was done by comparing conventional methods of construction with the improved methods for activities such as rebar of column footing, shuttering works for plinth beam, masonry works and wall-ceiling plastering activities. In the CBA analysis, the inferences were derived by considering the average of the performances of the five projects with respect to time and cost. The viability of these improvement plans using CBA included comparing with the quality, labor intensity, time consumption and effectiveness of the existing system. While CBA helped to quantitatively compare and analyze, qualitative analysis was also done for quality assurance.

Data collection

Five different residential construction sites in Kerala were selected for the study which included:

1) Project 1 at Kuttikad- 263 Sq.m,
2) Project 2 at Chulliote-175 Sq. m,
3) Project 3 at Moothakunnam-225 Sq. m
4) Project 4 at Kochi- 212 Sq. m and
5) Project 5 at Ponjassery- 211 Sq. m.

Construction activities in these sites were managed by a single PMC- BuildNext Construction Solutions Private Limited, located at Kochi. The labor contractors for these projects were local contractors selected through competitive bidding. The site visits were done by keeping the COVID protocols. Four common construction activities were selected and observed during the site visits which included: rebar cutting bending, and tying of column footing, shuttering of plinth beam, masonry works and plastering of wall and ceiling. Activity will be the term used to represent the main group and task will be the term used to define subgroups of work throughout this paper. The tasks of each activity were represented in a graphical form with the help of process flow charts. This helped to identify NVA in the tasks. Data such as the drawings, the measurements, and work updates were available in the BuildNext app and this helped us to get updated information about

the works on the sites during the COVID scenario. The following figure, explains the process of the activities observed through a flowchart. Based on the flow chart and critical examination and reflection, the team came up with improvement strategies through constant brainstorming and numerous discussions within the team as well as with various companies such as steel manufacturing firms (Prince TMT, Kalliyath TMT), formwork manufacturing companies (NOVA Formworks), lightweight concrete (Magicrete Building Solutions), machine manufacturers, and machine suppliers. In parallel, the existing improvement plans for these structural activities were also studied.

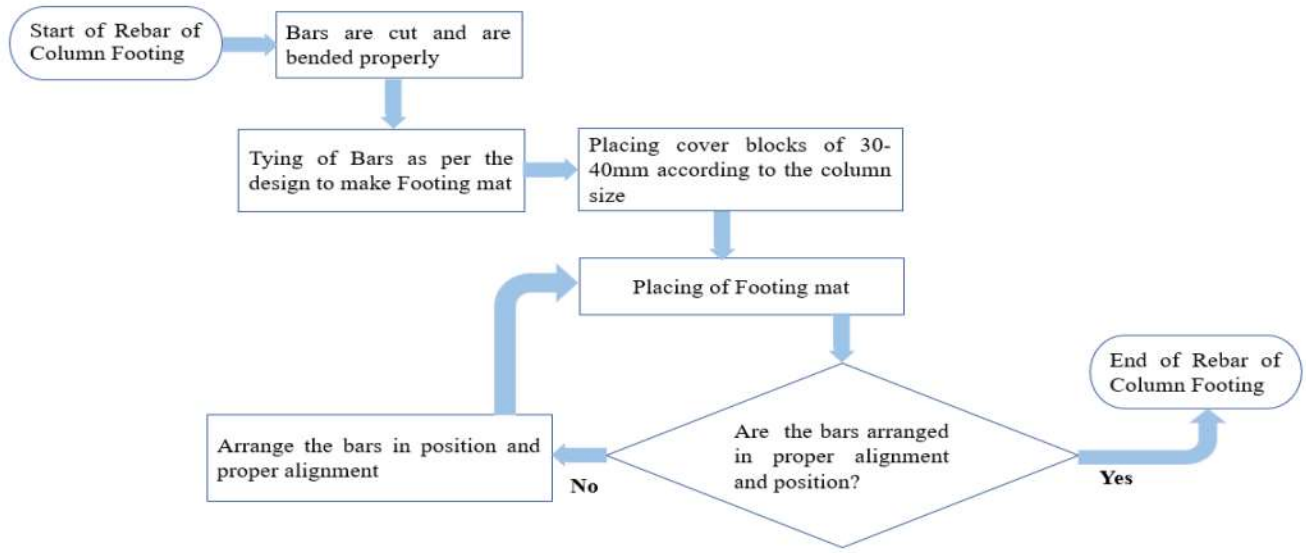

Figure 1: Process flow chart for Rebar works of Column Footing

Analysis and findings

The process flow chart prepared in the data collection phase was used to identify the waste laden NVA tasks. Market study, discussion with industry experts and research on innovative alternatives were done to remove or minimize the NVA tasks. Later these alternative options were analyzed in monetary terms to understand the feasibility of the proposal by CBA.

Rebar works of column footing

Based on the process flow chart and site observation, this activity in column footing was found to be time consuming. In conventional system, it required three days for cutting, bending and tying of 15 column footings (i.e., 1.6 hr/column footing). In comparison, the improvement method by using bar bending and cutting machine and rebar tying gun, required 0.0471 days for 15 column (i.e., 0.025hr/column footing) footings in site. One labor was assigned for cutting and bending of rebars for this activity in the warehouse. The sites were in a 50 km radius from the warehouse. Site to site transportation was done using ape (carrying capacity – 500Kg) which costed 35 Rs/Km, the average weight came around 400Kg. The wages considered for skilled and unskilled laborers were 1000 Rs/day. Transportation cost was considered from warehouse to site and site to warehouse for owned machines.

Table 1: CBA for Rebar works of Column Footing

No.	Improvement Method	Cost (Rs)	Conventional Method	Cost (Rs)
Project 1	Time Taken (hrs)	1 (0.125days)	Time Taken (hrs)	48 (6 days)
	Cost of project	5225	Cost of project	18000
Project 2	Time Taken (hrs)	0.36 (0.04days)	Time Taken (hrs)	24 (3 days)
	Cost of project	4984.37	Cost of project	9000
Project 3	Time Taken (hrs)	1 (0.125 days)	Time Taken (hrs)	24 (3 days)
	Cost of project	5225	Cost of project	9000
Project 4	Time Taken (hrs)	1.15 (0.14days)	Time Taken (hrs)	24 (3 days)
	Cost of project	5280.237	Cost of project	9000
Project 5	Time Taken (hrs)	1.15 (0.14days)	Time Taken (hrs)	24 (3 days)
	Cost of project	5283.250	Cost of project	9000
	Cost per project (Rs)	5199.571	Cost per project (Rs)	10800
	Time taken per project (hrs)	0.932	Time taken per project (hrs)	28.8
	Profit Per Project (Rs)		5,600.43	
	Capital Cost (Rs)		73,000.00	
	No. of projects required to catchup capital cost		13.034	

Table 1 shows the CBA for Rebar works for column footing. The comparison of the improvement method produced for the five projects had an average profit of Rs 5,600.43 per project and on the 13th project, the capital cost was recovered. By this improvement method using machinery, average time taken per project (average of the five projects considered) reduced from 28.8 to 0.9 hrs.

Conclusion

NVA tasks are those that consume direct and indirect costs, time and resources while providing no value to the process or project. Defect, overproduction, waiting time, non utilized talent, transportation, inventory, motion, and extra processing, often known as downtime, are the eight categories of NVA activities (Ismail and Mohd Yusof 2016). This study helped them to understand about the repeated structural activities involved in residential projects and the process flowchart was a way to identify the NVA/NVAN tasks involved in it. The study was intended to eliminate NVA tasks or optimize NVAN tasks. CBA helped to identify a viable solution with respect to time, cost, and quality for proposed improvement techniques.

