Lecture Notes in Civil Engineering

Anil Kashyap · N. Raghavan ·
Indrasen Singh ·
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Arun Chandramohan *Editors*

Sustainable Lean Construction

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Dedicated to all Lean Construction Enthusiast

Preface

Infrastructure projects play a crucial role in driving economic growth and development in India. The country has witnessed a significant focus on infrastructure development in the past two decades, and the trend is expected to continue in future. However, according to the Ministry of Statistics and Programme Implementation (MOSPI), time and cost overruns distressing major infrastructure projects led to financial impact of Rs. 4.5 trillion as of December 2022. This has an impact on both the productivity and the profitability of such projects.

Given this context, it has been found that the successful implementation of Lean principles has benefitted organizations significantly. Further, with the industry moving towards prefabrication and digitization, Lean-integrated digital tools have the potential to manage resources in an optimum manner without compromising on time, cost and quality.

However, there is a need to bring Lean awareness to construction corporates, government contract companies and stakeholders in the academic and research domains. This is because studies have also indicated that only under 10% of Lean implementation initiatives have actually been successful. This success rate can be attributed to two factors—lack of awareness regarding Lean and restricting Lean implementation to tools and techniques. The need of the hour is to recognize that Lean Transformation is more of a methodological, systemic and cultural transformation that can be engendered through interventions at various levels. This was the main objective of the Fifth International Lean Construction Conference (ILCC) hosted by the National Institute of Construction, Management and Research (NICMAR) in collaboration with the Institution for Lean Construction Excellence (ILCE) at its Hyderabad campus from December 13 to 16, 2022.

The overarching theme of the conference was "Sustainable Lean Construction". While the workshop sessions were focussed on creating the digital and cultural awareness related to Lean Transformation, the invited national and international speakers and panellists engaged with the current trends, issues and possible solutions for Lean Implementation in the construction and infrastructure domains. The technical sessions provided a forum for discussing some cutting-edge Lean research initiatives in the construction domain. The delegates included owners, contractors, consultants, coaches and academics.

This book comprises some selected research papers from this conference dealing with several topics and research areas which will be beneficial to students, researchers and professionals working in the field of Lean Construction. These include

- Lean Culture and Behaviour
- Lean Health, Safety and Quality
- Leadership and Motivation for Lean Implementation
- Digital Technologies/BIM and Lean
- Automation and Industry 4.0 in Lean
- Lean Design Management
- Lean in Sustainable and Green Technologies
- Lean Supply Chain Management and Offsite Construction
- Lean in Public Sector
- Lean in Contract Management
- Lean Production Planning and Control
- Cost–Benefit/Return on Investment (RoI) of Lean Implementation
- Lean Readiness and Maturity
- Waste and Productivity
- Integrated Lean Project Delivery
- Lean in Modern Construction Techniques
- Teaching Lean and Way Forward.

I thank all authors, co-editors, reviewers, volunteers, faculty and staff of NICMAR Hyderabad, ILCE board members and our sponsors for their support and cooperation during this event. I would also like to thank the team at Springer Nature for publishing the conference proceedings.

Hyderabad, India

Dr. Anil Kashyap
Director General—NICMAR

Acknowledgments

This edition of ILCC 2022 with the theme "Sustainable Lean Construction" has achieved its aim of providing a common platform for the Lean enthusiasts from the Architecture, Engineering, Construction and Facility Management (AEC/FM) disciplines who came forward and discussed and shared their experience with Lean adoption and implementation of Lean techniques in construction projects. Such a strong interface between the industry and academia resulted in a lot of learning along with an overwhelming sense of gratitude. We, the conveners of ILCE 2022, take this opportunity to acknowledge all those who have wholeheartedly supported the successful completion of this mega event.

At the outset, we would like to express our deep gratitude to our Director General, Dr. Anil Kashyap, for motivating us to organize this prestigious conference to us. We are extremely grateful to him for his kind support, constant encouragement and guidance. We would also like to thank the ILCE Board of Directors for involving themselves in a committed manner and rendering their support in all aspects possible for the conference including arranging the major quantum of sponsorship.

We express our gratitude to Mr. Anup Mathew, Chairman and Director, of ILCE for his constant support and for arranging the gold sponsorship from M/s Godrej Constructions. We would also like to thank Mr. Sagar Gandhi, SPCL, for his valuable suggestions and for arranging platinum sponsorship from M/s Shapoorji Pallonji Engineering and Construction. We would also like to express our gratitude to Mr. Devarajan, URC; Mr. Harleen Oberoi, Tata Realty; and Mr. Giridhar Rajagopalan, Afcons, for their support and for arranging the silver sponsorships from URC Construction (co-sponsorship with M/s Tactive Solutions), Tata Realty and Afcons. Our sincere thanks to the bronze sponsors M/s Aparna, Hyderabad, and M/s vConstruct, Pune. Also, our special thanks go to co-sponsors M/s VisiLean, Ahmedabad, and M/s Bexel Manager.

Additionally, we would also like to thank Mr. Sankar Narayanan, L&T; Mr. Debashish Guha, Arcop; and M/s Puneet Narang for their suggestions and immense support. We would also like to acknowledge the support of all the directors with whom we had interacted during this edition of ILCC.

We owe special thanks to ILCE Directors and IIT Madras senior faculties, Prof. N. Raghavan and Prof. Koshy Varghese, for providing valuable guidance and support in identifying key speakers and domains and in structuring the conference. We would like to express our sincere thanks to the ILCE secretary general Mr. Kaezad Karanjawala and the ILCE technical secretary Dr. K. Marimuthu and their team members for their immense support from the beginning especially in making all the necessary arrangements and for making this event very successful.

Our special thanks go to our media partner M/s Construction World, Mumbai, and our publication partner M/s Springer Nature, Singapore. We acknowledge the contribution made by various authors from academia and industry which resulted in fresh thoughts for knowledge exchange and discussion during the conference. We are sincerely grateful to all the reviewers for their time and effort to align with the theme of the conference and improve the quality of the manuscripts.

Our sincere thanks to Lean workshop coaches Dr. Bhargav Dave, VisiLean; Mr. Prasad Sukumaranunni, Beebox; and Dr. V. Pramadha, NICMAR. We are grateful to our industry day speakers Prof. N. Raghavan, IIT Madras; Dr. Rustogi, ILMA; Mr. Sharique Khan, Turner; Mr. Jayadatta V. Lad, Afcons; Mr. Karun Raj Singh Sareen, KPMG; and Mr. Sabarinath C. Nair, SkillVeri. Our sincere thanks go to conference speakers Mr. Naveen Mittal IAS, Government of Telangana; Mr. Ramamoorthy Rajendran, DigitalBuild, Singapore; Col. Dr. Pawan Pandey, Indian Army; Ms. Durga Saripally, vConstruct Pune; Mr. C. Devarajan, URCL; Dr. Glenn Ballard, University of California Berkeley; and IIT Madras faculties Dr. Koshy Varghese and Dr. Ashwin Mahalingam. Our sincere thanks go to panel moderators Dr. Koshy Varghese, IIT Madras; Dr. Venkata Santosh Delhi, IIT Bombay; and Dr. P. Muralidhar, NICMAR. Our special thanks go to panel members Dr. Rustogi, ILMA; Dr. Barghav Dave, VisiLean; Mr. Kalyan Vaidyanathan, Bentley; Mr. Sabarinath C. Nair, SkillVeri; Mr. G. Suresh Kannan, URCL; Mr. Manish Mokal, Afcons; Dr. Deepak Bajaj, Amity; Dr. Shobha Ramalingam, NICMAR; Mr. Jayadatta V. Lad, Afcons; Ms. Ragavi Prabaharan, URCL; Mr. Yash Saraiya, Turner; Mr. Parijat Naha, TRI; and Prof. Rajasekar, NICMAR. The ILCE coordinators and SPOC members are the backbones of the event. Immense thanks to Mr. Jitendra, Ms. Diamond, Mr. Vinay and Mr. Pandiaraja, Godrej; Mr. Jayadatta and Mr. Manish, Afcons; Mr. Girish, Mr. Aritra and Mr. Parth, SPCL; Mr. Tapas and Mr. Parijat, TRIL; and Ms. Raghavi, Mr. Karthikeyan, Mr. Suresh Kannan URCL and Mr. Suresh Kamal, Umar Belal, L&T, who have extended all their support to the best possible. We appreciate the assistance provided by our NICMAR community organizing this event. Sincere appreciation is extended to Dr. Indrasen Singh, Dean (Academics), for facilitating academic arrangements and providing constant support and encouragement throughout the event. Dr. Seshadri Tirumalla merits our gratitude for coordinating the infrastructure and support facilities on campus. Dr. R. Sathish Kumar and Dr. V. Srihari, we appreciate your assistance in organizing and coordinating the students for the numerous events of the conference, as well as your support since the conference's inception. Dr. Mahesh Balasubramani, Dr. B. Ravinder and Dr. P. Muralidhar, thank you for being accommodating and scheduling the classes accordingly.

Dr. Savitha Chilakamarri and Professor Raja Sekhar Mamillapalli are deserving of our appreciation for sharing their expertise and contributing to the souvenir. Regarding Logistics, I would like to commend the web team, led by Dr. Kedar Phadke and comprised of Mr. Sandeep Daware and Mr. Amit U. Bartakke, who gave the event a wonderful start and supported us throughout the proceedings. Dr. Amit Hedau and Prof. Saurabh Jindal deserve special recognition for their efforts to decorate and illumine the campus.

We are indebted to the technical committee, led by Dr. Mahesh Balasubramani and comprising of Dr. Vinay Agrawal, Prof. K. V. Prasad, Prof. Vijeyata Malla and Prof. Prashant Kumar Sreram, for coordinating the reviewing and categorization of papers and posters into various themes for scheduling the presentations. We thank Dr. Subash Rastogi, Dr. V. Aneetha, Dr. Mahesh Gangadhar, Dr. Abhay Tawalare, Dr. Deepak Bajaj, Dr. Ganesh Devkar, Dr. Shobha Ramalingam, Dr. Nilesh Patil and Prof. K. Ravindranath Chowdary.

This event would not have been possible without the immense and unwavering support of our faculty colleagues who worked assiduously to ensure its resounding success. We thank Dr. R. Sathish Kumar, Dr. Hanumanth Rao, Dr. Sinha Ajay Kumar, Prof. Shyam Kumar Inturi and Prof. Onkar Chothe for coordinating the Logistics and VIP & Guest Management; Dr. Kedar Phadke and Dr. D'Souza Lyseth for coordinating the activities related to hospitality and food; and Dr. P. Ammani and Dr. Savitha Chilakamarri for coordinating the speaker arrangements, proceedings and cultural events in the auditorium. We also appreciate the efforts of Dr. Pramadha, Prof. K. Ravindranath and Dr. Vinay for coordinating the events at various venues in coordination with the technical team.

We are grateful to Dr. V. Sri Hari, Dr. Lyseth D. Souza, Dr. P. Vimlesh and Dr. P. Ammani for coordinating the Delegate Reception and Registration and Prof. Mamillapalli Raja Sekhar and Dr. Muralidhar P. for coordinating the procurement and arrangement of the conference kit. Prof. Onkar Chothe merits special recognition for designing the conference's posters and other promotional materials.

We take this opportunity to appreciate the efforts of our support teams including the IT team: Mr. P. Sivakumar, Mr. S. Praveen Kumar and Mr. P. Sridhar; the administrative and accounts team: Mr. S. Subrahmanyam, Mr. V. Giri Prasad, Ms. Haritha Davuluri, Mr. Shaik Sammad, Mr. M. Suresh Babu and others; Mr. Amol in the DG's office; and Ms. Savita Alandkar for their support in organizing this conference. We would also acknowledge our support staff, operators, drivers, technical staff, housekeeping and security personnel who toiled day and night to make this event even more successful and are greatly appreciated.

The mentorship of Dr. Vikrant Yadav, the student coordinator who coordinated the student volunteers for various technical and cultural activities, deserves special appreciation. We appreciate the team efforts of the students led by Mr. Adith, Ms. Abhirami, Mr. Digen, Ms. Farha, Mr. Viraj, Mr. Debaditya, Mr. Hirosh, Mr. Venu, Mr. Sumanth, Mr. Md. Zain, Ms. Afreen, Mr. Anuranjan Dung Dun, Ms. Rupali and Ms. Alisha for their support in organizing the event and making it a wonderful success.

We hope that all the participants in ILCC 2022 had a joyful and fruitful learning experience in this one-of-its-kind industry–academia conclave.

Hyderabad, India

Dr. Venkatesan Renganaidu
Dr. Arun Chandramohan
Editors and Conveners—ILCC 2022

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About the Editors

Dr. Anil Kashyap is the first President and Chancellor of NICMAR University Pune and Hyderabad. He has 30 years of experience in practice, academia and research—both in India and abroad. In his leadership roles, Dr. Kashyap has been Head of UWE Bristol School of Geography and Environmental Management, Deputy Head of Coventry University School of Energy, Environment and Construction, and Founding Professor and Director of RICS School of Real Estate before joining NICMAR as the Director General in September 2021.

His expertise includes Infrastructure Development and Finance, Urban Regeneration, and Real Estate Research. Dr. Kashyap holds a bachelor's degree in Civil Engineering with distinction from NIT Kurukshetra, master's in Urban Planning from the School of Planning & Architecture, New Delhi, and a Ph.D. from the University of Ulster, UK. Dr. Kashyap is Alumnus of Harvard University with training in Higher Education Leadership and Change Management. He is Fellow of the Higher Education Academy of the UK.

Prof. N. Raghavan is currently Professor of Practice, BTCM division, Department of Civil Engineering, Indian Institute of Technology Madras, Director at Institute for Lean Construction Excellence (ILCE), Independent Director at Vadodara-Bharuch Toll Roads Ltd., Panipat Elevated Corridor Ltd., L&T Transportation Infrastructure Ltd., and Member. He obtained a Bachelor of Technology (Civil Engineering) from the Indian Institute of Technology Madras in 1970 and a Master of Technology (Structural Engineering) from the Indian Institute of Technology Bombay in 1976. Professor Raghavan is Elected Fellow of the prestigious INAE (INAE has only 860 Fellows in the country across all disciplines covering academic, industry, and R&D), Fellow of ICE(UK), IofE(I); prestigious SB Joshi Award for Excellence in Structures & Bridges, Chairman of Research Council of CSIR-Central Building Research Institute, Best Overseas Article Award from ICE (UK), Member of International Steering Committee for Lean Construction in Public Sector (LIPS). As Member of the Top Management of L&T ECC Construction Division at retirement, Prof. Raghavan set up and managed as its Chief Executive L&T—Ramboll Consulting Engineers Ltd.; Engagement with different facets of the profession with passion

(Engineering, Consultancy, Construction, Project Management, Academic). He has a patent for a new method of excavation, the patent for precast segmental foundations (being applied). Professor Raghavan published more than 200 international journals and conference papers and six technical books and book chapters and guided 18 M.Tech. project students of IIT Madras.

Dr. Indrasen Singh has over 35 years of experience in teaching, research, administration, strategic planning, institutional reforms, accreditation, and consultancy work. He has been responsible for traffic and transportation departments at ICT (P) Limited, Green Park New Delhi, NICMAR Delhi, and NICMAR Goa Campus. He was the founder Professor and Dean of NICMAR Goa Campus and developed the M.Tech. Programme in structural engineering, transportation engineering, and environmental engineering in civil engineering at Lovely Professional University, Punjab. Dr. Singh has received 41 awards and has published 173 scientific technical papers in various national, international journals and conferences, and has worked on 45 major highway and transportation projects. He has guided one Ph.D. thesis, two M.S. theses, nine M.Tech. theses, and 187 PG theses.

Dr. Singh has taught 18 subjects and developed 13 at the PG level. He has experience in academics and industry, as well as expertise in World Bank/ADB-funded projects. His many research papers are listed on the Transportation Research Board, USA for reference. He is a Fellow of the Institution of Engineers (India) and a life member of the Indian Roads Congress, Indian Buildings Congress, and Institute of Urban Transport. Dr. Singh has leadership qualities and has led the overall management and administration of NICMAR University, Hyderabad, with a vision to develop the university into a Centre of Excellence.

Dr. Venkatesan Renganaidu is currently Professor and Director of IQAC at the National Institute of Construction Management and Research, Hyderabad. He has been awarded a Ph.D. from the Department of Civil Engineering, IIT Madras, in the area of Construction Management, then pursued his master's in Business Administration with a specialization in Human Resources & System Management from Madurai Kamarajar University, Madurai, and B.E. (Civil) from Maharaja Sayajirao University, Vadodara. Dr. Venkatesan has been associated with the Central Public Works Department (CPWD) in numerous capacities for two decades and took a Voluntary Retirement (VRS), while he was serving as Executive Engineer, later he headed the Management Development Center (MDC) of Consolidated Construction Consortium Ltd. (CCCL), Chennai, and also served as Director in Engineering Project Management Consultancy and Research (EPMCR), an incubated company of IIT Madras. Dr. Venkatesan Renganaidu obtained the "Research Excellence Award" from the National Institute of Construction Management and Research, Pune, Maharashtra, India. He had published ten international peer-reviewed journal papers and two national journal papers and also presented nine international conference papers and three national conference papers. He is also Member board of studies at Vellore Institute of Technology (VIT) Vellore and Chennai.

Dr. Arun Chandramohan, Professor and Dean (Research) and the School of Business Management at NICMAR Hyderabad, is one of the experts in Construction Materials, Construction Scheduling and Risk Assessment, Sustainable construction techniques, and Lean Construction.

Dr. Arun graduated in Civil Engineering from Calicut Regional Engineering College, Kerala (Presently NIT Calicut) in the year 1999. He did his master's in Construction Engineering and Management in 2001 and Ph.D. in the area of Construction Management in the year 2004 from the College of Engineering, Guindy, Chennai.

Construction of 80 m Steel Open Web Girder Over Gaddigodam Railway Span in Nagpur—A Lean Approach

Sarbajit Roy Choudhury, Pradeep Kumar, and Roshan Lal

Abstract The Nagpur Metro Reach-2 viaduct project is a unique project from many aspects. The project team overcame all kind of challenges including the global pandemic COVID-19 and was truly focused to achieve the given target. The project team used various innovative techniques, did detailed planning, adopted time saving approaches by adopting Lean approaches and team work to achieve the stiff target of completion of 3 months for the erection of 80 m open web girder over the railway tracks. The safety and quality parameters were given highest priority during the process of superstructure erection. Unique challenges and working on new methodology and continual guidance from specialists motivated the team to accomplish the job. Apart from presence of railway tracks and OHE lines, launching methodology and time constraint, transportation of oversized and heavy components of truss was one of the problems which was mitigated by prior checking of route by dry run of ODC trailer. The 80 m steel span launching included assembly of members over temporary structures in three parts, pulling of assembled part over railway tracks and assembly of balance members over temporary structures. Part 1 and Part 2 of the structure were assembled over temporary supports in parallel, thereby reducing the waiting time for successor activities. The project team analysed the total workflow and the cycle time in order to remove the waste to achieve the minimum time required for superstructure erection. The findings in this paper demonstrate that through effective application of Lean methods waste can be removed from the workflow and stiff completion targets can be achieved.

Keywords Workflow · Process · Waiting time · Waste · Parallel activity

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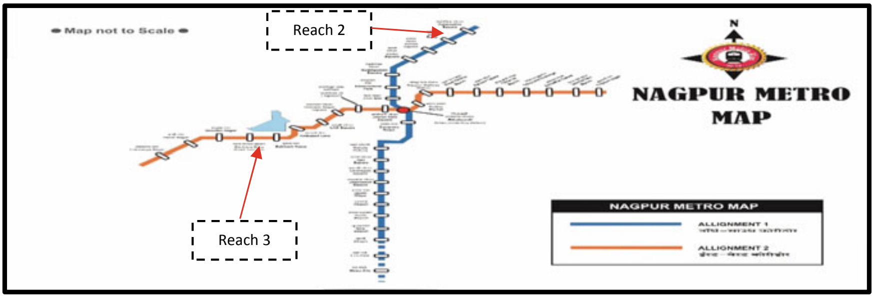


Fig. 1 Route map of Nagpur metro

1 Definition of Waste

In Lean thinking waste involves many kinds of waste, including the waste of excessive human motion, over production, etc., and to make the process more that reduces cost and improves overall revenue. Under the Lean system, seven wastes are identified: overproduction, inventory, motion, defects, over-processing, waiting, and transport.

2 Introduction

Nagpur Metro Phase-1 consists of two corridors North–South and East–West with a total length of 41.7 km out of which 17.087 km, i.e. 41% of the viaduct was awarded to AFCONS in Reach-2 (North–South corridor) and Reach-3 (East–West corridor) stretches. AFCONS has executed more than 51% of the value of civil structure for Nagpur Metro Project. AFCONS has executed Reach-2 package in North–South corridor which consists of India's longest 5 km double decker structure for metro viaduct and 1.7 km metro viaduct structure which starts from Automotive Square on Kamptee Road and ends at Sitabuldi (Fig. 1). AFCONS had also executed 11 spans and 4 elevated stations in Reach-1 of Nagpur Metro Project.

3 Project Details

Nagpur Metro Phase-1 consists of two corridors North–South and East–West with a total length of 41.7 km out of which 17.087 km, i.e. 41% of the viaduct was awarded to AFCONS in Reach-2 (North–South corridor) and Reach-3 (East–West corridor) stretches. AFCONS has executed more than 51% of the value of civil structure for Nagpur Metro Project. AFCONS has executed Reach-2 package in North–South corridor which consists of India's longest 5 km double decker structure for metro viaduct and 1.7 km metro viaduct structure which starts from Automotive Square on

Kamptee Road and ends at Sitabuldi (Fig. 1). AFCONS had also executed 11 spans and 4 elevated stations in Reach 1 of Nagpur Metro Project.

In order to commission the metro viaduct structure by mid of April 2022, the client gave a 3 months target on 18 December 2021 after discussion between MD Maha Metro and EVC of AFCONS to complete the 80 m railway span open web girder by 17 March 2022 in order to facilitate the opening of the full Reach-2 metro stretch. As per the approved baseline program, the total construction duration of the 80 m railway span was approx. 7.5 months.

4 Challenges and Methodology

The 80 m railway span (Fig. 2) is located at the most congested area of the alignment where access to the site for equipment movement and material storage is quite next to impossible. The stretch is also part on the major connectivity route between rural and urban location of Nagpur due to which very high traffic volume is present along the stretch. At the crossing, 150 number of railway movement per day, i.e. roughly more than average 6 trips per hour with peak railway movement of 8 trips per hour, is scheduled.

Due to the presence of railway track, any works carried out within the railway boundary would require permission from the railway authorities. The establishments/ shops, workshops along the work location led to very limited options for erection of the OWG. Different erection/launching schemes were explored—Full span launching with nose from either side of the railway tracks, incremental launching, etc. However, all these launching methods did not fructify due to non-availability of land and presence of utilities—large diameter water lines at the proposed temporary foundation

Fig. 2 80 m railway span open web girder general arrangement

locations. The difficult part of the substructure construction was to build the 4 temporary supports on the railway embankment. The constraints were evolving one after the other and at a point of time during the planning stage it looked like the construction works will be seriously jeopardized [1].

The project team proposed the part erection and part launching scheme—a hybrid model which have never been tried for any steel structure crossing over the railway tracks of the Indian Railways. The hybrid model of launching the 80 m truss (Figs. 3, 4, 5 and 6) was planned to be done in 3 parts, namely

Part 1—20 m—2 panels stationary at one end (Weight—387.5 MT).
Part 2—30 m—3 panels erected and pulled to connect with Part 1 (Weight—581.25 MT).
Part 3—30 m—3 panels erected behind the Part 2 in continuation after completion of Part 2 launching (Weight—581.25 MT).

In total approx. 80,000 nos. of HSFG bolts (M24 10.9 grade) were used for the assembling of the structure and 28 nos. of torqueing machines including 5 nos. electronic high-speed torque machines brought from other site was used for the torqueing purposes. In order to expedite the design works of the temporary structure, local

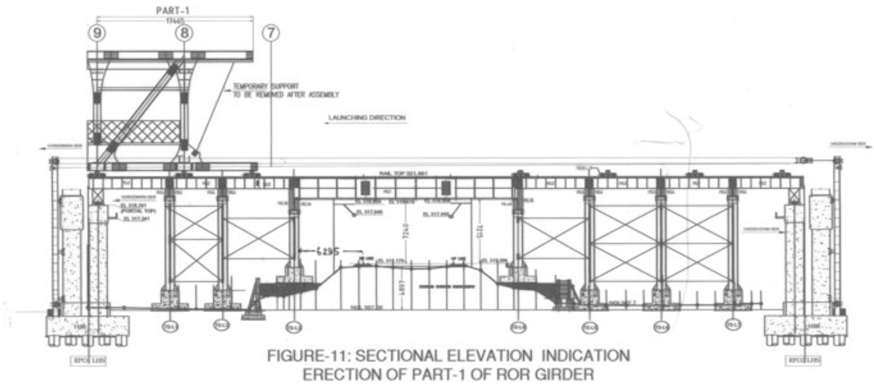
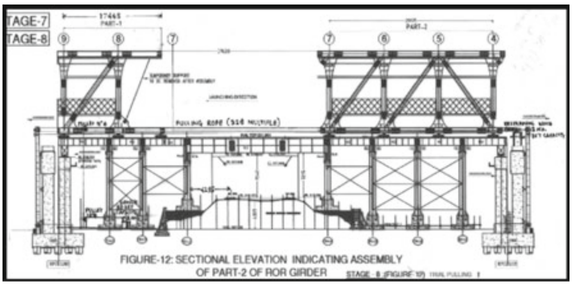


Fig. 3 Erection of PART-1

Fig. 4 Erection of PART-2



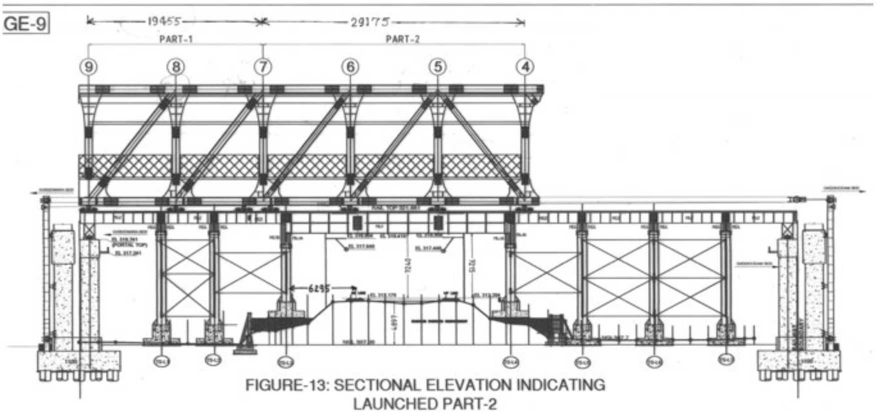
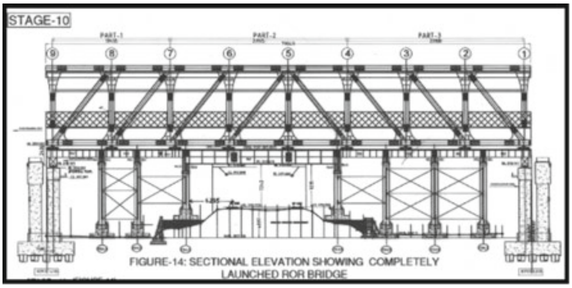


Fig. 5 Pulling of PART-2

Fig. 6 Assembly of balance parts



designer from Nagpur was appointed as per client request. Also, as per client request additional third-party reviewer for the temporary works design was appointed.

The review by client appointed DDC was started in October 2022 and completed in 24 December 2022. Additional fabrication works of 150 tons were carried out to meet the DDC requirements (additional bracings in track girders, round stiffeners in liners, etc.). The project team deployed total 32 nos. of welders (16 nos. in each shift) to complete the additional works of strengthening works of the temporary structure. The project team identified different activities which were to be carried out during the day and night shift to reduce the duration of the works [2] by doing parallel activities and reduce the waiting time (Table 1).

The project team did detail planning to identify and remove nonvalue adding activities and making activities in parallel in order to reduce the time cycle. Figure 7 shows the areas where improvements (Fig. 7) were made to achieve the schedule completion date.

The project team also gave immense importance to avoid any defects during the fabrication and erection of the structural steel members like proper alignment during member erection, thorough checking during the full trial assembly, checking the

Table 1 Day and night time activities for railway span

	Day time activities		Night time activities
a	Structural members erection	a	Structural members erection
b	Members assembly	b	Members assembly
c	Bolting and torqueing	c	Bolting and torqueing
d	Sand blasting and painting at fabrication yard	d	Sand blasting and painting at fabrication yard
		e	Members transport to site from fabrication yard
		f	Crane shifting

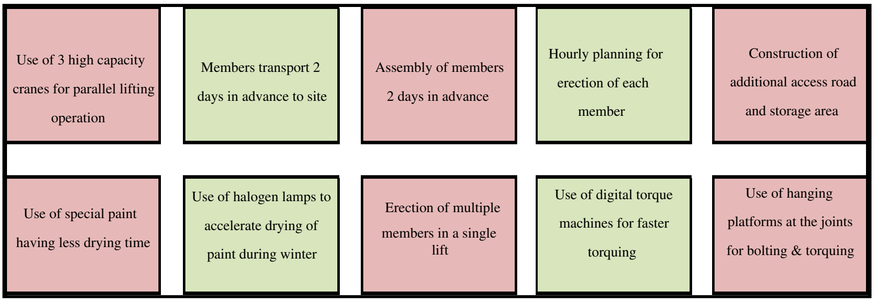


Fig. 7 Areas of improvement

bolting and torqueing of each joint from the very beginning, continuous monitoring of the whole structure during the erection for orientation and levels of the structure.

5 Use of 3 Nos. of High-Capacity Cranes for Parallel Lifting Operation

Constraint: At the initial stage of the planning, the erection of the members at railway span for members erection was planned with two numbers of high-capacity cranes. However, in order to achieve the stiff completion target given by client and to do more numbers of parallel members erection, the project team decided to remove waiting time from the process.

Lean Method: In order to avoid waiting time, the project team decided to use an additional one number of high-capacity crane. This helped to increase the number of parallel lifts per day and meet the target date of erection completion (Fig. 8).

Fig. 8 Use of 3 nos. of cranes for parallel erection of members

6 Members Transport 2 Days in Advance to Site

Constraint: The fabrication of the steel structure was carried out at Nagpur. The fabrication yard was located approx. 35 kms from the erection site. As multiple cranes were deployed for erection purposes, so it was the highest priority for the project team to feed the members to all the cranes in a timely manner and to eliminate the waiting time between the two successive lifts.

Lean Method: The delay in the transportation of the structural members was avoided by transporting the members to site 2 days in advance in order to ensure that cranes do not become idle at any point of time. To ensure smooth transport of trailers, the project team deployed 6 nos. of retired police officers with pilot cars to escort the trailers from the fabrication yard to the site.

The transport of members by trailers were planned in advance, and type of trailers to be used (Normal, ODC) were identified in advance a list of trailers (refer Table 2) for structural member transportation was prepared and used for monitoring purposes.

7 Assembly of Members 2 Days in Advance

Constraint: Waiting for assembled structural steel members for lifting.