2. LEAN ENABLERS, INTEGRATION & IPD & ILPD

Abstract
The construction industry has been badly affected by the outbreak of COVID-19 pandemic. Thousands of projects are being delayed due to lockdowns and supply chain challenges. Most of the projects are experiencing cost overruns, while companies are filing for bankruptcy. There are ongoing challenges due to shortage of labor and disruption in the supply chain across the world. While the pandemic may possibly last for another few years, construction companies need to approach these challenges with a transformative mindset to deliver their projects under these new conditions. This paper presents a case experience of an improved project delivery system based on Lean construction and Digital transformation. This system is termed as Integrated Lean Project Delivery (ILPD) providing a backbone for effective integration of the three core aspects of project delivery: people, processes, and tools. The system comprises both a methodology and a synchronized digital system called Lean PlanDo (LPD). The paper also covers other observations and learning points to expand the implementation of ILPD through Lean PlanDo in the context of other regions.

Keywords
Lean construction, last planner® system, collaboration, digital tool, COVID-19 pandemic.

Introduction
Time and cost are the major constraints to construction projects, and it is identified that most of the construction projects fail to deliver projects on time. It is often that the more time we build, the more cost we pay accounting direct and indirect cost of the project. Construction productivity has been flat over several decades while other labor-intensive industries are experiencing improved productivity. Poor planning, lack of commitment and blame-game culture have led to weaker control over construction processes. These have compounded the problem of project delays, wasted time, defects and reworks. Majority of the projects get delayed due to ineffective planning techniques.
With the changing era, the project management has come up with many principles and guidelines for effective project management where they stress more on Transparency and Trust. When more people are involved, we need to maintain transparency in the accomplishments of the project so that every stakeholder has a common understanding on the projects. When the environment of trust is built in the project everyone in that project owns their responsibility for the project success. Advances in information technology could provide great benefits to this important aspect of construction planning where a collaborative environment is established. Lean construction has been promoted as an effective approach for improving productivity in construction (Aziz, et al., 2013) through better project planning and collaboration. It is the application of lean thinking into construction projects, and essentially focuses on maximizing the performance and value for the customer and minimizing waste through increased transparency and trust between the project stakeholders. In general, lean construction makes the project easier to manage, safer, complete earlier, cost less with better quality. While we are all enduring the effects of the COVID-19 global outbreak which is not just physically and economically draining, but psychologically too. In most of the world, the lockdown measures are still in effect which has resulted in full or partial closure of construction. There will be ongoing challenges with manpower shortages and delayed material delivery due to increased control measures. This period needs optimistic thinking which is crucial to re-strategize and re-plan collaboratively. This will create options to recover and minimize losses for companies to drive towards the best possible outcome for all the project stakeholders.

The key areas in project delivery at these times of the pandemic that needs to be specially handled through innovative project delivery methods are:
• Optimal manpower and resources planning for project execution to raise productivity
• Reliability and resilience against potential disruptions due to external factors
• Shortening of construction period But, in reality these three areas offer the greatest challenge to the

project stakeholders during these times as well as at normal times .

Overview of integrated lean project delivery (a method based on lean construction)

Delivery of Capital projects incorporates resolving complexity progressively and continually reducing the risks during its delivery from design to handover. In order for a successful delivery of a project, it is essential that there is integration of all the stakeholder's intentions towards a common set of goals for this definition of success i.e., timely completion, productive and safe execution, at well-defined quality standards, and profitability levels for the key stakeholders. Integrated Lean Project Delivery (ILPD) provides a system for collective involvement of all project stakeholders while binding them all together with Lean processes and methods to enable effective delivery based on these common goals for continual success.

It incorporates both macro and micro perspectives in planning, execution, monitoring and analysis to achieve the common goals. It also incorporates a continual improvement framework to make decisions more effective based on-site data/information. It enables the improvement of the project performance incrementally through improving the decisions and the execution progressively in the project. The goal of ILPD itself is not to manage and control the project or process or the stakeholders, but it is to improve the process, the people, and the tools. It becomes essential for ILPD to incorporate both the method and the digital tools that are fused with similar intentions to help the stakeholders to transform from conventional project delivery to enable continual project improvement mindset.

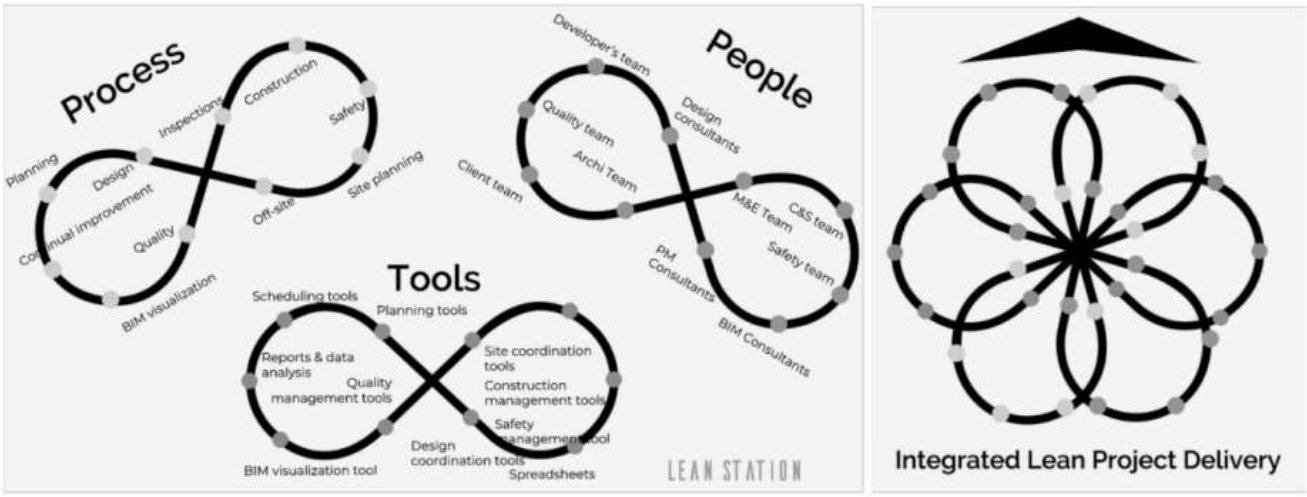

Figure 1 - Integrated Lean Project Delivery (ILPD): Integrating Process People and Tools towards the common goal

The tools that support ILPD should provide in itself these transformative abilities to improve agility, information availability, reduce response times, reduce anxiety of change during this transformation, while also providing them a progressive path of learning that grows and improves along with the stakeholder. Lean Plan Do (LPD) is designed and built as an ILPD system that fuses Lean + Digital in order to achieve the needed transformation in the capital project delivery.

Abstract
The construction industry has been badly affected by the outbreak of COVID-19 pandemic. Thousands of projects are being delayed due to lockdowns and supply chain challenges. Most of the projects are experiencing cost overruns, while companies are filing for bankruptcy. There are ongoing challenges due to shortage of labor and disruption in the supply chain across the world. While the pandemic may possibly last for another few years, construction companies need to approach these challenges with a transformative mindset to deliver their projects under these new conditions. This paper presents a case experience of an improved project delivery system based on Lean construction and Digital transformation. This system is termed as Integrated Lean Project Delivery (ILPD) providing a backbone for effective integration of the three core aspects of project delivery: people, processes, and tools. The system comprises both a methodology and a synchronized digital system called Lean PlanDo (LPD). The paper also covers other observations and learning points to expand the implementation of ILPD through Lean PlanDo in the context of other regions.

Lean plando as an integrated lean project delivery (ILPD) system

Lean PlanDo brings common alignment between all the project stakeholders towards one common intention of achieving timely, safe, and profitable project delivery. Lean PlanDo incorporates Lean principles and a scientific method of project improvement. Through this proprietary method of project delivery, a smooth production flow is established through collective planning and commitments, establishing real-time collaboration and a data analysis system for continual improvement. With these systems it binds all the stakeholders to one source of truth and improves proactive and agile mindset for sustained performance in the project progressively.

Lean PlanDo addresses the three identified areas of project delivery specifically to find the most appropriate balance between the expected planning on one side and the possible execution at the other end. The following aspects of Lean PlanDo are described below.