Lean Method: The project team ensured that the assembly of the members on ground is completed well in advance, so that there is no waiting time for the cranes during the lifting operation. The project team ensured that the bolting and torqueing is completed on time and checking by client is also completed well in advance. By

Table 2 Member-wise erection program with trailer details

Sl. No.	Member description	Bolt	Mark number	Unit weight (Kg's)	Erection part number	Quantity (Nos.)	Weight (Kg's)	Grid #
PART # 1—Part 2								
1	FLY OVER STRINGER BEAM—FSB1/3	48	9—7 FSB 1/3	1928.75	1	1	1928.75	9 to 7
2	FLY OVER STRINGER BEAM—FSB1/4	48	9—7 FSB 1/4	1928.76	1	1	1928.76	9 to 7
3	FLY OVER STRINGER BEAM—FSB1/5	48	9—7 FSB 1/5	1928.66	1	1	1928.66	9 to 7
4	FLY OVER STRINGER BEAM—FSB1/32	48	9—7 FSB 1/32	1928.66	1	1	1928.66	9 to 7
5	FLY OVER STRINGER BEAM—FSB1/32	48	9—7 FSB 1/32	1928.66	1	1	1928.66	9 to 7
6	FLY OVER STRINGER BEAM—FSB1/32	48	9—7 FSB 1/32	1928.66	1	1	1928.66	9 to 7
7	FLY OVER CROSS DIAPHRAGM FCD/1	74	9—7 FCD 1	401.94	1	1	401.94	9 to 7
8	FLY OVER CROSS DIAPHRAGM FCD/2	74	9—7 FCD 2	401.94	1	1	401.94	9 to 7
9	FLY OVER CROSS DIAPHRAGM FCD/3	74	9—7 FCD 3	399.97	1	1	399.97	9 to 7
10	FLY OVER CROSS DIAPHRAGM FCD/4	74	9—7 FCD 4	401.94	1	1	401.94	9 to 7
11	FLY OVER CROSS DIAPHRAGM FCD/5	74	9—7 FCD 5	401.94	1	1	401.94	9 to 7
12	BOTTOM BRACING BB1/1	40	9—7 BB 1/1	572.49	1	1	572.49	9 to 7

(continued)

Table 2 (continued)

Sl. No	Member description	04.01.2022											
		Day shift						Night shift					
		No of bolts		Duration (Hrs.)	Weight	Trailer type	No. of trailers	No of bolts		Duration (Hrs.)	Weight	Trailer type	No. of trailers
		Required for permanent joint	For crane release					Required for permanent joint	For crane release				
PART # 1—Part 2													
1	FLY OVER STRINGER BEAM—FSB1/3	48	24	2	1928.75	Normal	1						
2	FLY OVER STRINGER BEAM—FSB1/4	48	24	2	1928.76	Normal	1						
3	FLY OVER STRINGER BEAM—FSB1/5	48	24	2	1928.66	Normal	1						
4	FLY OVER STRINGER BEAM—FSB1/32	48	24	2	1928.66	Normal	1						
5	FLY OVER STRINGER BEAM—FSB1/32	48	24	2	1928.66	Normal	1						
6	FLY OVER STRINGER BEAM—FSB1/32	48	24	1	1928.66	Normal	1						

(continued)

Table 2 (continued)

Sl. No	Member description	04.01.2022											
		Day shift						Night shift					
		No of bolts		Duration (Hrs.)	Weight	Trailer type	No. of trailers	No of bolts		Duration (Hrs.)	Weight	Trailer type	No. of trailers
		Required for permanent joint	For crane release					Required for permanent joint	For crane release				
7	FLY OVER CROSS DIAPHRAGM FCD/1							74	37	2	401.94	Normal	1
8	FLY OVER CROSS DIAPHRAGM FCD/2							74	37	2	401.94	Normal	
9	FLY OVER CROSS DIAPHRAGM FCD/3							74	37	2	399.97	Normal	
10	FLY OVER CROSS DIAPHRAGM FCD/4							74	37	2	401.94	Normal	
11	FLY OVER CROSS DIAPHRAGM FCD/5							74	37	2	401.94	Normal	1
12	BOTTOM BRACING BB1/1							40	20	1	572.49	Normal	

adopting this method, the project team ensured that there are no defects in assembly of members and torqueing of bolts. This approach helped the site team to achieve faster work progress with minimum time wastage.

8 Hourly Planning for the Erection of Each Member

Constraint: Delay in structural steel members erection.

Lean Method: The project team did the detail planning for each member erection for Part 1, Part 2 and Part 3 members. The detailing was done by the team for each shift (day and night) in order to control the erection time of each crane and monitor any deviation from the planned duration. The shift-wise lifting program including the number of bolts required in each joint (refer Table 2) for crane releasing before erection of next member helped the project team to reduce the time cycle of each lift. All the required bolts and nuts for each individual joint were kept ready in advance to avoid any wastage of time and avoiding use of wrong bolts and replacement of the same at a later stage.

9 Construction of Additional Access Road and Storage Area

Constraint: To avoid delay in transportation and shortage of storage area.

Lean Method: The project team developed additional access road and storage area near to the erection site to store and assemble structural members two days in advance. The temporary area and road development along the railway tracks were completed within 3 days (total volume approx. 11,000 m^3) after taking permission from the railway authorities. The creation of additional access road and storage area (Fig. 9) helped the project team to avoid any delays and idling of cranes.

The additional storage area also helped for materials stacking for deck slab construction in advance as deck slab construction was completed immediately after truss lowering operation was completed.

10 Use of Special Paint Having Less Drying Time

Constraint: To reduce waiting time during the painting of the members.

Fig. 9 Additional storage and assembly area

Lean Method: As the delivery of the members on time was the most important activity for erection purpose, the project team gave special attention for blasting and painting operation. The project team identified that the drying time of the zinc chrome primer initially used is 16 h for one coat of paint. In order to reduce the drying time of the zinc chrome primer which used to take 16 h for one coat, the project team used special zinc chrome primer from ASIAN Paints which had a drying time of 8 h only. This helped to reduce the painting time by 50 percent and timely delivery of members at site.

11 Use of Halogen Lamps to Accelerate Drying of Paint During Winter

Constraint: To reduce waiting time during the drying of the paint of the members.

Lean Method: The blasting and painting of the structural members were carried out round the clock. Due to the winter season, the atmospheric temperature was used to be less and drying of paint used to take longer duration. In order to avoid longer drying time of each coat of paint, the project team installed halogen lamps to provide heat generated from the lamps to avoid delays due to delay in paint drying. This approach by the project team helped in the timely completion of the painting of the structural members and delivery of the members as per erection sequence at site.

Fig. 10 Erection of multiple members in single lift by 500-ton crane with super lift

12 Erection of Multiple Members in a Single Lift

Constraint: Reduction of erection time of the members.

Lean Method: Assembly of multiple members were carried out at site to reduce erection time. Special software from Chenab bridge project was used to determine the lifting points of multiple assembled members (Fig. 10). High-capacity crane of 500-ton capacity with super lift facility was used to lift the heavy members. Safe access was provided for pedestrians, public announcing system used for better communication, cordoning off the site location during pulling and erection operations and issue of special ID cards for working force only were the other initiatives taken by the project team to expedite the works.

13 Use of Digital Torque Machines for Faster Torqueing

Constraint: Reduction of time for the torqueing of the HSFG bolts.

Lean Method: In total approx. 80,000 numbers of HSFG bolts (M24 10.9 grade) were required for the whole structure. The project team used 28 nos. of torqueing machines—hydraulic type, electrical impactor type and 5 nos. electronic high-speed torque machines brought from other site was used for the torqueing purposes. The use of high-speed electronic torque machines helped in reducing the torqueing time of each joint and also helped in early release of the crane for the subsequent lifting operations.

Fig. 11 Typical hanging platform

14 Use of Hanging Platforms at the Joints for Bolting and Torqueing

Constraint: Reduction of time for the torqueing of the HSFG bolts.

Lean Method: During the erection of the members, only 50% of the required bolts were inserted for securing the members, and the rest of the bolts were inserted and torqued at a later stage. As the joints of the members were at considerable height and multiple joints had to be bolted and torqued at the same time, the project team fabricated customized hanging platforms (Figs. 11 and 12) as there was not enough space to deploy multiple man lifts. The hanging platforms were extremely helpful in expedite the final torqueing of the joints as multiple gangs were deployed round the clock, and there was no waiting time for man lift or any breakdown issue in case of use of man lifts.

15 Construction of Portal Beams for Approach Spans

Metro level portals of approach spans to connect metro rail with upper level of OWG were to construct amid erection of Railway span. Portal beam consisted of 40 T of reinforcement steel and 190 cum of M60 grade concrete at a height of 24 m above ground level. Placing cribs and ISMB 600 sections in narrow space was a difficult and time-consuming task. In order to achieve the targets, supporting arrangement with cribs were changed to cup-lock system. Steel shutters were replaced with wooden shutters. Construction of metro-level portal of adjacent span was completed

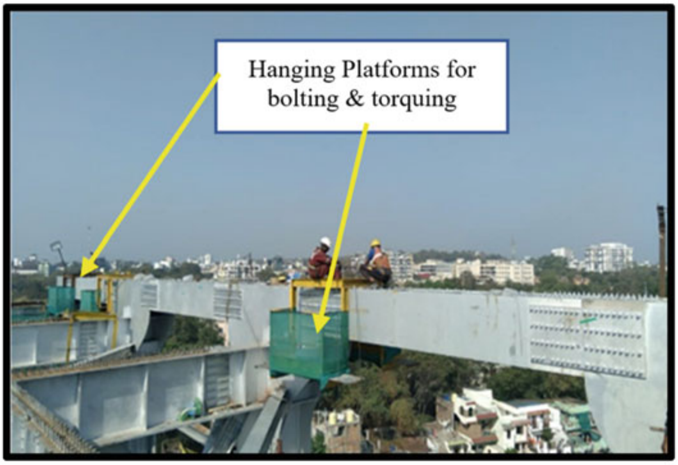


Fig. 12 Hanging platforms

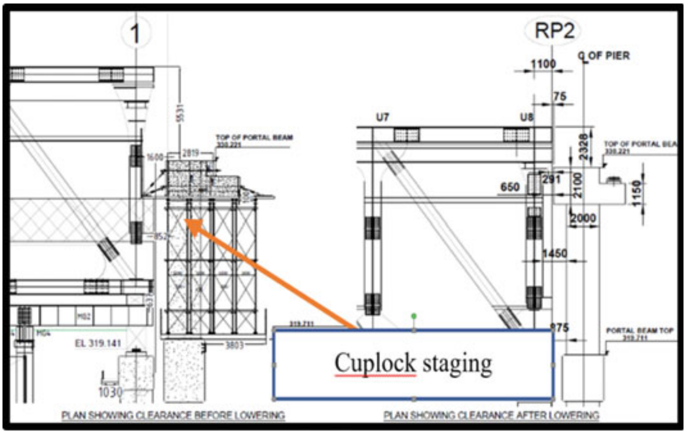


Fig. 13 Portal staging sketch

in a record time of 12 days. The middle reinforcement cage was fabricated on the nearby ground while staging, and shuttering arrangement was carried out parallel. The middle cage was shifted to the portal location with trailer and was erected using crane (Figs. 13, 14, 15 and 16).

Comparison of time cycles of portal beam for planned duration Vs actual duration with Lean approach are shown in Table 3.

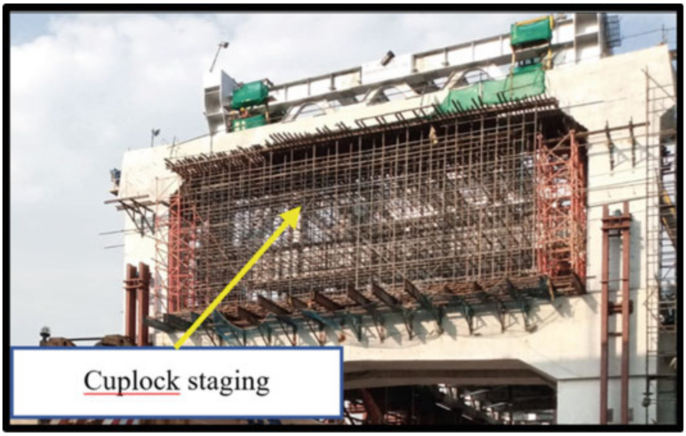


Fig. 14 Cuplock staging—at site

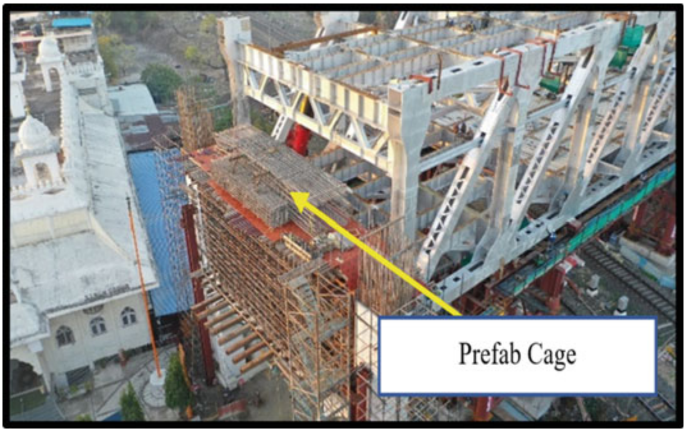


Fig. 15 Prefabricated cage for portal

16 Summary

The double decker open web girder over Gaddigodam Railway crossing was completed in stiff targets of 3 months against planned duration of 8 months. Assembly of OWG was completed over temporary structures in 3 parts including 1 part pulling which is a unique approach in girder launching. Second level Metro portal spanning 24 m in length and which is very near to the OWG was also constructed during erection works in record time of 12 days.

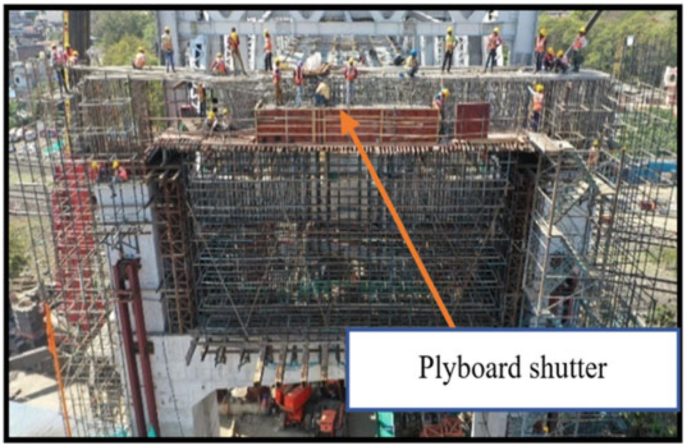


Fig. 16 Plywood shutter for formwork

17 Limitations

Area: The surrounding area was full of establishments such as Gurudwara, school, hospital, garages, and various shops. Working area for crane placement, trailer movement and other construction equipment's movement was limited.

Power and Traffic Block: To work over railway tracks, certain power and traffic blocks were required. The blocks were given according to the railways time table of trains movement.

Time Duration: The construction work of railway span was to complete in a limited duration of 3 months.

Table 3 Comparison of time cycles of portal beam

Construction of metro level portal at railway span						
Planned duration			Actual duration with lean approach			
Sr. No.	Description of activity	Planned duration (days)	Description of activity	Actual duration (days)	Parallel activity (Days)	Remarks
1	Support girders (ISMB 250) and ISMC 100 over 1st level portal	3	Support girders (ISMB 250) and ISMC 100 over 1st level portal	3		
2	Cribs fixing in mid portion	3	Staging using cup-lock system	2		
3	Placing and fixing ISMB 600/ 500 over vertical supports	2	Placing and fixing ISMB 250 over staging arrangement and ISMC 100 as cross members	1		
4	Fixing of cross girders	1	–	0		
5	Placing of bottom MS shutters and alignment	2	Placing of bottom wooden shutters and alignment	1		
6	Temporary arrangement fixing for reinforcement fixing	1	–	0		
7	Fixing of reinforcement steel of portal beam	7	Fixing of portal middle reinforcement cage on ground	0	4	Parallel activity
8	–	0	Placing of prefab reinf. cage over bottom shutters and balance reinf. fixing works	2		
9	Fixing of MS side shutters	5	Fixing of wooden side shutters	2	3	Parallel activity
10	Concrete	1	Concrete	1		
	Total duration (days)	25	Total duration (days)	12		

18 Conclusion

The construction of the 80 m railway span involved many challenges. The project team adopted various Lean methods and was able to reduce the construction time by approx. 60%. Table 4 gives the comparative analysis of initial time duration and actual time duration after application of Lean methods:

The Nagpur Metro Reach-2 team was able to reduce construction time by application of Lean methods which was necessary to achieve the project completion requirements.