LPD for optimal manpower and resources planning for project execution to raise productivity

Current practices of manpower/resource estimation and capturing information about actual deployment does not address the project performance issues like delays and low productivity due to process wastage. This challenge is amplified with misalignment between the overall master program with the various stakeholders' detailed programs. Lean PlanDo system follows a rigorous planning and collaboration regime allowing the various stakeholders to achieve common alignment and practice the Plan-Execute-Monitor-Analyse framework. Through this framework, the developer, the contractors, and the consultants are all aligned on the long-term objectives of the project (milestones) as well as the short-term planning of the processes that lead to these milestones. The key stakeholders are alerted on any process issues to take preventive actions. The system also allows detailed monitoring and analysis of all the project performance and challenges. Through just-in-time (JIT) planning and execution, process wastages like idle/waiting time, reworks, incorrect deployment of manpower/resources are reduced and potentially eliminated through a continual improvement process.

3. VALUE STREAM MAPPING

A study on construction of precast slab by adoption of value stream mapping

Abstract
People in URC Construction (P) Limited, have been practicing Lean in their projects for the past eight years in all construction projects. Practicing lean in all projects is possible because of its high adaptability and also it adds value to the project. Their organization today is on an accelerated growth path with major diversification in executing projects in different sectors like

Airports, Stadiums, Factories, Power, Oil and Gas, Railway, Metro, Buildings, Irrigation, Bridges, and Roads. This study was done by adopting Value stream mapping Technique on Precast slab activity at their stadium project at Rourkela, Odisha. VSM adopted in two major tasks namely of casting of Precast slab concrete and formwork methodology. By implementing VSM, the process of each activity gets well organized and achieved 95 minutes per slab casting from our previous experiences of 180 minutes. The study concludes that Value stream mapping technique will improve project performance and achieving project targets.

Keywords
Lean Construction, Value Stream, Waste.

Introduction

The construction industry is considered to be one of the unorganized sectors as it depends on workers working. Even in today's mechanical era, its importance to workers has not been diminished. It has also been compared to manufacturing industry for low production efficiency, low quality, natural resources waste and the high rate of work accidents during the production process and operating performance. For improving quality, efficiency, and reducing waste, Lean Thinking philosophy has been imported into the construction industry since the 1970s (Fontanini et.al. 2013) Some successful experiences in implementing lean construction have been achieved. Lean the best practices followed in many industries. In general, lean defined by Womack and Jones as "the set of all the specific actions required to bring a specific product through the three critical management tasks of any business: problem solving, information management, physical transformation". Alternatively, Rother and Shook defined as "all the actions (both value-added and non-value-added) currently required to bring a product through the main flows essential to every product" (Rother et.al.1999) This case study on a stadium project aims to address "How the flow of construction process becomes easier, and the occurrence of wastes are minimized effectively" by
implementing the lean practice in the construction site.

Value stream mapping

Value stream mapping (VSM) is used to identify value-adding activities and non-value adding activities and also the flow of activity/information. The main reason for learning and understanding this VSM tool is to understand how is helpful in reducing the nonvalue added activities and reducing the cycle/duration by eliminating the waste. And this will help us to develop and improve the performance/progress of the activity. The space between the existing state and the proposed state of different construction activities will also be reduced. VSM provides that clarity for us by charting the flow of work through the different steps involved in the development/delivery of a product or service. Flow is 'good' when work moves progressively and surely to customer demand and supplier capacity. Flow is 'bad' when work starts and stops unprogressively and regularly. By visualizing flow, VSM helps organizations move from bad to good through improvements in productivity and reduction in waste leading to value creation for both you, as the supplier, and your customers

Fig 1.0 Value Stream Mapping Overview

	Process Activity	Lean
1	Value Add Activity	Optimize
2	Essential Non-Value Add Activity	Minimize
3	Non-Value Add Activity	Eliminate

Fig 2.0 Categories of Activities

In summary, this study has shown that Value stream mapping is an effective tool which will enhance the continuous flow of work by eliminating the waste as far as possible. The application of VSM in association with some other tools also will increase the progress and value of the project to the maximum extent. From the above study, the total operation time of the precast slab activity and non-value added time were successfully reduced from 180 Min to 95 Min respectively. Therefore, it is evident that this VSM tool will helps us in reducing the cycle time, wastage and continuous flow of work will be there through which we can reduce the operation cost, enhance the operating performance, and also satisfy the customers demand.

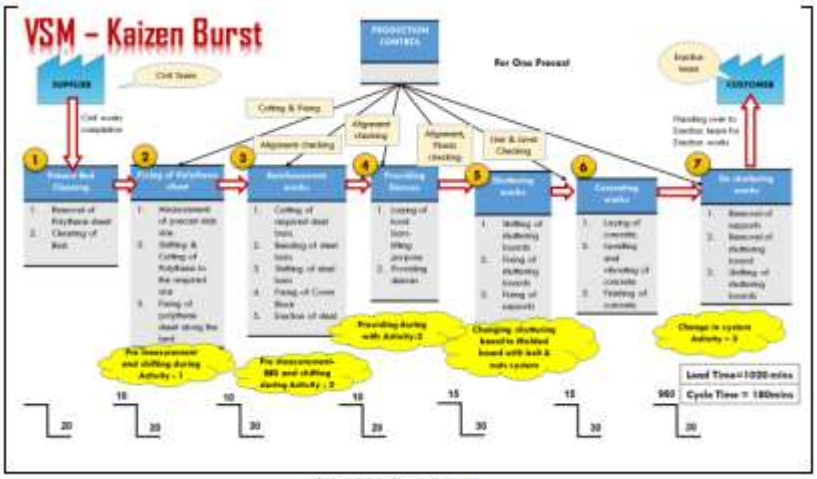

Fig 5.0 Kaizen Burst

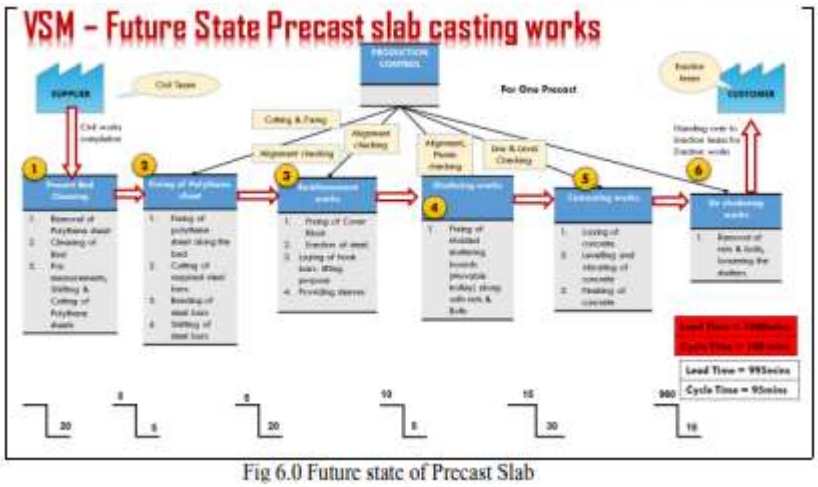

Fig 6.0 Future state of Precast Slab

4. 5S

Site information

The project is exactly located at Satyanagar, Unit- IX, Bhubaneswar. It is an EPC mode project of cost Rs. 73, 30, 20,000/- under Bhubaneswar Smart City Limited surveillance. The project duration was bound to 24 months. The area allotted is 4.2 acres.

5 S' principle of stocking

5S was followed up for the project team to increase the focus on housekeeping activities. It was indicative that, Sort, Set in order, Shine, Standardize, and Sustain takes a lot of time since each project was unique and time bound. In a time bound project of 24 months and an area restricted site of 4.2 acres 5S Principle helped us a lot to have hassle free access to all the materials required at site immediately

Figure 9: Materials stocked with proper levelling at store

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3. *Journey of enlightment towards 'lean construction' S.Venkatachalpathy1 , P. Thangapandian2 , and Puravi Priyadarsini Maharan*

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

SARA7403 - LEAN CONSTRUCTION MANAGEMENT

UNIT – IV– PLANNING AND PROJECT PERFORMANCE

PLANNING AND PROJECT PERFORMANCE

1. LOOK AHEAD PLANNING

Lean Construction Practicemaking Of The Mahatma Mandir Project -*Krishna Nadoda1, Chandni Nathani2, Reshma Shah3*

Abstract
Mahatma Mandir Convention and Exhibition Centre is an iconic project involving a theme-based conceptual design supplemented with Construction components of the project. The said complex project was designed and constructed with overcoming project challenges like land acquisition, site conditions, development of Master plan, project phasing, changes in designs with approvals, Space limitations, need of speedy execution and stringent timeline by holistic pursuit of concurrent and continuous improvements in all the dimensions of the project. The active participation of all stakeholders and strong conceptualization from the initial stage of the project provided a solid intellectual foundation for implementing the project with a specific set of processes. The collaborative, commitment-based planning system with integrated pull planning and scheduling, look ahead planning with constraint analysis, regular weekly planning meetings based on commitments of project participants, timely release of all approvals and variations, adoption of offsite construction works and mechanization, optimization of efforts focusing on making workflow reliable and increased transparency among the team lead to timely completion of the project with safe man hours. The purpose of this case study presentation is to share insights, disseminate learning's and use of lean concepts to an industry wide community.

Keywords Waste reduction, offsite construction, safety-quality-health, continuous improvement, workflow

Introduction

The main aim of lean construction is to maximize the value of the project in terms of delivering what the client expects. This can be achieved by adopting practices that reduce waste by optimizing the use of resources like time, cost, and effort. One such case study is represented in this paper where lean practices were adopted to overcome project challenges and deliver the project in the stipulated time

Mahatma Mandir – Gandhinagar, is an iconic building constructed in the honor of the Father of the Nation, Mahatma Gandhi in the Capital City of his home state. Mahatma Mandir is strategically located as the gateway to Gandhinagar – the capital of Gujarat, enhancing the capital's characteristic central vista as an entry node leading to the assembly complex in one way and as a new connection to the future.

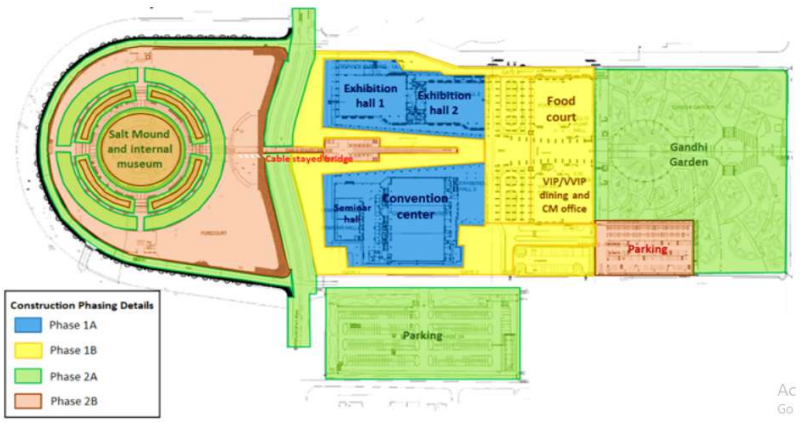

Figure 1 Project Layout

Phase 1A: Exhibition Halls and Convention Centre (Total BUA of 33238 Sq. m)
Phase 1B: Food Court, Photo Gallery, Parking, Hardscape area, Corridor (Total BUA of 27349 Sq. m)
Phase 2A: Salt Mount Structure, External Mound, Gandhi Garden, Parking Area (Total BUA 56927 Sq. m)
Phase 2B: Internal Museum, Cable Stayed bridge, Landscape for salt Mound, Artificial Turf Garden on Terrace. (Total BUA 94625 Sq. m)

The project was implemented in four phases spanning from July 2009 to September 2016. iNDEXTb (Industrial Extension Bureau) was given the responsibility to develop an international level Business and Exhibition Centre at Science City, Ahmedabad (which was later shifted to Gandhinagar), and they were the owner for phase 1. Roads and Building Department (R&B-Government of Gujarat) was the project owner for phase 2 of the project. Centre for Research and Development Foundation (CRDF) was deployed as Professional Advisor for the project from the inception till the handover. PMC deployed were GherziEastern-1A, Dorsch-1B and R & B (2A and 2B). The project was completed as EPC (Phase 1 and 2B) and item rate (Phase 2A) contract. This paper is written to identify various lean practices adopted in context to successful implementation of "Mahatma Mandir Convention and Exhibition Centre" project.

Research methodology

This paper is adapted from academic research of authors (Nadoda, K. 2020) 1 and (Nathani, C. 2020). 2 The research was part of directed research program (DRP). The aim was to identify the issues and challenges, analyze the strategic decisions taken and performed, and document the lessons learned in form of a book covering the phase wise project life cycle of the Mahatma Mandir Convention and Exhibition Centre. This paper summarizes the lean practices adopted during executing the case study. The qualitative data collected was combination of primary and secondary data. The source of primary data was unstructured interviews of project stakeholders viz., Client, Advisors, Coordinator, Contractor team and consultants. Secondary data referred was project data like concept presentations, DBRs, tender, BOQs, drawings, photographs, method statement, project progress reports and presentations, manuals, schedules, research done on same project, certificates, correspondences, checklists, etc. Literature study focuses on understanding the lean principles applied in the project. Further the identified lean practices are illustrated and analyzed. The qualitative identified lean practices are grouped in major categories and fishbone analysis is done.

Literature review

A project is ideally expected to have a specific start and end date within which time it is needed to be successfully delivered to the client as per the contract. A project involves various stakeholders like Owner, architect, Project Management Consultant, Contractor etc. and these are the active participants of the business flow. The project duration and construction rhythm are determined by the Business Flow and has great impact in indirect costs. (Picchi, July 2000). A well-executed Project mirrors its Production Planning precisely, and good Production Planning comprises planning elements that can effectively be executed (Itri Conte,2002). Proper and effective communication is must for seamless flow of work. In other words, information or output of one activity could affect the decision made for another activity and vice versa. Thus, continuous

communication among the involved parties is needed to insure that as much relevant pieces of information as possible are made available to the disciplines that requires them before a decision is made. (Hammond et al, 2000). Many construction projects use project schedules designed for shorter term to focus on the details of project. These schedules are often called "lookahead schedules" because many look ahead several weeks into the future. Lookahead schedules are commonly used in the construction industry in order to focus management attention on what is supposed to happen at some time in the future, and to encourage actions in the present that cause that desired future (Ballard, 1997).

Project Coordination can be understood as the successful achievement of the commitments by all the stakeholders involved in the implementation of the specific objective by optimal use of all the resources and to keep the project organized and smooth running. To do so, the traditional practices need to be upgraded with modern and constructive practices like lean. Successful design management implementation ensures error-free design application just in time so that activity can start when scheduled with confidence of quality (Uusitalo, P, 2020).