From this paper, it can be concluded that successful implementation of Lean methods can lead to reduction of wastage and construction time, better workflow and achieve very tight construction durations. Similar attempts can be made in ongoing and future projects which will be helpful in achieving better productivity and timely completion of projects.

Table 4 Comparison of time duration

Erection of 80 m railway span					
Planned duration			Actual duration with lean approach		
Sr. No.	Description of activity	Planned duration (days)	Description of activity	Actual duration (days)	Parallel activity (Days)
1	Lifting arrangements for railway span Phase-1	30	Member erection for PART—B	47	
2	Lifting arrangements for railway span Phase-2	30	Member erection for PART—A	0	25
3	Transportation and lifting of fabricated elements	45	Pulling of PART—B and connecting with Part—A	1	
4	Temporary support arrangements	28	Member erection for PART—C and balance erection of Part-A	19	
5	Assembly of railway span at site Phase-1	45	Dismantling of temporary structures	8	
6	Assembly of railway span at site Phase-2	45	Lowering of truss	5	
7	Deck slab construction—NHAI and metro level	15	Deck slab construction—NHAI and metro level	7	
	Total duration (days)	238	Total duration (days)	87	

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Investigation of Work-Related Musculoskeletal Disorders Among Rebar Workers in South India

P. S. Kothai, D. Ambika, G. S. Rampradheep, and K. Preethi

Abstract This study is aimed to identify the prevalence of work-related musculoskeletal disorders in construction industry. The data collection is carried by Nordic musculoskeletal questionnaire and direct observations. The survey is conducted for 113 rebar workers in various construction site of Virudhunagar district in India. The mean average of age and work experience of workers are 30.51 ± 8.09 and 7.74, respectively. From the statistical analysis, it is found that 43.4% of participants were exposed to MSDs in the past 12 months. The lower back (70.8%), knee (60.2%), shoulder (49.6%), wrist (48.7%) and ankle/foot (36.3%) are found to be have higher prevalence of pain. The workers in the age group ≥ 41 years (65.9%) and workers with experience > 10 years (68.3%) were suffering from high risk of MSDs. The male rebar workers participated in the study were found to be exposed to MSDs, environmental and ergonomic hazards.

Keywords Ergonomics · Work-related musculoskeletal disorders · Rebar workers · Lower back pain

1 Introduction

Construction industry is one of the largest industries that involves intense manual labour and machineries. The construction industry which comes under the secondary sector of economy has contributed about 7.16% of total economy in GDP of India. The construction industry prompt to more accidents than other industries, some of them are fall from height, machinery accidents, slips and falls and exposure to

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dangerous chemicals and fire incidents. These are some of the unexpected and immediate responses that may occur when the safety regulation fails in an environment. In addition, with these the gradual effect on the worker that may affect the protectivity and health of the worker is due to repetitive stress injuries; it is called as work-related musculoskeletal disorder (WMSD). The musculoskeletal disorder (MSDs) is one of the unanticipated injuries in construction because the consequences will be determined only at the later stage. These disorders are caused due to repetitive motion of a particular task, awkward posture and excessive force while performing lifting and lowering activities. The MSDs are a huge burden to the society in terms of both direct (healthcare system) and indirect costs (loss of work and productivity). In United States, the MSDs among construction workers contribute about wage loss of 46 million. These injuries are more prone to emerging and developing countries like India, China, United Arab Emirates and Singapore since the level of industrial growth is increasing year by year. Among these India is more prevalent to musculoskeletal disorders due to the lack of knowledge about the aspect of injuries related to musculoskeletal disorders, and the work is still performed manually. To access the musculoskeletal disorders, there are many numbers of risk assessments methods are available to determine the contributing factors. The root cause of development of musculoskeletal disorders includes various risk factors such as personal characteristics, social, phycological and health-related factors. Based on the problem stated a Nordic musculoskeletal questionnaires survey was conducted to evaluate the discomforts faced by bar bending workers in construction industry. The survey focuses on the study of sociodemographic profile, health- and work-related that contributes to the disorders. Globally the prevalence of musculoskeletal disorder ranges from 14 to 42%, and the construction accounts for over 77% of work-related injuries and illness. Only a fewer number of studies are carried out in India relating to the psychological, social and health factors affecting the bar bending workers. Based on the context of the stated problem, the research focuses on the factors that affect the health condition of construction workers particularly bar bending workers in south India.

2 Subjects and Materials

2.1 Workplace

The study was conducted among male bar bending workers from various construction sites in Virudhunagar district which is a southern part of the state of Tamil Nadu, India. Observations were carried out during the study period regarding the risk factors and working environment. The workplace encompasses various equipment and machineries like saw machine, bar bending machine and other components associated with it.

2.2 Participants

The study is initially aimed to investigate the MSDs of more than 200 rebar workers. Later the study is limited to a strength of 113 male rebar workers in age groups from 19 to 52. The study is in line with analysis carried out by Drisya [1] with limited rebar workers. The present study group consists of shuttering workers (43.4%), bar benders and tying workers (46.9%) and machine cutters (9.7%). All the participants were full-time workers performing bar bending, shuttering works for at least 8 h/day. The foreman was excluded from this study since they do not have physical workload.

2.3 Pilot Survey

Questionnaire were framed based on the pilot survey conducted with minimum number of questions, well understandable for the layman working at the construction site. Initially to carry out the questionnaire survey, few simple questions portraying the real difficulty of bar benders have been formed and questioned them in site directly. Based on the response, they gave further questionnaire was designed to focus on all type of workers suffering from WMSD's during their work at construction site.

2.4 Data Collection

In this study, samples are collected with a set of questionnaires and by some direct observations. The questions are framed based on the Nordic musculoskeletal questionnaire (NMQ) [2]. The risk factors are studied through literatures and direct observation during working hours. The questionnaire survey contains the sociodemographic, work-related and health-related queries. The first section of questionnaire contains the sociodemographic information of workers, i.e. age, education, body mass index (BMI) and marital status. The second section of questionnaire consists of work-related information such as daily working hours, nature of work, total work experience, involvement of bending the trunk, repetitive work, rest breaks, exercise/sports activities non-work-related physical activity, smoking behaviour and chronic illnesses and working environment. The third section contains information on MSDs, including intensity and frequency of pain. The rebar workers were examined about their musculoskeletal symptoms (pain and discomfort) for the past 7 days and 12 months, and finally, they were asked to check the inference on the body discomfort chart. In addition, the intensity and frequency were recorded for the identified risk factors. They were asked to choose any one from the following choices: low, moderate and high. Furthermore, some of the health-related factors like the personal satisfaction, level of stress, micro breaks during work and getting tired at end of work were recorded. Finally, subjects were asked to quantify the overall discomfort in body regions while performing daily activities. The data collections and investigations are carried out only for the male rebar workers ($n = 113$).

2.5 Data Analysis

The analysis has been done using the management tool called Statistical Package for Social Sciences (SPSS). The collected responses from various workers depicting the constraints and difficulties faced during work have been fed as inputs in two different modes such as dependent and independent variables. This tool has been chosen for accuracy and precision where the Chi-square test has been used for analysis of the collected responses. The independent variables include sociodemographic lifestyle or behaviour of workers, occupational information. On the other side the musculoskeletal complains we considered to be the dependent variable.

3 Results

3.1 General Characteristics

The study sample consisted of 113 male rebar workers. Among these, 43.4% were shuttering workers, 46.9% bar benders and bar tying workers and 9.7% bending bar cutters. The mean age of the male rebar workers was 30.51 (SD 8.09 and range 19–52), and about 49.6% of them belongs to age group of 25–40. The participants had an education level of 17.7% primary, 38.1% of intermediate, 20.4% of high school and 23.9% of diploma or other educational qualification. Around 40.7% of them were unmarried, and the rest were married (59.3%) having at least one child. Three-quarters of them (74.3%) had good health condition, the rest of the participants have average health condition, and even some of them are under medication. The vast majority of them (70.8%) were cigarette/tobacco consumers, and only 33.6% of them involves in exercise and outdoor sport activities. Nearly 90% of them are under normal weight condition (Table 1).

3.2 Work and Workplace Characteristics

The average total working experience of the participants was 7.74 years. Average working hours were 8.5 h/day. It has been found that 25.7% have work experience more than 10 years and 45.1% of them have working less than 5 years. Furthermore, 74.3% of rebar workers were working 8 h/day and 25.7% working more than

Table 1 Relationship between the sociodemographic, health- and work-related factors and reported musculoskeletal disorders

Risk factors	n	(%)	Reported MSDs		Statistics		
			Yes (%) (n = 49)	No. (%) (n = 64)	χ^2	df	p^a
Sociodemographic							
Age (years)							
≤ 25	41	36.3	3	38			
26–40	56	49.6	34	22	35.076	2	< 0.05
≥ 41	16	14.2	14	4			
Education							
Primary	20	17.7	14	6			
Intermediate	43	38.1	28	15	32.655	3	> 0.05
High school	23	20.4	5	18			
Others	27	23.9	2	25			
Marital status							
Married	67	40.7	47	20	48.085	1	< 0.05
Single	46	59.3	2	44			
Health-related							
Body mass index							
Underweight	2	1.8	0	2	1.679	2	> 0.05
Normal weight	103	91.2	45	58			
Overweight	8	7.1	4	4			
Current health status							
Good	84	74.3	24	60	29.325	2	< 0.05
Average	27	23.9	23	4			
Bad	2	1.8	2	0			
Level of stress due to work							
Low	83	73.5	28	58	22.672	2	< 0.05
Moderate	28	24.8	22	6			
High	2	1.8	2	0			
Getting tired at end of work							
Yes	76	67.3	42	34	13.384	1	> 0.05
No	37	32.7	7	30			
Cigarette/tobacco consumption							
Yes	80	70.8	42	38	9.312	1	< 0.05
No	33	29.2	7	26			
Exercise/gaming activities							
Yes	38	33.6	4	34	25.136	1	< 0.05

(continued)

Table 1 (continued)

Risk factors	n	(%)	Reported MSDs		Statistics		
			Yes (%) (n = 49)	No. (%) (n = 64)	χ^2	df	p^a
No	75	66.4	45	30			
Work-related							
Daily working hours							
≤ 8 h	84	74.3	44	40	10.839	1	> 0.05
≥ 8 h	29	25.7	5	24			
Total working experience (years)							
≤ 5	51	45.1	5	46			
6–10	33	29.2	21	12	44.168	2	< 0.05
> 10	29	25.7	23	6			
Feeling stress due to work							
Low	60	53.1	14	46			
Moderate	46	40.7	29	17	22.168	2	< 0.05
High	7	6.2	6	1			
Heavy lifting/lowering							
Yes	36	31.9	30	6			
No	77	68.1	19	58	34.368	1	< 0.05
Prolonged standing							
Yes	67	59.3	47	20	48.085	1	< 0.05
No	46	40.7	2	44			
Excessive force							
Yes	15	13.3	13	2	13.206	1	< 0.05
No	98	86.7	36	62			
Repetitive bending							
Yes	48	42.5	40	8	54.283	1	< 0.05
No	65	57.5	9	56			
Microbreaks at work							
Yes	62	54.9	42	20	33.244	1	< 0.05
No	51	45.1	7	44			
Personal satisfaction in work							
Low	7	6.2	4	3			
Moderate	65	57.5	25	40	1.667	2	> 0.05
H igh	41	36.3	20	21			

10–12 h/day. The rebar workers exposed to heavy lifting, prolonged standing, repetitive bending and excessive force. In addition, with the physical exposure's workers exposed to physiological stresses like feeling stress in the workplace. Three-quarters of them were adopted to the working environment, and the remaining participants who are having educational level of diploma and higher were forced to work due to financial instabilities.

There are two breaks during the day and a 1 h break for lunch. During working, 54.9% of the workers take microbreaks. Around 90% of the participants are right hand workers and mostly involve in repetitive bending and prolonged standing. Among the workers, 42.5% involves in repetitive bending postures. The majority of the workers, nearly 59.3%, were involved in prolonged standing, 31.9% involved in heavy lifting and lowering, and only 13.3% work with excessive force. About 26.5% of the participants felt moderate physical stress during their work, 36.3% of them are personally satisfied, and 57.5% of were moderately satisfied in their work. The rebar workers do not provide with any personal protective equipment and proper working guidelines while working in the site and even if provided they do not utilize them in an effective manner. Furthermore, 18% had work-related accidents like fall from height, minor electrocutions, slips, struck by objects and minor cuts and scratches.

3.3 Prevalence of WMSDs from Past 7 days

Participants reported with discomfort, pain and fatigue with frequency often and very often and intensity high and very high is considered as suffering musculoskeletal disorders. During the past 7 days rebar workers have experienced symptoms in neck (15.9%), shoulder (38.1%), upper arm (14.2%), lower arm (28.3%), wrist (42.5%), finger (10.6%), upper back (16.8%), lower back (59.3%), hips (21.2%), knee (52.2%) and ankle/foot (17.7%) (Table 2).

3.4 Prevalence of WMSDs from Past 12 months

During the past 12 months, rebar workers have experienced symptoms in neck (36.3%), shoulder (49.6%), upper arm (33.6%), lower arm (39.8%), wrist (48.7%), finger (26.5%), upper back (27.4%), lower back (70.8%), hips (34.5%), knee (60.2%) and ankle/foot (36.3%). It is observed that the participants experience higher prevalence of pain in shoulder, wrist and lower extremities like lower back, hips, knee and ankle/foot. Table 1 summarizes the factors affecting the prevalence of MSDs. From Table 3, the factors affecting the prevalence of MSDs are identified. There is no significant difference ($p > 0.05$) found in the variables such as education, getting tired at end of work, daily working hours, personal satisfaction in work and BMI. The factors like prolonged standing, heavy lifting/lowering, repetitive bending, excessive force and total years of working experience were statistically significant ($p < 0.05$).

Table 2 Site-wise distribution of participants on prevalence of WMSD's from past 7 days

Body region	Symptoms occurred in the last seven days/week	
	Yes	No
Neck	18 (15.9%)	95 (84.1%)
Shoulder	43 (38.1%)	70 (61.9%)
Upper arm	16 (14.2%)	97 (85.8%)
Lower arm	32 (28.3%)	81 (71.7%)
Hand/wrist	48 (42.5%)	65 (57.5%)
Finger	12 (10.6%)	101 (89.4%)
Upper back	19 (16.8%)	94 (83.2%)
Lower back	67 (59.3%)	46 (40.7%)
Hips/thighs	24 (21.2%)	89 (78.8%)
Knee	59 (52.2%)	54 (47.8%)
Ankle/foot	20 (17.7%)	93 (82.2%)

Table 3 Site-wise distribution of participants on prevalence of WMSD's from past 12 months

Body region	Symptoms occurred in the last 12 months/year	
	Yes	No
Neck	41 (36.3%)	72 (63.7%)
Shoulder	56 (49.6%)	57 (50.4%)
Upper arm	38 (33.6%)	75 (66.4%)
Lower arm	45 (39.8%)	68 (60.2%)
Hand/wrist	55 (48.7%)	58 (51.3%)
Finger	30 (26.5%)	83 (73.5%)
Upper back	31 (27.4%)	82 (72.6%)
Lower back	80 (70.8%)	33 (29.2%)
Hips/thighs	39 (34.5%)	74 (65.5%)
Knee	68 (60.2%)	45 (39.8%)
Ankle/foot	41 (36.3%)	72 (63.7%)

3.5 *Discomfort on Performing Daily Activities*

Table 4 and Fig. 1 deal with the interference of discomforts, pains and fatigue in daily activities. The questionnaire form consists of three choices not at all, slightly interfered and substantially interfered. From the descriptive statistics, 35% of the participants have slight discomforts on performing daily activities. The slightly interfered MSDs can be avoided by maintaining proper food diet and physical activities, substantially interfered MSDs may result in chronic injuries, and it requires proper

Table 4 Interference of discomfort on daily activities for the past 12 months

Body region	Interference of discomfort on performing daily activities		
	Not at all	Slight	Substantial
Neck	68 (60.2%)	41 (36.3%)	4 (3.5%)
Shoulder	38 (33.3%)	58 (51.3%)	17 (15%)
Upper arm	61 (54%)	48 (42.5%)	4 (3.5%)
Lower arm	50 (44.2%)	48 (42.5%)	15 (13.3%)
Hand/wrist	48 (42.5)	42 (37.2)	23 (20.4%)
Finger	70 (61.9%)	38 (33.6%)	5 (4.4%)
Upper back	56 (49.6%)	51 (45.1%)	6 (5.3%)
Lower back	24 (21.2%)	52 (46%)	37 (32.7%)
Hips/thighs	37 (32.7%)	55 (48.7%)	21 (18.6%)
Knee	25 (22.1%)	56 (49.6%)	32 (28.3%)
Ankle/foot	27 (23.9%)	74 (65.5%)	12 (10.6%)

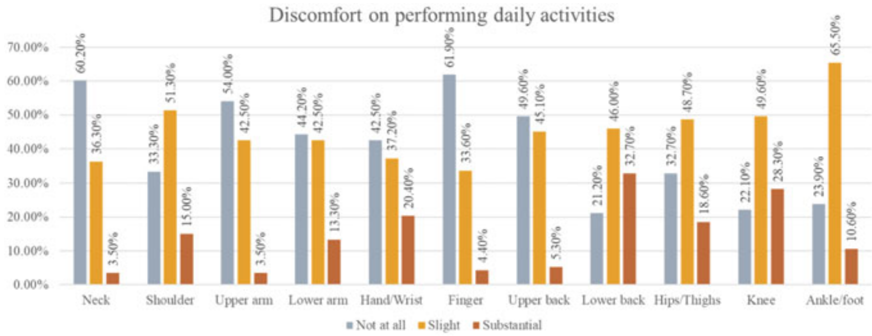

Fig. 1 Discomfort on performing daily activities in the past 12 months

medical care and lifestyle habitual changes. Highest discomfort and pains are identified in the lower back (32.7%), knee (28.3%), hand/wrist (20.4%), hips/thighs (18.6%) and shoulder (15%). From the study, it is found that there is less intervention of pain in neck, finger during daily activities.

3.6 Prevalence of MSDs Among Different Age Groups

Table 5 represents the prevalence (%) and 95% characteristic intervals of musculoskeletal pain in different body regions during the past 12 months among rebar workers by different age groups. The reported MSDs of the group with age ≥ 41 were higher (65.9%) than 26–40 (54.7%) and ≤ 25 (16.4%). The age group ≥ 41reported neck pain, CI [28.95, 83.55], shoulder pain, CI [28.95, 83.55], lower arm pain, CI [51.17, 95.53], hand/wrist pain, CI [51.17, 98.83], finger pain, CI [1.17, 48.83], upper back, CI [16.45, 71.05], lower back pain, CI [78.56, 96.44], hips/thighs, CI [35.86, 89.14], knee pain, CI [1.64, 23.16], ankle/foot pain and CI [28.95, 83.55]. Figure 2 shows the % of prevalence of MSDs among rebar workers with respect to different years of work experience, and the workers have experience more than 10 years have reported higher prevalence of pain and discomforts in body regions like lower back, knee, hand/wrist and ankle/foot. Similarly, in Fig. 3, it is observed that the workers with age $\geq$ 41 have reported MSDs in lower arm, hand/wrist and in lower extremities. Hence, it is evident that the rebar workers exposed to ergonomic hazards in the workplace and risks associated with the various body regions.

Table 5 Prevalence (%) and 95% confidence intervals (CIs) of musculoskeletal pain in different anatomical sites during the past 12 months among rebar workers, by age group

MSD	$\leq$ 25 years (n = 41)		26–40 years (n = 56)		$\geq$ 41 years (n = 16)		Total (n = 113)	
	%	CI	%	CI	%	CI	%	CI
Neck	19.5	[6.85, 32.18]	42.9	[27.78, 54.37]	56.3	[28.95, 83.55]	36.3	[26.45, 44.35]
Shoulder	26.8	[12.67, 40.99]	64.3	[51.34, 77.23]	56.2	[28.95, 83.55]	49.5	[40.20, 58.92]
Upper arm	12.2	[1.74, 22.65]	42.8	[29.48, 56.23]	56.2	[28.95, 83.55]	33.6	[2.78, 42.47]
Lower arm	12.1	[1.74, 22.65]	50.0	[36.49, 63.51]	75.0	[51.17, 95.53]	39.8	[30.66, 48.99]
Hand/wrist	19.5	[6.85, 32.18]	62.5	[49.42, 75.58]	75.0	[51.17, 98.83]	48.7	[39.31, 58.03]
Finger	9.7	[0.27, 19.24]	39.3	[26.09, 52.48]	43.8	[1.17, 48.83]	27.4	[18.28, 34.82]
Upper back	4.9	[2.01, 11.76]	39.2	[26.09, 52.48]	43.7	[16.45, 71.05]	27.3	[19.08, 35.79]
Lower back	36.6	[21.19, 51.98]	87.5	[78.56, 96.4]	100	[78.56, 96.44]	70.8	[62.28, 79.31]
Hips/thighs	4.8	[2.01, 11.76]	48.2	[34.71, 61.72]	62.5	[35.86, 89.14]	34.5	[25.61, 43.41]
Knee	22.0	[10.67, 38.11]	76.8	[65.38, 88.19]	100	[1.64, 23.16]	60.2	[51.93, 70.19]
Ankle/foot	12.2	[1.74, 22.65]	48.2	[34.71, 61.72]	56.2	[28.95, 83.55]	36.3	[27.28, 45.29]

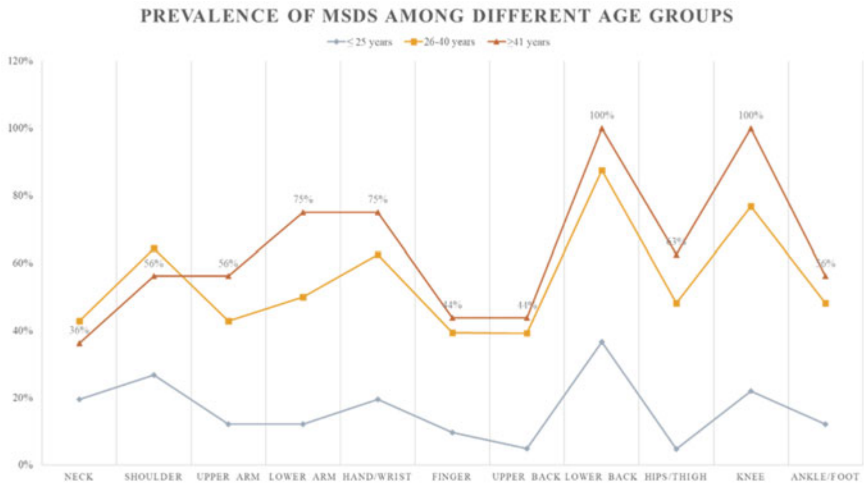

Fig. 2 Prevalence of MSDs among different age groups

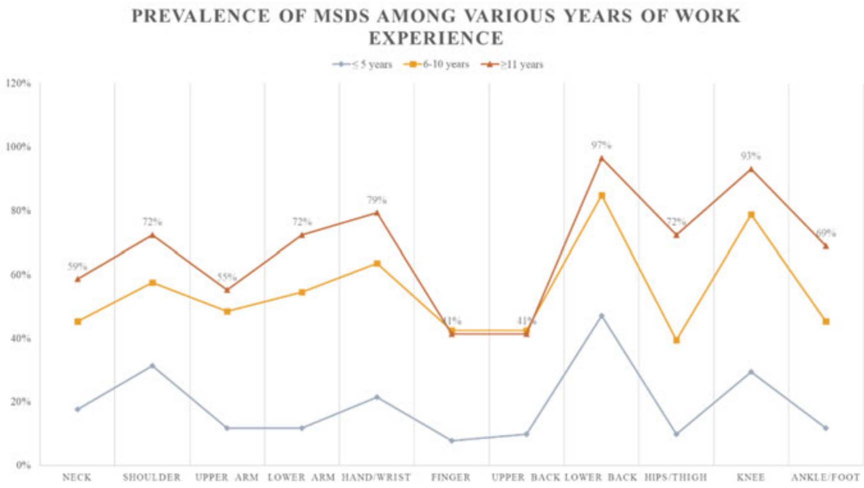

Fig. 3 Prevalence of MSDs among various years of work experience

3.7 Prevalence of MSDs Among Various Years of Work Experience

Table 6 represents the prevalence (%) and 95% characteristic intervals of musculoskeletal pain in different body regions during the past 12 months among rebar workers by years of work experience. The workers with years of experience ≥ 10 years have reported higher prevalence of MSDs (68.3%) than ≤ 5 and 6–10 years

Table 6 Prevalence (%) and 95% confidence intervals (CIs) of musculoskeletal pain in different anatomical sites during the past 12 months among rebar workers, by years of work experience

MSD	≤ 5 years ($n = 51$)		6–10 years ($n = 33$)		≥ 11 years ($n = 29$)		Total ($n = 113$)	
	%	CI	%	CI	%	CI	%	CI
Neck	17.6	[6.82, 28.48]	45.4	[24.63, 60.22]	58.6	[39.55, 77.69]	36.3	[26.45, 44.35]
Shoulder	31.4	[18.19, 44.55]	57.6	[39.78, 75.37]	72.4	[55.11, 89.72]	49.5	[40.20, 58.92]
Upper arm	11.7	[2.61, 20.92]	48.5	[30.49, 66.48]	55.2	[35.92, 74.42]	33.6	[24.78, 42.47]
Lower arm	11.7	[2.61, 20.92]	54.5	[36.62, 72.48]	72.4	[55.11, 89.72]	39.8	[30.66, 48.99]
Hand/wrist	21.5	[9.89, 33.25]	63.6	[46.31, 80.96]	79.3	[63.63, 94.99]	48.7	[39.31, 58.03]
Finger	7.8	[0.21, 15.48]	42.4	[16.6, 50.31]	41.4	[32.38, 71.07]	26.5	[18.28, 34.82]
Upper back	9.8	[1.36, 18.25]	42.4	[24.63, 60.22]	41.4	[22.31, 60.45]	27.4	[19.08, 35.79]
Lower back	47.1	[32.88, 61.24]	84.8	[71.94, 97.76]	96.5	[89.49, 103.62]	70.8	[62.28, 79.31]
Hips/thighs	9.8	[1.36, 18.25]	39.4	[21.80, 56.99]	72.4	[55.11, 89.72]	34.5	[25.61, 43.41]
Knee	29.4	[16.47, 42.35]	78.8	[67.93, 95.71]	93.1	[83.29, 102.91]	60.2	[51.93, 70.19]
Ankle/foot	11.8	[2.61, 20.92]	45.4	[27.52, 63.38]	68.9	[51.06, 86.87]	36.3	[27.28, 45.29]

of work experience group. The workers with ≥ 10 years neck pain, CI [39.55, 77.69], shoulder pain, CI [55.11, 89.72], upper arm pain, CI [35.92, 74.42], hand/wrist pain, CI [63.63, 94.99], finger pain, CI [32.38, 71.07], upper back, CI [22.31, 60.45], lower back pain, CI [78.56, 96.44], hips/thighs, CI [35.86, 89.14], knee pain, CI [83.29, 102.91] and ankle/foot pain, CI [51.06, 86.87].

4 Discussion

The purpose of the study is to identify the prevalence of ergonomic risks and work-related MSDs of rebar workers in southern regions of India. The construction is one of the industries that involves extreme man power, and rebar workers are one of the core workers in this sector. The prevalence of MSDs in rebar workers study is conducted based on NMQ and statistical analysis (SPSS). The participants involved in the study involved in the construction of residential, commercial and institutional building. It is found that 43.4% of the participants experienced WMSDs during the past 1 year/12 months. The rebar workers experienced higher prevalence of pain in lower back (70.8%), knee (60.2%), shoulder (49.6%), wrist (48.7%) and ankle/foot (36.3%). The reported MSDs of the $\geq$ 41 age group were significantly higher (65.9%) than the other two age groups, 54.7% and 16.4%. From the reports, it is obvious that workers with years of experience $\geq$ 10 years have reported higher prevalence of MSDs (68.3%) than $\leq$ 5 and 6–10 years of work experience group. The identified risk factors from the study are prolonged standing, repetitive bending, heavy lifting/lowering, awkward posture and excessive force. These results were compared with similar studies on rebar and construction works.

A study related to the rebar workers with 20 male participants performing repetitive lifting tasks is conducted using electromyography and motion sensors in Hong Kong [3] identifies that repetitive lifting of different weights increases muscular activity in L3 regions of lower back and potential risks of chances of occurrence of low back pain disorder. In an another study, the prevalence of WMSDs among 25 rebar workers in Karnataka was chosen and studied for a period of 30 days and have reported pain in shoulder (64%), upper back (40%), knee (40%) and lower back (16%) during the past 6 months [1]. Furthermore, the study identified 25 postures by REBA and RULA about 60% of participants are at medium risk, 26% at high risk and 4% at very high risk. In a similar study in Hong Kong University, the disability index of rebar workers was identified by electromyography and wearable sensors, and it is found that the participants exposed to moderate knee pain [4]. In a Thailand study [5], the prevalence of musculoskeletal disorders associated with upper limb and lower back were identified. The study consists of 241 participants, and the highest prevalence of discomfort were recorded in the wrist/hand 78.8% and in lower back 68.9%. In a similar study in Thailand [6], the prevalence of MSDs in the past 12 months were in wrist/hand (78.8%), low back (68.9%) and shoulder (46.9%). The study also founded the workers were provided with inappropriate tools and have poor lighting conditions. In a similar Iranian study [7], the participants reported 60% low back pain, 46% wrist pain and 40% ankle/foot pain. In another study, the disorders and risk factors of hand-operated rebar workers were analysed, and the body regions of neck (91.8%), shoulder (87.8%) and spine (89.1%) were identified to be highly affected [8]. In another study in Thailand [9] the MSDs among informal sectors rebar workers, it is found that in body regions of wrist/hand (90%), low back (80%) and neck (56.4%) were exposed to higher degree of discomforts/pain in the past 12 months. Similarly, a study is conducted to identify the negative impacts of long-term squatting in working environment [4]. Furthermore, a squatting tool is ergonomically designed to sit and work instead of squatting and about 68% of them give positive responses in terms of physical and subjective outcomes. These observations imply the data related to risk factors associated with prevalence of MSDs among male rebar workers in construction industry.

5 Conclusion

The present study concludes the prevalence of discomforts/pain in various body regions of rebar workers with higher pain in lower back, knee, wrist and shoulder in the last 12 months. The NMQ and statistical analysis approach provides quite accurate and proper validation. Thus, the male rebar workers participated in this research were exposed to both MSDs and ergonomic risks.