Illustrations of adopted lean practices through overall project -Look Ahead Planning

Master planning at initial stage

Vibrant Gujarat was held at Tagore Hall in 2003 and since then for the years 2005, 2007, and 2009 it was held at Science City. The growth and support received in these events was enormous, there was no facility to host such a large-scale event, due to which a strong need to develop a convention and exhibition Centre in Gujarat was realized. It was Honorable Chief Minister's vision to develop such a structure and the proposed location for the project was at Science City, in Ahmedabad, Gujarat. Planning for this project commenced in 2009 and various different convention and Exhibition centers like Hyderabad International Convention Centre and HITEX were studied to understand the size and scale of the project. Initial area requirement of project was 15000 Sqm. Later location was changed to helipad area in Gandhinagar and then to the 'Kh' road. It was during this time that the project 'Mahatma Mandir' was incepted. Major components of the final master plan were the Inclined columns, turbine together with blades of windmill, Cable Stayed Bridge, Salt mound, and Gandhi Garden, all inspired from life and principles of Mahatma Gandhi. Initially due to change in location there was delay in mobilization but there was continuous improvement in design, planning and management (explained later in the paper). Each phase was successfully inaugurated with Vibrant Gujarat events and end dates were met with proper scheduling and compression wherever needed. All the delays encountered were overcome by the implementation of the mitigation plans which led to no stoppage of work and completion of the project under stipulated time. Planning and monitoring during execution Various project sub-tasks as a part of planning and monitoring during execution are discussed below: Scheduling: Planning was done using the software MS Project, where a macro schedule for the whole project was made, and accordingly, micro scheduling based on daily, weekly, and monthly forecasts were created. Daily planning helped to achieve daily target goals and accordingly plan for anything left as balance and similarly weekly and monthly planning was done. Material requirement planning: Due to micro scheduling, resource planning was done well in advance and long lead materials like façade lighting, wind turbine, lifts, and escalators, etc. were identified and specifications were finalized from the beginning. Schedule with specifications was prepared after approval from Professional Advisor to avoid the chances of errors. The schedule was timely followed and tracked to avoid issues. TEP: A schedule of Plant, Equipment, and Machinery was maintained with data like asset code. This is a code given to each equipment for its easy identification. The

planning of TEP usage was done based on its requirement for each activity. This record-keeping fuel number of hours for which the equipment was running, maintenance requirement, etc. helped to identify any equipment being idle for a long duration or not performing according to expectation due to some fault so that it can be sent for maintenance

Progress Monitoring: Site Progress was measured in the forms of Physical work. Progress sheets were maintained for daily, weekly, and monthly progress and financial progress. Data like work progress, material stock, labor strength, plant, and machinery, etc. were collected daily from the site for the work executed in hard copy. Monitoring reports were prepared to identify the exact status of execution, identify issues, the quantity of balance work, overproduction as well as any overuse or underuse of resources. Contingency plans were prepared as required so that target can be achieved by completion of the work in the stipulated time.

2. WEEKLY WORK PLANS

Journey of enlightment towards 'lean construction'

Abstract

This is an overview of their LEAN JOURNEY followed at Bhubaneswar Smart City Limited project by URC Construction (P) Ltd. in the form of a case study. Construction Industry being the spine of the country's economy faces a lot of pressure in delivering the projects in time whilst of all external factors. This case study extensively focuses on slab Cycle reduction duration. The major fragments which we have incorporated in our site are '5S' Principle, Location Based Management System and reduction of slab cycle duration. The major outcomes of LBMS, 10 weeks look ahead plan, weekly plans, and daily huddle meetings entrusted us a useful and quick response to all the hindrances towards the progress of project. They used LPS system to reduce the slab cycle duration technique. Labor shuffling and resource allocation remained fixed throughout, which demarked the unnecessary delay. The PT Slab pour of 1200 Sqm which would take a minimum of 25 days in conventional way but with the help of LPS technique it was possible to achieve in 15 days which in turn reduced the time of project by 52% of the total duration of the project without any compromise in safety and quality of work.

Keywords LastPlanner®System, Job Sequencing, Location Based Management (LBM) logistics, daily huddle, continuous improvement/kaizen,5 S principle.

Introduction

"Last Planner System" tool of Lean construction has withstood their expectations and now they are at the verge of completion of project. In addition to this they developed a Slab Cycle time reduction, which enabled them to complete the civil structure as soon as possible. In order to facilitate the same LBMS, 5 S Principe, Constraint log were followed up.

Site information

The project is exactly located at Satyanagar, Unit- IX, Bhubaneswar. It is an EPC mode project of cost Rs. 73, 30, 20,000/- under Bhubaneswar Smart City Limited surveillance. The project duration was bound to 24 months. The area allotted is 4.2 acres.

It has a basement with lower ground floor, upper ground floor with 10 floors. It has got a heavy raft foundation of 1900 mm; underground vehicle parking facility with an eminent architecture following up natural ventilation to the basement. The building is a 4- Star Griha certified project. Completion of this huge task in just 24 months despite this unexpected pandemic situation on COVID- 19 was a tedious challenge for our team. Last Planner system had enabled us to keep the workflow intact. We were also able to have a tight grip on cost control. It helped us to have more practical visualization towards timely completion of the

project. 5s principle helped us to have all the constructional materials stacked in an orderly manner which helped us to avoid unnecessary hassle.

Objective of lean techniques

The main objective of our team was to reduce the slab cycle duration and complete the civil structure as soon as possible, so that later on we would focus on finishing part which generally takes more time. To achieve the set goal, we had planned judiciously and followed up last planner system and maintained the workflow throughout. It in turn helped us to minimize waste and brim utilization of manpower and resources was possible. The major four objectives of lean principle applications are: Waste Minimization, Cost Reduction, Meet promised dates, and Improve quality. (planettogether.com/blog).

Figure 2: Lean Objectives achieved at site

LEAN METHODOLOGY

The basic methodology implemented in our project was progressive - preplanning. This exclusively dealt with proper setting of milestones at first followed by monthly planned activities. The monthly planned activities were again fragmented to weekly planned activities and further to the grass root level of daily planned activities for a detailed continuation of workflow. The major predicted delay was expected in slab cycle as the building had 10 floors. So as per the above mentioned methodology the flow was generated by fixing the set of shuttering materials, dedicated labors engaged, and resources such that the task would be accomplished in a definite period of 15

days. The slab was of 1200 Sqm from 4th floor till 10th floor (Tower Area). Daily huddle meetings were held to eradicate the obstacles beforehand.

Figure 3: Lean Methodology adopted at site

Last planner system

The Last Planner System (LPS) in civil phase of the project helped us to reduce the slab cycle duration and eliminate delays. For the MEP phase, LPS combined with Location based management system was used to effectively coordinate work front across the subcontractors. (researchgate.net, conference: international group of lean construction, 2016). LPS is a form of lean construction which is currently used by around 15% of builders in some form or another and is growing in popularity (www.planrader.com) LPS brought all execution engineers who executed the work (the team) collaborated with proper planning and site management. It also helped us to recognize that personal relationships and peer pressure are critical to the success of creating the LPS culture. LPS facilitated us to identify the constraints and removal of it before scheduled time to maintain the workflow. It can be encapsuled that the workflow was maintained throughout the project duration.

Overall schedule

The updated overall schedule of all the activities involved including MEP and Civil work in completion of the project gives a basic idea as well as a definite timeline to work simultaneously. It helped us a lot to have a cross check over the progress of the project periodically.

Milestone schedule

Setting up milestones in the execution of a project is very essential. In order to accomplish milestones in time last planner system was followed ardently. In our project we had seven milestones; we made tabulation for following up these milestones as a planned date vs achieved date to have transparency in work progress.

10- week look ahead plan

The next level of planning is referred to as "Look- Ahead Planning". The look ahead planning comprises of rolling 10 week plan based on our project requirement. It helped them to keep a track on the milestone. The objective of LAP is to identify constraints that would prevent the planned activities to get delayed. By the help of look ahead plan we easily prepared weekly plans which facilitated us to achieve the planned activities in time.

Weekly work plan

They easily had a track on their project by deriving the weekly plan from 10 week look ahead

plan. It enabled them to have a more clarified knowledge regarding the constraints for their planned activities and it was resolved before the commencement of the task.