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Case Study on Value Stream Mapping for Precast Hollow Core Slab

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Abstract The construction sector in India is gradually undergoing critical changes in several aspects and transcending for the better. One of the significant changes in the sector is using precast technology and 'offsite' manufacturing techniques to enhance the speed of construction and optimize process methodology to reap added benefits apart from the traditional onsite means of construction. Despite its advantages, this method can be improved further by conducting proactive research. One of the tools which can be used widely to improve the process is the use of 'value stream mapping', a prominent Lean construction tool. Value stream mapping (VSM) as a management tool helps evaluate waste within the workflow, which can eventually identify several improvements to the process. This adaptation is possible through appropriate process mapping. This study aims to map the process of the construction system covering precasting of hollow core slabs. The case study sites were visited to record activity cycles. The study's primary objective is to map all relevant activities and further propose improvements to the process. Two maps were obtained for each activity, namely the current state—VSM and future state VSM, a map of the current state with improvements. This study demonstrated that it is possible to adapt the VSM in construction and highlights some of its key benefits.

Keywords Offsite construction · Precast construction · Value stream mapping · Lean construction

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1 Introduction

The construction industry plays a significant role in the global economy and GDP and accounts for 10% of the total, which signifies its impact and the giant footprint it leaves on the world. India, in particular as a developing nation, is highly focused on constructing world-class infrastructure and striving to be a 5 trillion economy by 2025. Some of the problems construction and infrastructure projects face commonly are substantial cost overruns, time overruns, a tremendous amount of waste material generated, safety issues, high dependency on labour, lack of availability of skilled labour, involvement of many participants in projects, lengthy legal proceedings and clearances. There are few drawbacks in the sector like the reduction in productivity of labour and machinery, improper decision making, use of obsolete working procedures, increase in rework, minimal use of information technology, improper coordination between project teams and stakeholders, design errors and lack of quality assessment and control management system.

The mentioned obstacles call for temporary measures and methods to mitigate their impacts on the sector, which will eventually avoid and suppress these problems, which will benefit companies and our economy as a whole. One of the significant advancements in the sector is the use of precast construction techniques. Precast construction eliminates the use of onsite casting needs, one of them majorly being on site formwork methodology and hence further improves efficiency in planning. Some of its other benefits are its effectiveness in large-scale construction because of reduction in cost due to economies of scale, standardization of elements due to repetitive production, reduced installation time, higher process quality control and increased strength parameters overcast in situ methods. There are many challenges which are being faced in this shift to 'offsite' manufacturing, which also faces many process-related difficulties with respect to each precast or offsite manufacturing facility, which can be optimized using certain tools and techniques.

One the most effective and most efficient tool to face these issues and to curb them to a large extent is the use of the Lean methodology. Lean tools are primarily executed to minimize waste or in fact nullify it in many cases, optimize process times, develop sustainable methods, improved decision making by management, reduce or avoid delays, increase productivity and safety, reduce direct and indirect costs, optimize process flow and overall financial performance of projects. The tool highlighted in this study is the use of value stream mapping in this sphere of the industry. Value stream mapping is an effective tool under the Lean methodology which defines process flow and information flow and brings about detailed outline of the process flow with the help of mapping and identifies critical aspects like time and waste to visualize a current map state which in turn can help in formulating a future flow of map by identifying key bottleneck areas in the process.

The focus of the study is to address some important features in the process flow of precast construction manufacturing of hollow core slabs in a manufacturing setup. The study will recognize key value and non-value areas in processes like time wastage, material waste, productivity and cost. This analysis will help in formulating an outline of the flow of the process and will also give future recommendations to reduce time, waste, cost and delays. Comparison of current state of mapping and future state of mapping in a Value stream would help in obtaining understanding about the workflow and solution to optimize workflow resulting in the smooth flow of process, increase in value-added activities, reduction in material waste, increase in labour and material productivity and better decision making.

2 Research Background

Pre-fabrication is used to optimize the existing process, such as a decrease in time and number of activities performed, which also has several other advantages. This case study uses value stream mapping to see the benefits of implementing the prefabrication process instead of the traditional method of construction in bridge construction in Sweden. The study uses the 'NCC Montegabro' method as the future state method in which pre-fabricated beams and slabs are mounted on plates and wing structures. Reduction in complexity in process and time savings in formwork, reinforcement and casting were the main results.

The current state resulted in 980 h of lead time and comprised of 12 activities whereas the future state took a lead time of only 249 h with only 6 major activities [1].

A case study brings about the use of value stream mapping to note changes in a construction process of a hospital in Santiago, Chile, by briefing the environmental and production waste. It brings about the structural concrete process for the hospital. It highlights the use and significance of VSM in establishing a green Lean approach in construction for process and environmental goals. Value stream mapping was mapped for walls, respectively. Several problems were highlighted in the current state, namely process variability, human resource management difficulties, large inventories, value stream sync, low value-adding percentage, material resources supply, planning and control issues and waste management issues with short descriptions of each. The current state showed a value addition of 33%. The future state was mapped with suggestions using bursts like clouds, and this state showed a value addition of 51%. VSM differentiates between value-added and non-value-adding activities in the stream and adds a sustainability approach dimension to the study [2].

This study talks about the inefficiency and low productivity of the Indian industry as a result of implementing value stream mapping (VSM) and work sampling (WS) techniques. These two methods are well known for the waste reduction and time saving which directly reduces the cost. The data collected was from a single site by a team of researchers using a feedback system by taking photographs, videos and hand-written notes. The study says that the vacuum dewatering concrete flooring (VDF) activity in this case can be done in 2.5 days by making the reinforcement set up near the site which can later be transported to the site. We can conclude by clear observation, analysing the productivity of the work force that implementation of VSM and WS can reduce the duration and increase overall profits [3].

Construction waste due to improper planning is highlighted. Lean tools contribute in improving quality, supply chain problems and reducing waste. Using JIT approach, material is directly transported and immediately installed eliminating the process of storage so that engineer could coordinate in manufacturing, transport and installation. VSM is useful to visualize process, identify waste and its sources and to redefine the process from information and material. The company after observation and collection of data through determined average time. The shed has total of 161 panels. Design team completed 10 detailed panels per day and submission of design was a day prior to the production.161 panels took 17 days to complete detailed design, and then, each panel was cured as per plan. Maximum panels produced was 7 per day but curing actually consumed more than 24 h. Each panel was installed in one hour, and 10 panels were installed per day.

A current map was drawn stating 10 detailed panels for every 8 h were designed producing 7 panels per day and 10 panels assembled per day on site. Waiting time for about 24 h is considered between concrete curing and withdrawal process. The current map gives a total lead time of 46 days from design to production stage. Future maps according to 2 scenarios were drawn. The first scenario gives a solution of designing all the 161 panels for due process which reduced the design to production time to 16 days and the total time to 42 days. Detailed designs of all panels must be ready before the starting of production. Scenario 2 stated that every panel produced in a day has to go assembly site the next day after it has been designed using the Just in Time approach. This reduces storage costs, movement and freed up space amounting to a lead time of 21 days [4].

This study deals with a case study in Lima Peru uses VSM to improve process flow and productivity in basement construction by identifying and removing waste in the process. The study deals with deep wall or 'anchored wall' system to stabilize soil after excavation. System contains panels of 5 m * 3 m retained through an anchor. The construction consisted of nine basements. Define, Measure, Evaluate, Improve and Control process was implemented for the full process. The define stage defined the process, and measure stage identified the flow and waste. Evaluate stage measured the amount of waste and identified root causes by discussion with project members. VSM1 and VSM2 maps were developed in this stage. Improve stage suggested corrective measures, and control stage tracked project performance and suggested a VSM3 map too. A detailed flow of the conventional anchor wall system is explained, and by observation a cycle time (CT) of 6815' and lead time (LT) of 1350' was observed, and a VSM was drawn.

Solutions were created to eliminate problems such as waiting time, non-value activities, contributory activities which are not productive by discussion with project team and were represented in yellow triangles on the map. VSM 2 mainly proposed the 'formwork burial system' eliminating CT to 6280 'and LT to 1120' by reducing formwork making, resources and equipment, increase in space for formwork and to construct 2 continuous walls with enhanced safe working methods represented in red in the map. A concrete bar with metal tip further enhanced the manual excavation

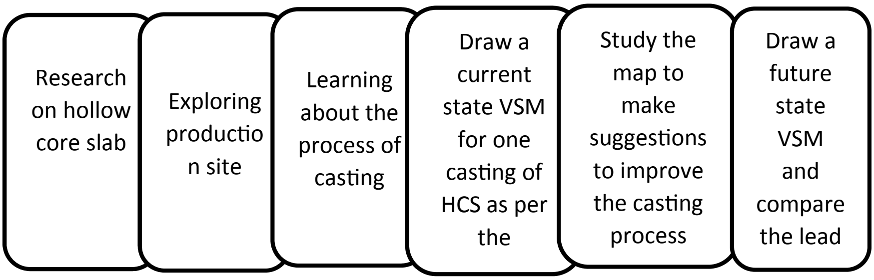

Fig. 1 Methodology of the case study

process. VSM 3 further proposed improvements to the process by mainly using shotcrete to make the screen wall by eliminating the formwork burial and non-productive activities reducing the CT to 5200 'and LT to 760'. New activities are proposed in VSM 3 in blue. The LT of the VSM3 in relation to the VSM2 was reduced by 32%, as well as the number of workers. The study showed that VSM can be used in other projects by collection of data and control of process [5].

3 Methodology

This study is based on a precast hollow core slab and was carried out to use VSM for the process of production of one type of precast element on site. Permission was granted by authorized personnel to make use of the data on terms that their identity is being kept confidential. The methodology adopted for the study is depicted in Fig. 1.

The data utilized as input for VSM was obtained by acquiring cycle times of each activity for the entire casting process. Precast hollow core slabs (HCS) have high demand in the market, where it fulfils customer needs with optimistic resources. The data collected consists of a list of various activities related to casting of HCS along with each activity durations, the number of workers and equipment required for each activity and the idle times and waiting times. The current state map was then drafted, and suggestions were made based on the areas of improvement. The lead times and value-added (VA) times of current state map and future state map were compared and analysed.

4 VSM Case Study

The site consists of an automatic batching plant which can facilitate various grades of concrete, and it has approximately 2.5 acres of stacking yard. A quality team will be assigned on site for material inspection and testing. The process includes two EOT cranes (electrical overhead travelling crane) and one hydra or mobile crane.

The site has two hollow core slab casting beds with length of 100 m and width of 1.2 m each. The casting of hollow core slab is situated outside the indoor production facility where several activities contributing to the casting process as a whole are executed. The process of casting begins with cleaning of the bed, after which oiling activity will be continued, where the full stretch of the bed will be oiled for ease of demoulding. After preparation of bed, low relaxation pre-stressed (LRPC) strands will be tightened across the bed where each strand will be passed from one end to other end manually. As per design, five number of strands will be passed through the slab as reinforcement. When the strand has tightened at the one end, extra part of it will be welded, and both sides will be tightened with couplers. Safeguards will be installed across the bed to prevent strands from breaking while doing pre-tensioning activity.

Pre-tensioning activity begins with the setup of a hydraulic pre-tensioning machine at each cable and will be joined with strands, where each strand will be tightened until a pressure of 140 kg/cm^2 is reached using equipment operated on five horse power motor. After pre-tensioning, the quality team will inspect strands for achieved or perceived strength gain after which authorization for concreting activity would be given. The concrete used for the hollow core slab is M_{50} grade concrete, and there will be four feeder buckets which are used for concrete transportation to respective locations from the batching plant, each feeder bucket carrying 0.5 cum of concrete. In concreting activity, the transportation of concrete from batching plant to casting bed, concrete feeder bucket(s) will change several locations to reach the casting yard. The locations are named with activity description at each location as shown in Table 1.

Precast hollow core slab forming machine is the crux of the whole concreting activity where the machine forms the slab on the casting bed. The machine is equipped with eight augers, inbuilt vibrators and one concrete bucket which have a capacity of 0.5 CUM as per management regulations. The concrete which is prepared in the batching plant will be transferred into the two feeder buckets which has a capacity of 0.5 CUM each and poured from batching plant to feeder buckets placed at L1, and then, the buckets will be carried by a trailer from L1 to L2 using trailer mounted on track. These buckets are further lifted to L3 by EOT, where hydra crane will carry buckets filled with concrete over to hollow core slab forming machine for casting. The empty buckets will be returned back by hydra crane at L3, after which the two empty

Table 1 Locations of the production facility

Location	Description
L1	Movement of concrete from batching plant to feeder buckets
L2	Transportation of feeder bucket from L1 by trailer
L3	Transportation of feeder bucket from L2 by EOT and transportation to casting yard by hydra crane
L4	Movement of empty feeder bucket from location by trailer from L3

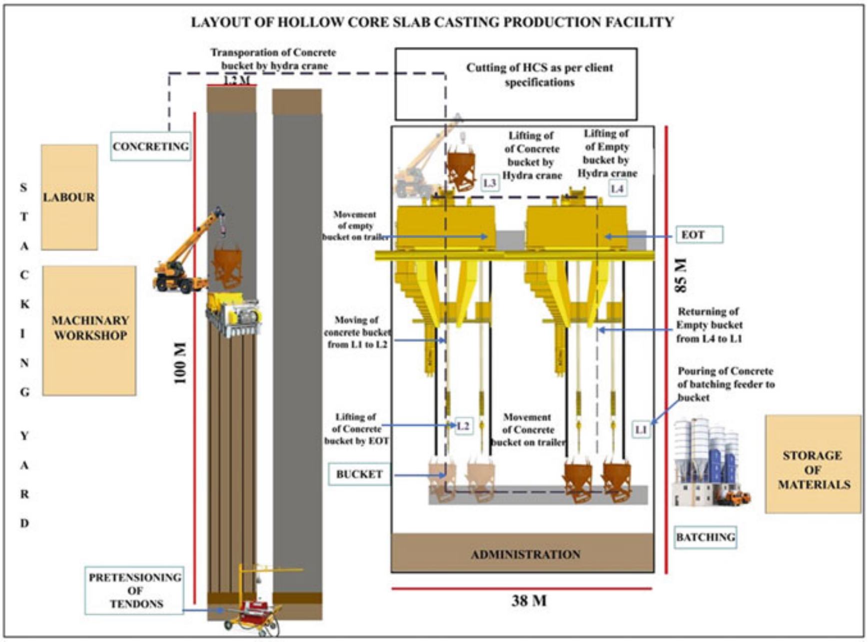

Fig. 2 Layout map of HCS production facility

buckets will move to L4 by trailer mounted on track. A diagrammatic representation of the top view of the production facility is given below in Fig. 2.

In the concreting activity, augers play a crucial role because they will make the hollow shape in the slab, which defines the design of the hollow core slab. For the whole concreting activity, 26 buckets of concrete are required to complete the entire one hundred meters bed. At the same time, in some situations, during the laying of the slab, the auger can get jammed in the bed, due to which the process might get halted indefinitely.

In such a situation, the machine is transported to the garage, and the auger should be removed manually under the supervision of the authorized team, after which the repaired augers will be fixed again. The machine will be transported to the bed from the garage by hydra crane. In the process of casting the bed, two masons simultaneously do the finishing work of the slab. A three-layer cover will be wrapped on the completed hollow core slab immediately as the casting takes place ahead. Then, the bed will be cured for next 48 h. After completion of curing time, the slab will be ready for cutting. A cutting machine will be inserted on the bed, and marking on the slab for every 5 m is done. Stacking activity is the final activity of this process which will start after cutting of the slab into respective five-meter parts, after which the cut slabs are stacked using a crane above each other in numbers of five.