WEEKLY WORK PLAN

					CATEGORIES OF VARIANCE																								TOTAL ACTIVITIES		39			
	URC Construction				1	Less Manpower skilled mason			8	Less Manpower/absence-Bar Benders																							
	Project Name : BSCL				2	Carpentor engaged in other work			9	Area occupied with scaffolding affected the work				This week Planned Amount				15 78 050								ACTIVITIES COMPLETED (Daily PPC)		1			
	Project Location : BBSR				3	Lack of enough skilled labor-Carpenter			10	crane engaged in other area																			DAILY PPC		3%			
					4	Lack of painter			11	Power cut in evening time affected the concrete progress				This Week Achieved Amount				13 83 050																
					5	Bar Bender engaged in other area			12	area clearance not available																				ACTIVITIES COMPLETED (Weekly PPC)		1			
					6	Sequence Delay			13	Absence of Waterproofing sub contractor				Percentage of Achievement				87.64%												WEEKLY PPC		3%			
					7	Material insufficience-Scaffolding material			14	Absence of painter																								
									15	Waterproofing labour absence																								
									16	Heavy Rainfall at Site																								
BOQ Code	ASSIGNMENT DESCRIPTION	RESPONSIBLE PARTY	Quantities/ Comments	UOM	STARTING ON		14-Jun-21					Rate	Planned Amount	STARTING ON		14-Jun-21					Achieved Qty	Achieved Amount	PPC ANALYSIS										
					Planned									Achieved									DONE?			REASONS FOR VARIANCE	Category						
					Mon	Tue	Wed	Thr	Fri	Sat	Sun			Mon	Tue	Wed	Thr	Fri	Sat	Sun			YES	NO	Week								
					14-Jun	15-Jun	16-Jun	17-Jun	18-Jun	19-Jun	20-Jun			14-Jun	15-Jun	16-Jun	17-Jun	18-Jun	19-Jun	20-Jun														
1	Shuttering Work (Box & Beam)		80	Sqm	15	8	10	15	10	12	10	1 500	1 20 000	15	8		15	10	12	20	80	1 20 000										
2	Reinforcement Work For box and lintel, tie beam		7.9	mT	1.2	1	1.5	1.2	0.8	1.2	1	1 20 000	9 48 000	1.2	1		1.2	0.8	1.2	1	6.4	7 68 000				Barbender shortage	5						
3	Blockwork 7th to terrace floor		110	Sqm	12	10.00	15.00	15.00	18.00	20	20	1 200	1 32 000		12.00	15.00	15.00	18.00	20	30	110	1 32 000										
4	Fly Ash Brick (Lift Area)		2.6	Cum			0.60	0.60	0.80	0.6		28 000	72 800			0.60	0.60	0.80	0.6		2.6	72 800	X									
6	Concrete Work		6.75	Cum	1.5	1.50	0.75	0.75	0.75	0.75	0.75	28 000	1 89 000	1.5		2.25	0.75	0.75	0.75	0.75	6.75	1 89 000										
7	Plastering Work		155	Sqm	20	20.00	20.00	20	25	25	25	750	1 16 250	20	20.00		20	25	25	25	135	1 01 250				Heavy Rainfall at site	16						
			Daily PPC		5	5	6	6	6	6	5		15 78 050	4	4	3	6	6	6	5		13 83 050										
			Daily PPC %											80%	80%	50%	100%	100%	100%	100%												

Figure 4: Weekly Work Plan Schedule

Constraint log analysis

As a progressive approach to LAP, we swiftly prepared our Constraint log which was updated in regular interval of time along with LAP. This indeed was an important monitoring aspect to know our constraints before execution of planned work. Knowing our constraints beforehand, let us to resolve the same as soon as possible.

Root cause analysis

From the PPC analysis they had their variance chart in the form of Parito chart. This specific chart helped them to have a track on repeated nature of delays caused to their project which in turn enabled them to eradicate at instant. This was a key tool to implicitly follow up the progress of project.

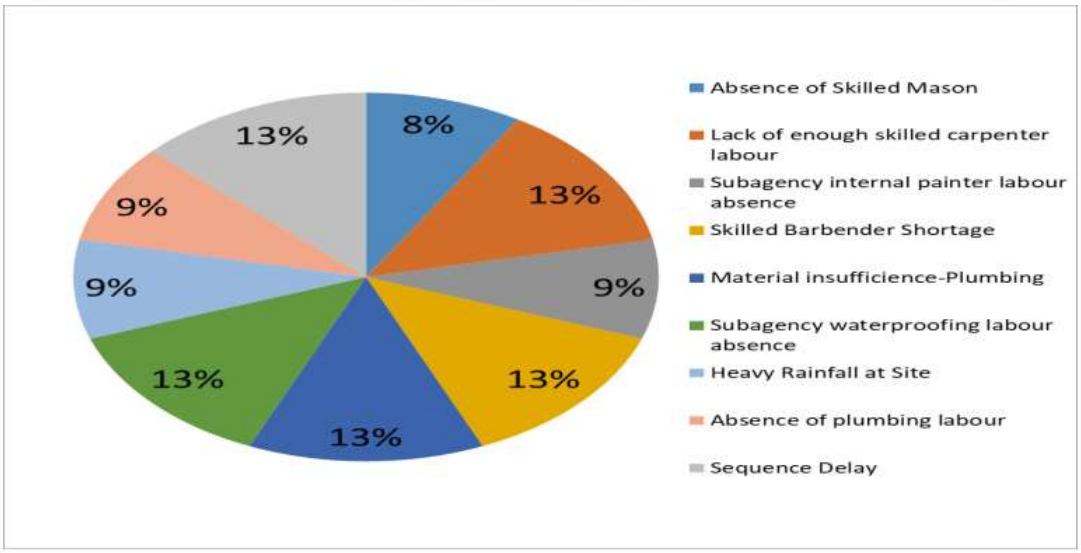

Figure 5: Weekly Root Cause Analysis Parito chart

Daily huddle meeting

After a keen review of the root cause analysis and the variance chart another key tool of lean construction is daily huddle meeting by which we had regular discussions on our short falls and the basic reasons behind the lack on as/delays and the various ways to overcome the same. This helped them to stick to their planned timelines.

Figure 6: Daily Huddle Meeting

Slab cycle time reduction

Their project being a tall giant building of 13 floors including basement. From 4th Floor till terrace floor, they had a typical floor design and had repetitive nature of work. With the help of PPC, LAP, Constraint log they developed a Slab cycle time reduction. They planned and achieved casting of each slab in a duration of 15 days. The slab is a combination of post tensioning slab and conventional slab. The below table states the specific allocation of the resources for easy workflow.

Table 1: Effective tabulation for reduction of slab cycle duration

Description	Unit	Total as Per Drawing	Allocated Resource	Duration
Column	Nos	13	6 column boxes with starter	0 to 7th Day (For 2 lift)
750mm x 750mm Size	Nos	2	1 column box with starter	
1000mm x 350mm Size	Nos	3	Complete set available	0 to 10th Day
Shear Wall – 80 Rmt	Sqm	1200	Complete set available	4th to 11th day
Slab Shuttering	MT	30		8th to 12th day
Slab Reinforcement	MT	3		12th to 13th day
PT Strands	Cum	270		15th day
Slab RCC				

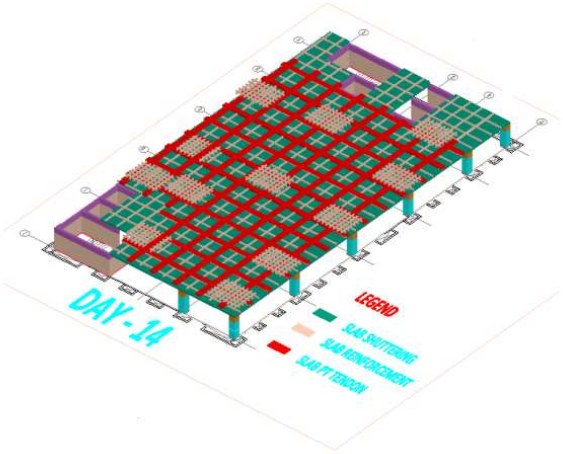

Figure 7: Top Reinforcement Activity accomplished as on 14th day of the previous slab casting date.