Table 2 Definitions of different terminologies for value stream map

Key word	Definition
Value-added time	Time where machinery (or) resource (or) manpower are actually utilized or productivity is fully efficient
Non-value-added time	Time where machinery (or) resource (or) manpower indirectly benefits the productivity of the process or not directly contributing to the activity
Idle time	Time where machinery (or) resource (or) manpower are halted (or) in stationery or no efficiency is achieved
Cycle time	Value-Added time + Non-value-added time
Lead time	Value-added time + Non-value-added time + Idle time

A current state map and future state map have been prepared with process flow explained with the help of a value stream map. Cycle time, value-added time, non-value-added time and idle time for each activity are represented in the value stream. The total process time of the entire casting process recorded is also given. Total lead time established will help notice the difference in current and future state VSMs. With the help of a current state VSM and future state VSM, the case study will help in identifying the value addition to process as a whole by suggestions or modifications given to the existing current state and mainly focus on optimizing process by reduction in activity cycle times or by execution of specific activities in a different manner or methodology. The current state and future maps are given below for better understanding. Key definitions used in VSM have been elaborated in Table 2 for ready reference.

In the current state as shown in Fig. 3, concreting is represented as an activity which includes activities from batching, casting of concrete, transportation of concrete in feeder buckets from batching plant and also considers the return of empty buckets after casting. Hence, this activity is taken as one activity by grouping several activities because it is cyclic. The total process time for the entire process is in the current state map. The future state map will include change in time for certain activities and some suggestions using Kaizen Bursts.

5 Results and Discussions

After studying the current state of VSM, it was observed that there are some changes to be made which will achieve speed in productivity of the process and reduction in total lead time. The total lead time from the current state to the future state is reduced by 2520 s (42 min) as shown in Fig. 4. The marking activity happening after cutting slabs could be executed while casting a particular slab section for regular intervals. This resulted in a saving of 740 s (12 min) which was a non-value-added activity under the cutting process and hence added value to the concreting process without affecting its cycle time.

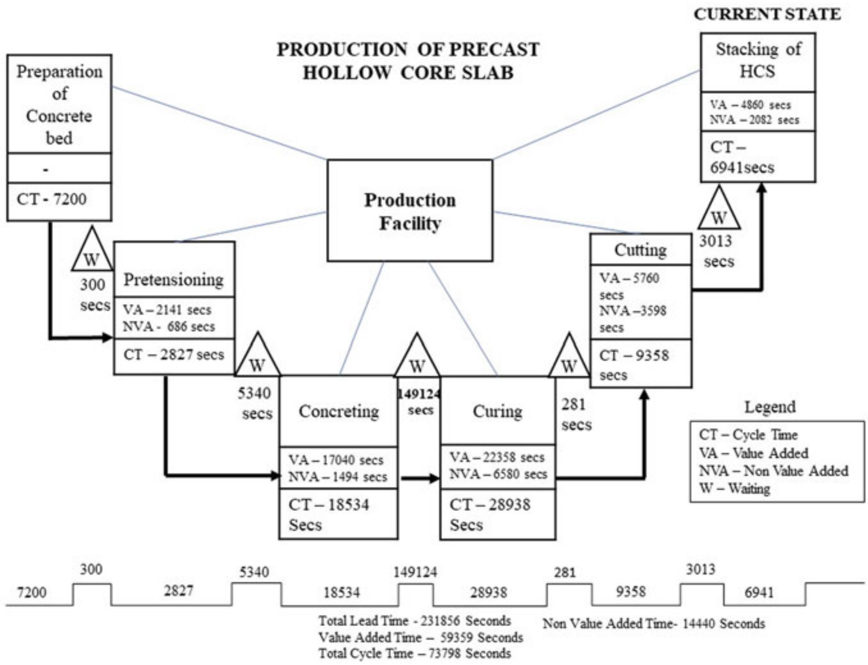

Fig. 3 Current state map of VSM

An inspection activity could be implemented before starting of concreting activity which includes diagnosis of hollow core slab forming machine, where every part of the machine will be oiled, riveted and inspected by quality team, for an approximate time of 20 min with the pre-tensioning activity saving time of an average of 3720 s (1 h 2 min). This would result in less time wasted on repair work of the casting machine, which breaks down frequently during casting encountered by the team almost daily. This could eventually lead to lesser cycle times, and the entire production of the facility could be increased by casting two beds in a day instead of one at present. Hence, the total lead time of the process for one hollow core slab production in the future state could be reduced by 2520 s (42 min), and the reduction in total non-value-added time from the current to the future state is reduced by 740 s. (12 min) The future state VSM is shown based on these immediate implications using ‘Kaizen Bursts’.

Some crucial suggestion points require hierarchical permissions from management to be executed onsite. The casting beds, which are situated outside the indoor facility, could be made under one roof. With this method, the EOT could be installed in such a way that the EOT will directly transport the feeder buckets which are coming from batching plant to the concrete bed directly. As a consequence, the need of a hydra crane, labour and existing transportation activity could entirely be banished from the concreting activity. Also, rain which was a significant barrier for concreting

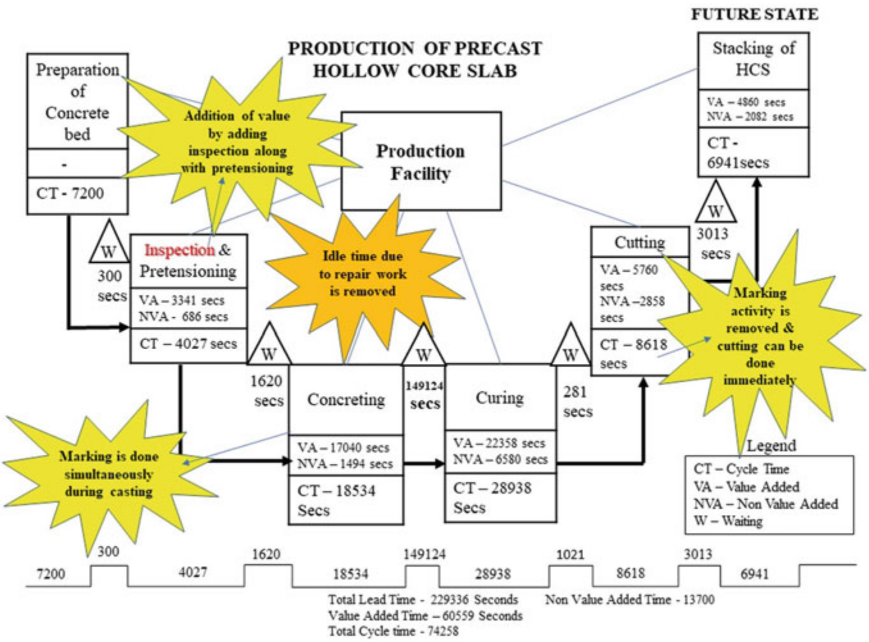

Fig. 4 Future state map of VSM with Kaizen Burst

and uncertainty in weather could be removed entirely from the equation by having the casting bed under one roof.

A machine known as a multi-functional tool which is used in other precast facilities could be used where the machine will by itself clean, oil the bed and insert strands on the bed automatically by making some adjustments concerning the dimensions of the bed. This will massively reduce the cycle time in pre-tensioning and reduce labour costs and also could lead to an increase in productivity by using labour otherwise used in pre-tensioning activity elsewhere in the facility. It also ensures no defect in tightening the desired strength of the strands. These implications could be taken up for study or discussion, and their real implications can only be measured if implemented actually in the production facility.

6 Conclusion

Precast construction should be used more extensively in the construction industry. Extensive research and tools to improve process methodology will help promote the use of precast technology in the sector. Many approaches from the Lean methodology can be used to improve process efficiency. As explained in this case study, value stream mapping is a crucial tool in this study to enhance process outcome and efficiency. We have identified significant changes in cycle times, increased possible production capacity, rise in labour productivity, decrease in cost for implementing each activity and an overall reduction in fixed and operating costs in the process. This approach also sheds light on improvements from the micro-level to macro-level aspects in the supply chain and on the overall economy of the sector, which will promote fresh financial flow and renewed interest from different professional backgrounds in this aspect of offsite or precast construction in the sector.

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Assessment of Factors Affecting Productivity of Pilot Tube Micro-tunneling Operation Through Case Study

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Abstract Pilot tube micro-tunneling (PTMT) has become a mainstream trenchless technique worldwide in high and mega-value projects and will continue to be, as it minimizes the dis-benefits of open-cut method involving traffic congestion, soil subsidence, relocation of existing services, noise and dust emission and safety hazards. As the number of successful projects increased, the confidence of the council, contractors, and consulting engineers also increased. However, the factors influencing the project's success are not completely clear among the industry parties. The factors were identified through literature and in-person interviews and were further assessed at the site of the Cuttack wastewater network large value project in Orissa in relation to how productivity is hampered and how it can be improved in relation to those factors through recent industry best practices. Currently, the quantitative factors are given more weight while decision-making, while this study shows that both qualitative and quantitative factors are equally crucial for productivity monitoring. Benchmarking how each factor influences the productivity at the site will always help achieve the project's success with maximum profitability.

Keywords Pilot tube micro-tunnelling · Trenchless technology · Productivity assessment

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1 Introduction

In India, the subsurface utility market is theoretically over 50,000 kms of infrastructure throughout a total urban area of 77,370 km^2 (JNNURM, Jawaharlal Nehru National Urban Renewal Mission). PTMT has a wide scope for main and sub-main sewer connection all over the country with negligible surface disruption.

Pilot tube micro-tunneling (PTMT), also known as guided auger boring and guided boring method, is a technique that was developed in Europe and Japan two decades ago to build 4 and 6-inch home connections [1]. Guided auger boring is defined as "Auger boring systems which are similar to micro-tunneling, but with the guidance mechanism actuator sited in the drive shaft (e.g., a hydraulic wrench which turns a steel casing with a symmetric face at the cutting head) [2]. The term may also be applied to those auger boring systems with the rudimentary articulation of the casing near the head activated by rods from the drive pit" [3].

To achieve the correct line and grade, the pilot tubes are driven using a steering head using a laser-guided system. Thrusting is halted, the jacking machine is pulled back to its starting position, and a new portion of the pilot tube is attached once the steering head and initial section of the pilot tube are inside the ground. Up until the steering head touches the reception shaft, the procedure is repeated. The second phase entails drilling an auger with casing pipes while reaming the pilot hole to a higher diameter. The new auger casing is attached by retracting the jacking machine once the reamer and first auger casing are fully embedded in the earth. The process begins when pilot tubes are received at the reception shaft and continues until the first casing pipe is encountered. The third stage involves replacing the auger pipe that was previously installed with the product pipe, which is connected using a unique connector. Similar to how auger casings replaced pilot tubes in the second stage, pipe sections replace auger casings in this step. The third step of the three-step process, however, does not require any excavation because the product pipe has an equivalent or smaller diameter than the auger casings. As the pipe sections are advanced, the auger casings are retrieved from the reception shaft.

Contractors aim to boost operational productivity to increase the success rate of micro-tunneling pipe installation projects while maintaining profitability. However, all the study carried out in past decades has limited factors, and most of the factors were quantitative, which were further incorporated for productivity modeling. The other qualitative factors identified in this study also play an essential role in affecting the productivity of operation and should be used to model the productivity. The objectives of this study are as follows

Identify and classify the factors through literature review and in-person expert opinion. The factors are being generalized from the factors affecting the productivity of micro-tunneling operation.

Assessing the factors for their impact on productivity of PTMT operation and suggesting possible solutions through best current practices at site.

2 Factors Affecting Productivity

Based on the literature review and in-person opinion of experts in the micro-tunneling industry, 27 factors were identified as in the previous study carried out for micro-tunneling operation [4]. The factors are being generalized, and some of them are eliminated from the factors affecting the productivity of micro-tunneling operation to PTMT operation as only the technical methodology of PTMT varies. The factors were classified further as direct and indirect factors, which might be quantitative and qualitative, and classification based on conditional aspects referring to physical, environmental and managerial conditions. Table 1 shows the proposed direct and indirect factors.

Table 2 shows the factor affecting productivity, and their classification based on conditional aspect, explanation, measure and significance. In addition to this, Table 2 also shows how they affected the productivity of mentioned case study with the remedy to eliminate or minimize that particular factor affecting the productivity of PTMT operation. All the 27 factors are classified into three different conditional aspects referring to physical, environmental and managerial conditions. It should be noted that physical conditions incorporate factors in relation to technical design, machine operation and machine specification, whereas environmental conditions are in relation with surrounding site conditions. Managerial condition refers to the extent of executional management and operation of PTMT.

Table 1 Proposed direct and indirect factors affecting the productivity of PTMT operation

Direct factors affecting productivity	Indirect factors affecting productivity
Steering head	Pipe usage
Machine torque*	Pipe material
Depth of installation*	Shaft design
Jacking thrust*	Underground obstruction/unusual soil condition
Drive length*	Groundwater conditions
Use of lubrication	Geotechnical investigation
Use of appropriate type of PTMT	Above ground impediments
Separation equipment	Crossing characteristics
Pipe segment length*	Operator/crew experience
Pipe size*	Site conditions
Soil type	Mechanical condition of machine
Curved alignments*	Safety regulations
	Managerial skills
	Technical support
	Working hours*

*refers to quantitative and others as qualitative

Table 2 Significance and assessment of factors affecting productivity of PTMT operation through case study

Sr. No.	Factors affecting productivity	Factors referring to	Explanation	Measure	Significance	How it is impacting productivity. (% overall)	What can be done to improve productivity
1	Steering head	Physical condition	Angle of slant and type of steering head	Degree	Efficiency of steering head of pilot with or without water jet, its type and its accuracy depends on angle of slant	NA	NA
2	Machine torque		Rotational Force to drive the bore	KNM	Progress of pilot tube micro-tunneling machine depends on the rotary torque	Machine torque was affected due to use of gunny bags at jacking shaft instead of rubber seal. Use of gunny bags hampered the machine torque as they were getting stuck in auger casing pipe. The rubber seals were broken and gunny bags were used to avoid delay. (10–12%)	Proper replacement of rubber seal and availability in more numbers for backup
3	Depth of installation		How deep is the pipe underground	M	Increase in a time required for lowering of PTMT machine, product pipe and other equipment into the shaft. It also affects the shaft design	Depth of installation was varying specially at junctions due to crossing of storm water drains. (5–6%)	NA

(continued)

Table 2 (continued)

Sr. No.	Factors affecting productivity	Factors referring to	Explanation	Measure	Significance	How it is impacting productivity. (% overall)	What can be done to improve productivity
4	Jacking thrust		Jacking force and its maximum limit	KN	Amount of jacking thrust applied in consideration with pipe material and soil type	Jacking thrust was affected due to use of gunny bags at jacking shaft instead of rubber seal. Use of gunny bags hampered the machine torque as they were getting stuck in auger casing pipe. The rubber seals were broken, and gunny bags were used to avoid delay. (8–10%)	Proper replacement of rubber seal and availability in more numbers for backup
5	Drive length		Length between jacking and receiving shaft	M	Longer drive length as per alignment consideration will involve infrequent lowering and retrieving of PTMT machine and other equipment, but will decrease the drive alignment accuracy	Large drive length would incorporate increase in cycle time of all activities impacting more use of equipment like mobile crane. Delay in cycle time was mostly the consequence of availability and transportation of mobile crane, i.e., Hydra. (5–6%)	This increase in cycle time of all activities cannot be controlled, but delays should have been managed at site
6	Pipe usage		Usage of jacked pipe	Sewer, storm water or water	Affects the design consideration of pipe installation operation	NA	NA

(continued)

Table 2 (continued)

Sr. No.	Factors affecting productivity	Factors referring to	Explanation	Measure	Significance	How it is impacting productivity. (% overall)	What can be done to improve productivity
7	Use of lubrication		Use of lubrication during tunneling	Y/N	Injecting lubricants such as bentonite slurry helps to reduce friction and ensures steady progression of pilot tube, auger and product pipe and product pipes	A standard bentonite slurry was used. (1–2%)	Use of bentonite slurry with additives like Zythum gum for sandy condition will increase productivity
8	Use of appropriate method of PTMT		Use of appropriate method with respect to soil type, design consideration and experience	Three step, two steps, modified three step or hybrid PTMT	Machine configuration and process time may change on selection of particular type of PTMT method	Modified three-step method was used and has a high productivity for given design consideration with use of PRH to increase diameter. (0%)	NA
9	Separation equipment		Configuration of separation equipment	Number of stages	Separation plant that has a set of equipment (such as shakers, hydro- cyclones and cones) where excavated material is separated from the circulation slurry in number of stages	Low capacity of separation plant hence the operation of lifting the bucket with hydra needed to be stopped. Furthermore, the buckets were drained beside the separation plant which hampered the hydra movement on site. (3–5%)	Increase capacity of separation plant for longer drive length