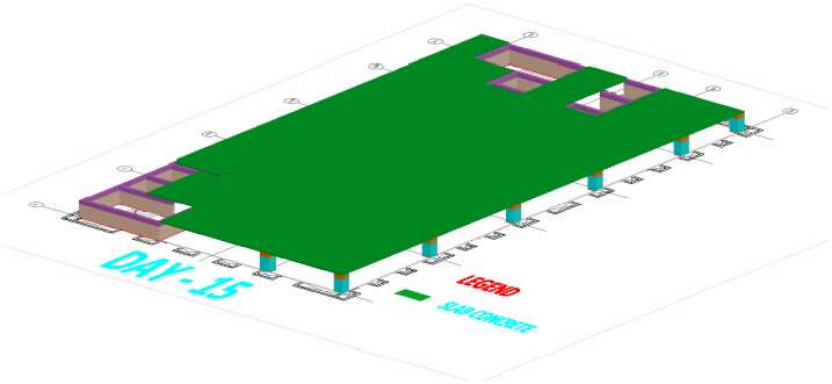

Figure 8: On the final day, Day 15th we have successfully casted the roof slab.

Result through last planner system

- Dedicated resource allocated at the particular work.
- Material and Labor shuffling avoided.
- Target conveyed up to last planner through LPS.
- 15 Days slab cycle time achieved after 5th floor till terrace floor.
- Productivity improved.
- Plan for the next day achieved through pull planning.

With the help of LPS they saved their valuable time of the project timeline effectively. Cost minimization and optimum utilization of labor was possible with less generation of waste. All the stated activities were successfully done without comprising with the safety and quality of work.

Conclusion

Lean is a long tern journey and needs a strong focus and persistence. They have been doing lean for past two years in this particular project and cumulatively following this culture past seven years. The main learning at the project was that if the designers imbibe the Lean Philosophy, larger benefits can be reaped such as lesser design iterations and a proper location based management system would help to reduce false of work building civil team and MEP team. This not only reduced rework but also helped the project execution team to complete the deliverables in time. Productive utilization of resources, manpower and waste reduction is the ultimate aim of Lean Construction. Lean is not something complex. It can be summarized as a philosophy to drive continuous improvement with customer focus by doing three things right-eliminating waste, simplifying everything, and creating a continuous workflow.

3. STAND-UP MEETINGS

Constraint management and production planning – a case study

Existing process (before solution)

On this project, the process of production planning starts with drafting plans on a scheduling tool called "Primavera P6" and decimating it through emails. Subsequently, the lookahead discussion sessions are held with constraint management on spreadsheets. The production plans are usually developed, coordinated, and updated by a dedicated Planner on the project. Here, the modes of communication are emails, phone calls, messages, or simply face to face interactions. The discussions may also involve any difficulties faced by the last planners in getting updates related to constraints or activities. The same Planner is responsible to update the P6 master plan, alongside communicating with the constraint owners and authors to update the progress manually on the spreadsheet. The typical routine is estimated to consume anywhere between two to three hours of the Planner's workday. On weekly basis, there are three meetings taking place: Lookahead sessions (3 hrs.), Constraint review sessions (1 hr.) and Progress review/support meetings (0.5 to 2 hrs.) involving the last planners and key project participants. The lookahead meetings are focused to discuss the upcoming 12 weeks of work and their dependencies, flow, and their make-ready needs, along with documenting the updates from the site. The dedicated Planner usually captures the discussions to update and align the master plan. Within this session, the milestones and key deliveries are conveyed to the last planners and their feedback is taken to build-up the high-level delivery plan. Additionally, the constraints are also matched with the production plan. Later, the last planners try to determine the potential constraints for their

deliverables. The Planner then collects all the constraints and compiles a spreadsheet to keep a track and conduct follow-ups on the listed constraints throughout the week. In the weekly constraint review meeting, the last planners and project facilitators provide further updates on the constraints. Using the same spreadsheet, the Planner updates the subcontractors on previous week's constraints and future week's activities via email, keeping the client in the loop as well. The support or progress review meeting is regularly held to resolve the pending issues during execution, as well as to address any newly reported constraints by the last planners.

Key observations in the existing process

While the constraints are usually mapped with the production deliverables during the lookahead meetings, the production is not restricted by the same. Hence, the last planners can simply bypass or miss the constraint to rush the delivery. Primarily because the production plan and constraints are managed on separate systems, there is excessive strain on the Planner for potentially losing the overall control of the production plan. Another key objective that constraints need to serve is to determine the knock-on impact on the successor works. However, the partially linked system does not allow for this analysis of the impact and severity of identified constraints. An example of the conventional constraint management using a spreadsheet is shown in Figure 1.

Last updated on: 30th Sept 2021
Project: Trial Project Name XYZ
CATEGORIES OF CONSTRAINTS: 1: Contracting / 2:Engineering / 3:Material / 4: Equipment / 5: Labour / 6: Utilities / 7: Submittals/Approvals / 8: Coordination / 9: Quality / 10: Safety / 11:Environmental
STATUS: 1:RED (deadline exceeded) 2: YELLOW (up to 7 days left before the need by date) 3: GREEN (complete)

ID	Company	Constraint Description	Type of Constraint	Activity	Responsible	Date Identified	Need by	Commitment Date	Date Complete	Status	Notes
54	ABC	Design level 3 approved by client - IFC (WP 5.4.1)	Engineering	Soil Improvement	Yogiraj Surti	28-Jun-21	12-Jul-21	10-Jul-21	11-Jul-21		M1: Already submitted to BN design review on W51. Coments received on 4-Jul-21 M2: Submitted 10.06 expectir tomorrow
56	PQR	Jet Grouting Spoil and Water management procedure approved by BN	Coordination	Soil Improvement	Vijayashree	26-Jul-21	03-Aug-21	04-Aug-21	04-Aug-21		M1: Enviroment received the (01E),went through it (for comments) and given feedba from Construction on when this will be submitted to the
98	ABC	Design and placement Ground monitoring system - inclinometers	Engineering	Soil Improvement	Paramjit Lota	30-Aug-21	11-Sep-21	15-Sep-21			M1: Inclinometers planned to going to install them - maybe after 13-09. 2 inclinom site, NR for 2 additional ones URGENT - when are these arri

For effective constraint management, it is necessary for the last planners to flag up and escalate the constraints to the planners/management. On an infrastructure project of this scale, it becomes difficult to convey this vital information from site to the support team. Since constraint resolution directly affects the successful completion of work on site, the project loses efficiency with teams spending critical time in collecting this information manually. Evidently, due to communication gaps and lags, there have been instances on site where the succeeding task crew have arrived at the jobsite despite having no clearance from the predecessor work crew. Such situations have a significant impact on productivity of site teams. This inventory of crews and machineries leads to considerable overhead costs, simply because of communication gaps and poor constraint management. For this project, the work is on-going for almost 21 hours in a day. To work during the late-night hours, a mandatory permission from the government is required. Moreover, even for applying for the permission, all the machineries are required to satisfy the requirement of permissible decibel levels. This process applies individually to all works in progress on the project. A rapid and effective coordination in this case becomes extremely critical to stay on top of the dynamics of the production environment. However, in lot of these instances, the project team has missed obtaining this permission, thereby being forced to postpone the work. It is evident that the latency in communication of this requirement is the root cause of these unwanted delays.

Effectively, the constraint and production management in itself are being constrained due to the listed observations:

- Latency and gap in communication.
- Multiple and distributed communication channels causing a lack of clarity.
- Lack of control over production planning due to high degree of constraints.
- Lot of unnecessary work and extra effort being put in the process.
- Standardization and mistake proofing is needed in the process.
- 'Proactiveness' and 'transparency' from the system is getting restrained.
- Analytics and trends mapping cannot be actively done due to extensive manual intervention

These observations have been responsible for multiple instances, at the time of significant wastes (motion, overprocessing, inventory, waiting) and loss of value in terms of delivery.

Developing an integrated solution

After the empirical analysis of the as-is process of constraint and production management system, authors and project team members were set to find an optimal solution to address the listed observation. The approach to do the same was simply addressing all the listed observations and draft ways to eliminate them. Starting with the inherent latency in the production process, many of the scholars have recommended to resort to real-time production management systems. On top of being real-time, the solution must be made centralized to collect all sorts of constraint and related information within one system. The solution should also be connected to the production planning to evaluate the impact of those constraints in the production. Moreover, the new system must support digitalization and mobility to element the unnecessary human intervention and let the team communicate freely without any restriction of predefined engagements/meetings. In fact, the system should be easy enough for ground users to raise their constraints directly from site, without having to deal with complex tools and processes. Additionally, the new system should support the standards to collect accurate and rich details related to constraints for minimizing gaps in communication. This collected information should have enough categorization, classification, and relationships (connection with production information). Considering the listed requirements and driving constraints through conventional processes for a year, in the last quarter of 2020, the authors started developing a constraint management solution to integrate with the production management system already deployed on the project; VisiLean. As a cloud-based Lean-BIM integrated construction management system, VisiLean has all the required capabilities for real-time production management and control.

Digitally integrated processes (after)

With the newly deployed solution, the planners are now importing their master level P6 (activities with average duration of nearly 20 days) program in VisiLean, making it realtime, up-to date, and available for all the project participants online. This has resulted in saving significant time and effort which was earlier spent in exchanging emails for planning coordination. Now, the subcontractors are also using the system to breakdown activities into detailed work tasks and allocate them amongst their team. Lookahead meetings have now became a review of upcoming activities in real-time with all the relevant parties involved and up to date with their production plans alongside the applicable prerequisites and constraints. The new process defines clear ownership of the constraint and an inbuilt structure to formally commit to their work within the system. Owners of the constraints are directly getting notified whenever a constraint is created and assigned to them. The weekly constraint review meetings are now just 15 minutes in length, with

the introduction of concurrent constraint management approach. Project planning teams are now spending minimal effort for collecting and processing the data for raised constraints. During this meeting, the system automatically generates a view where all the constraints can be seen with their allocation, priority, status, associated tasks, predefined category, location, and attachments, for the team to conduct a focused and efficient review of new, pending, or resolved constraints (Figure 2).

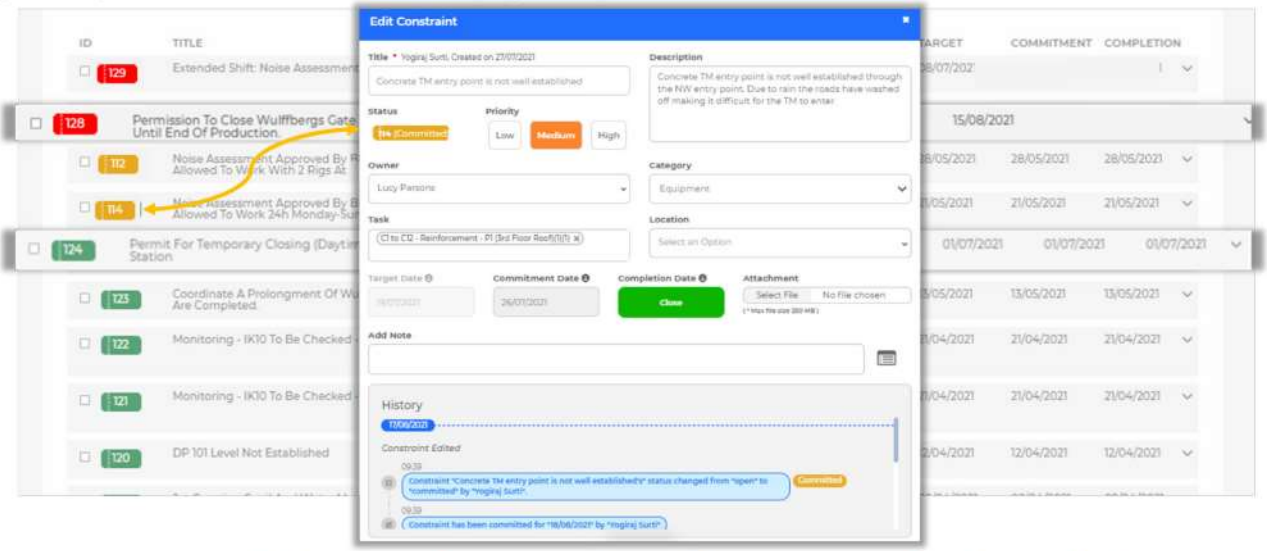

Figure 2: Live list and details of flagged constraints in VisiLean (Web)

Follow-ups and all communication regarding the constraints is now in-built within the constraint's log itself. Additionally, with the help of linkage between the production tasks and constraint, tasks cannot be started without closing out the open constraints. Consequently, the field team is now more conscious and responsive towards the constraints associated with their deliverables that were usually being neglected or skipped until they become a reason for completely stopping their work. Many of the critical constraints related to flow and logistics are now directly being reported from the field using the VisiLean Mobile App - LiveSite. In response, the project supporting team is also actively responding to these constraints, ensuring that the jobsite is ready in advance. Upon the introduction of this new concurrent constraint management solution, the project teams are now receiving massive amount of categorical and descriptive data from the last planners. Furthermore, this data is being analyzed by the support to generate trends and insights on flagging committing and resolving the constraints.

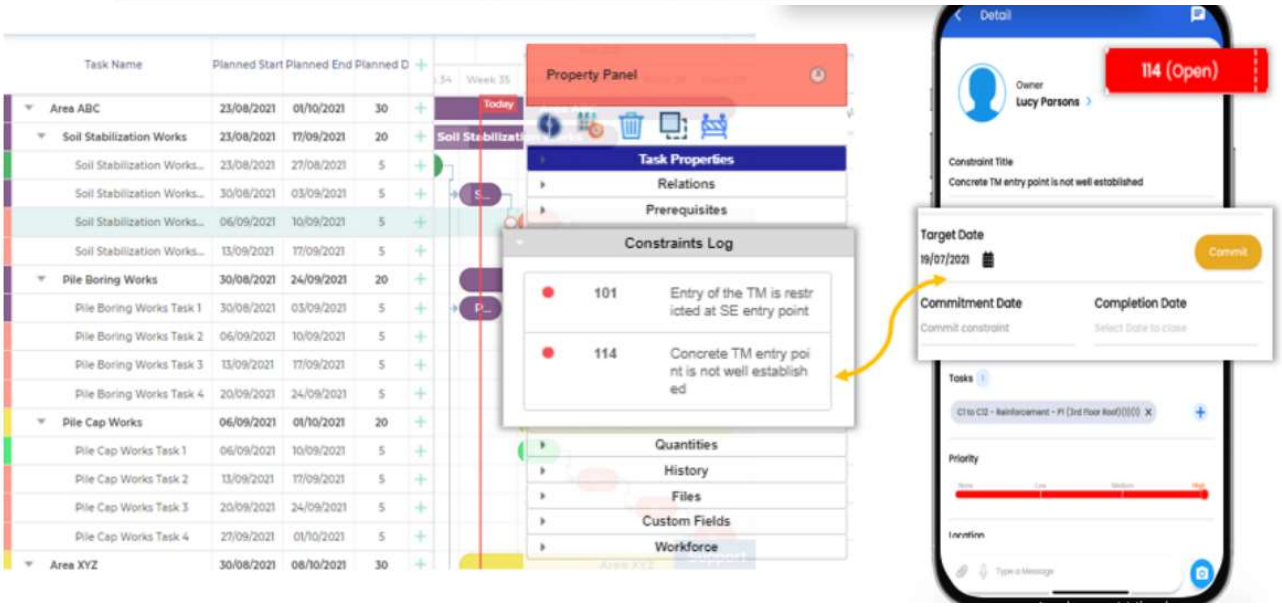

Figure 3: Constraint being reported from site (LiveSite) and reviewed in the office (Web)

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