(continued)

Table 2 (continued)

Sr. No.	Factors affecting productivity	Factors referring to	Explanation	Measure	Significance	How it is impacting productivity. (% overall)	What can be done to improve productivity
10	Pipe segment length		The used pipe length affects the preparation time and shaft design	M	Affects preparation time and entry shaft size for pipe installation	Same pipe segment length for longer as well as shorter drive. (3–5%)	Increase in pipe length for longer drive to decrease no. of cycles while jacking
11	Pipe size		Pipe diameter based on use as main, branch or outfall	M	Affects preparation time and entry shaft size for pipe installation	Optimum pipe size considered for high productivity. (0%)	NA
12	Pipe material		Material pipe of product pipe	VCP, concrete, steel, GRP and PVC	Frictional resistance between the pipe material and soil will hamper the productivity; however, slurry acts as a lubricant	Best pipe material considered from friction point of view. (0%)	NA
13	Shaft design		Shaft size and shape affecting construction time	Narrow, wide	Entry and reception shaft dimensions on the basis of machine size, pipe dimension and site condition should be accurately considered	Shaft size was optimally designed. (0%)	NA

(continued)

Table 2 (continued)

Sr. No.	Factors affecting productivity	Factors referring to	Explanation	Measure	Significance	How it is impacting productivity. (% overall)	What can be done to improve productivity
14	Soil type	Environmental condition	Actual soil type	Clay, sand, silt and pebbles or gravels	Affects the efficiency of spoil removal operation, separation equipment and penetration rate of pilot tube, auger and product pipe	Pure sandy soil or mixture of sand and clay impacted productivity due to variation across the drive. (0%)	NA
15	Underground obstruction/ unusual soil condition		Existing utility services, old foundation, trees or hard bouldery strata	Y/N	Such unforeseen conditions largely affect the operational or machine breakdown	Previously constructed utility lines of electricity and water were encountered. (8–10%)	Proper mapping and exploration with use of subsurface utility engineering
16	Groundwater conditions		Existing ground water	Above, below or through	Affects selection of machine type, installation depth and operational difficulties to conFig. PTMT machine in different groundwater level conditions	Sandy soil with high water table was encountered, and it was seen that pump capacity was too low to handle the dewatering. (3–5%)	Pump capacities should be increased or use of more number of pumps will not hamper productivity
17	Geotechnical investigation		Quality and quantity of available geological information	High or low degree	The extent of geotechnical investigation helps to select the best configuration for PTMT machine, separation plant, other equipment and shaft design	Sites which were not properly investigated for the problem of liquefaction caused damage to foundation nearby and added extra renewing costs for the contractor. (3–5%)	Geotechnical investigation at all major sites to be performed prior to start of operation

(continued)

Table 2 (continued)

Sr. No.	Factors affecting productivity	Factors referring to	Explanation	Measure	Significance	How it is impacting productivity. (% overall)	What can be done to improve productivity
18	Above ground impediments		Existing natural or manmade structures on surface	Y/N	Above ground impediments may largely affect the mobilization of equipment and alignment consideration	Above ground impediments like electric poles, haphazard electricity transmission lines affected crane movements on site. (0%)	NA
19	Curved alignments		Existence of curved alignment	Degree of curve	Affects the accuracy of guidance system and increases the activity time for pilot tube, auger and product pipe penetration and pipe jacking	Choosing curved alignments to the limit of guidance system did not affect the productivity. (0%)	NA
20	Crossing characteristics		Characteristics of natural or manmade crossing to be crossed	Railway, river, lake etc	Characteristics of a particular crossing type may add for additional complexity in design processes and execution of operation	Crossing of Mahanadi river stretches by choosing the best cost-effective alignment was seen. (0%)	NA
21	Operator/crew experience	Managerial condition	Operator/Crew experience in similar type of projects	High or low	Affects the activity cycle time to great extent as crew would be more experienced with similar type of project	Sub-contractor's operator and labors were highly experienced in similar type of projects. (0%)	NA

(continued)

Table 2 (continued)

Sr. No.	Factors affecting productivity	Factors referring to	Explanation	Measure	Significance	How it is impacting productivity. (% overall)	What can be done to improve productivity
22	Site conditions		Referring to environment, transportation, electricity, waste disposal, material storage and water availability	Good or bad	Contributes in smooth progress and success of overall operation at site	Site was not properly maintained in relation to its material management and space organization. Lot of mobilization problems were seen for the crane due to unfair site conditions. (3–5%)	Managing the site as per planned layout and following the 5 s would benefit in increasing productivity
23	Mechanical condition of machine		Frequency of maintenance provided to machine	Frequent or rare	In addition to breakdown maintenance, routine maintenance helps in eliminating future breakdown of machine and ensures highest efficiency	The maintenance was not carried out routinely, which lead to severe mechanical breakdown causing a lot of delays. (2–3%)	Periodic checks and routine maintenance with availability of mechanical parts are must
24	Safety regulations		Safety regulations prescribed and followed at site	Y/N	Extent to which environmental, health and safety policies are planned and executed at site will prevent the unnecessary operational breakdowns	Only safety pep talks were seen, without proper safety related supervision in daily execution increased the chances of accidents at site. (2–3%)	Safety management specially on field and not on paper should be mandatory

(continued)

Table 2 (continued)

Sr. No.	Factors affecting productivity	Factors referring to	Explanation	Measure	Significance	How it is impacting productivity. (% overall)	What can be done to improve productivity
25	Managerial skills		Managerial skills of project team	High or low	Effective leadership, strong decision-making, motivating and coordinating staff, and plan tasks effectively are important for success of project	Strong commitment was seen from the subcontractor's and L&T managers on site. (4–5%)	NA
26	Technical support		Existence of Manufacturer's technical support	Y/N	Technical support in relation with operation and maintenance of PTMT machine and other equipment from manufacturer will ease the solution for breakdown phase	Technical support during breakdown operation was available but at a slow pace. (8–10%)	A technical support team in the region looking at all mechanical operation of machine should be hired in direct contact with manufacturer
27	Working hours		Number of shifts per day	1, 2 or 3	Number of shifts per day will directly impact the machine and labor productivity	One 10 h shift was seen from the labors at site even the project was behind the schedule. (5–8%)	Two eight hours shift with different labors would greatly increase the productivity

NA refers to not applicable

3 Case Study-Cuttack Wastewater Network

3.1 Project and Site Details

Aspects: Gravity Sewer of 382 km long, STP-2 no. (36 and 16 MLD), Value: INR 1058.82 Cr.
Location: Bank of river Mahanadi with land formed from delta.
Geological condition: Sandy soil in abundance with some traces of silt and clay in it and high ground water table.
Compressive strength of soil is < than 47.91 kN/m^2
Angle of internal friction: < 34°.
Soil is considered as C-type of soil: As per OSHA classification, Type C is the least stable soil consisting of granular soil with non-cohesive particles and low compressive strength. Type C soil could be round-shaped gravel and sand. A soil with water flowing through it is stable. Type C can be benched or sloped at a 1.5: 1 ratio or 34-degree slope.
Old city: Haphazard settlement patterns with congested road network.
Terrain: Plain terrain causing increase in depth of gravity sewers along with length.

3.2 Details of Problems Posed at Site

Storm water drain (RCC/Masonry) which are newly constructed: Where storm water drain depth above 1.5 m and width of the drain also more and dismantle of drain not permitted and contractors are not able to install shoring below the drain structure to excavate and lay sewer pipeline to complete the sewer network. Important road crossing open cut not permitted because of high traffic delays: Where some important road crossing like NH/SH/Route of VVIPs, getting permission from concerned authority for an open cut is a very lengthy and time taking process, or it is not permitted for open cut.

The following problems were posed due to site conditions:

Sometime depth the sewer exceeds the width of the road. In this condition, normal steel shoring is not able to withstand the pressure of trench side wall soil. This may damage other underground utilities (like drinking water supply lines, OFC cables, etc.) available on that road.

Vibration during installation of sheet pile or any specialized shoring generates cracks into the neighboring houses, and there is also a probability of collapse of some part of structure if works continues with open trench.

Quicksand condition or sand boiling caused due to open trench technique may pose a threat to settlement or consolidation of neighboring soil and may cause cracks in the structure (Fig. 1).

Fig. 1 Building cracks observed during pipe laying by open-cut method (*Source* L&T Cuttack waste water network project report)

Fig. 2 PTMT job site (*Source* Cuttack waste water network project, L&T)

3.3 Applicability of PTMT for Given Site Conditions

PTMT method by pilot tube boring machine (PTBM) can solve this kind of problem. It is a very precise technique as the pilot tube is laser-guided. We can maintain exact slope and alignment for 150–600 mm inner diameter of RCC NP4 class pipe, which can be precisely jacked by this method. The weight of the Jacking machine is 3–3.5 ton, and NP4 class RCC pipe weighs 106–582 kg depending on the diameter of the pipe. Operation demands a reasonable space requirement for heavy machines, mobile gantry girder, pipe storage and shaft construction. Hence, PTMT solution was deployed for main sewer connections only (Fig. 2).

4 Assessing the Factors Affecting Productivity of PTMT Through Case Study

Each of the factors were carefully analyzed at the site, and the impact was judged based on the on-going operation. How the productivity was hampered and what should be the feasible solution to reduce the effect of that factor on productivity was found out through current best practices available at site.

Table 2 shows the assessment of factors affecting the productivity of PTMT operation in detail through observations made at site and suggesting corresponding solutions available by benchmarking the process through current best practices. The type of steering head used for the operation was the best suited for the sandy soil condition and hence did not impact the productivity at all. Machine torque was highly affected due to use of gunny bags instead of standard rubber seal. Similarly, use of lubricant as bentonite slurry was not that much efficient in sandy soil with high water table, and xythum gum mixed with bentonite slurry would have been adopted as a best current practice suitable for sandy soil condition.

Previously constructed electrical and water supply lines were encountered in the alignment and increased the risk to complete the drive on time as the only method available in these circumstances was open cut. This risk would have been eliminated, and productivity would have been increased if proper subsurface utility engineering techniques for mapping the pre-existing utilities would have been carried out.

5 Conclusion

The study shows the most important factors affecting productivity based on conditions such as physical, environmental and managerial, which can be the center of focus for project team from different point of view, aiming at the increase in the productivity of overall PTMT operation. The detail study of understanding the factors helps to gain insights on how the productivity of PTMT is analyzed and builds a basic step in productivity modeling including quantitative and qualitative factors as well. Knowing that how certain factors like machine torque, drive length, use of lubricants, use of appropriate type of PTMT machine for given site condition, underground obstruction, pipe segment length and other factors mentioned in Table 2 can be observed at site and or planned or executed to eliminate or minimize their corresponding impact on productivity. Assessment of these factors at the site shows how a factor was affecting the productivity and what would have been done as per industry best practice to answer it. Benchmarking each factor will always help in achieving the project's success with maximum profitability. The project team will come to know how the operational complexity of cyclic activities involved in the operation was affected due to involvement of qualitative and quantitative factors and will help to give out best possible solution by benchmarking through current beat practices.

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Application of Operational Management Tools at Precast Yard

Ashutosh Kumar Rai, Varun Kumar Reja, and Koshy Varghese

Abstract Achieving higher productivity and higher production rates can help in maximizing profits at the construction site. The current practices at construction sites carry large sources of waste and inefficiencies which is the major cause of a decline in productivity and decrease in production rate. Segmental bridge construction sites are not an exception. Therefore, this study aims to achieve higher productivity, overcome inefficiencies, and standardize best practices to achieve a higher production rate at segmental precast yard sites by adopting principles and tools of operational management. In this study, seven sources of waste are identified at the precast yard which directly or indirectly affect productivity. The importance of implementing other key concepts of operational management which include responsiveness versus crew productivity graph, and quartile analysis is illustrated. And further productivity measurement tools which include key performance indicators (KPIs), overall people effectiveness (OPEs), and overall equipment effectiveness (OEEs) are introduced to implementation in the construction industry, particularly in the precast yard.

Keywords Waste · Productivity · Production · Operational management · Segmental bridge construction · Precast yard

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1 Introduction

The construction industry is filled with complex and mega projects. Most project suffers either from cost overruns or schedule overruns [1] and in case the project makes a profit, the margin is very less. The profitability of a project depends upon productivity [2, 3]. The productivity at the site was decreased by several causes one of which is high construction waste [4]. Also, the works at the construction site are never performed as they are planned. And the major reason contributing to it is the lack of benchmarking tools [5]. As a result, site personnel adopt random strategies for carrying out project work. Hence, construction practitioners are looking at the success of benchmarking from the manufacturing industry to adopt and improve construction performance [6, 7]. In this context, the implementation of tools of operational management at precast sites can become useful. It has been said that harmony, cooperation, high efficiency, and maximum output would take place with the implementation of its tools [8]. Therefore, this paper attempts to:

Identify seven sources of waste at superstructure production sites to explore opportunities for implementing operational management.

Apply standardization tools of operational management to remove waste and inefficiencies at the precast yard.

Implement productivity tools of operational management to improve segmental construction performance.

This paper is divided into five sections. In the first section, the research problem is introduced, and the objectives for this study are presented. Section 2 presents the review of existing literature on productivity measurement and benchmarking. Section 3 identifies seven sources of waste that affect productivity. Section 4 presents the improvement suggestion. Section 5 presents the discussion and conclusion of the study.

2 Literature Review

Researchers have done several studies on benchmarking, productivity, and lean production. Some of which are discussed below.

Park et al. [9] in their study established a common set of construction productivity metrics. Their combined efforts help in developing Construction Productivity Metrics System (CPMS). And their further analysis made CPMS a standard construction productivity data collection tool. A study conducted by Enshassi et al. [10] presented an empirical approach for benchmarking productivity. In their study, the disruption index (DI), performance ratio (PR), and project management index (PMI) have been considered as project benchmarks. He establishes a connection between DI and PMI and further told that higher values of both DI and PMI are indications of sub-standard labour performance and poor management. Markovic et al. [11] have used the "destination matrix" as a productivity measurement system. According to them, management is responsible for determining the best performance and best practices in the industry and for setting the benchmarking process. Engineering Productivity Metric System (EPMS) was developed by CII to assess engineering productivity at multiple levels, but it cannot produce overall project level measurement. To overcome this limitation, Liao et al. [12] in their study developed a standardized approach of using "z-scores" to aggregate the engineering productivity measurement. With this, it created metrics for benchmarking productivity.

Nikakhtar et al. [13] in his paper present a systematic approach for the application of lean production principles in construction processes emphasizing waste reduction. Leksic et al. [14] in their paper presented a statistical model. The model shows that TPM, Poka-Yoke, Kaizen, 5S, Kanban, Six Big Losses, and Takt Time are statistically significant lean tools for waste reduction or even elimination. Ray et al. [15] in their paper presented an overview of lean manufacturing which help the precast concrete plant to reduce waste and improve production operations.

The above literature suggests that though lean principles can help in waste reduction, and benchmarking helps in increasing productivity, but there is no such practice adopted to minimize waste and inefficiencies and increase productivity at the same time in the construction sites by using benchmarking as a tool. Hence, the current study explores an option of looking at benchmarking tools from other industries which can increase productivity, optimize resources, and help in minimizing waste and can be practically implemented at segmental precast sites to improve construction performance.

3 Seven Sources of Waste at the Precast Yard

The segmental precast yard faces a lot of challenges in improving productivity and its performance because most of the waste at the precast yard is hidden and difficult to identify without measuring. It is obvious that if these wastes are eliminated or minimized, both productivity and performance can improve [16, 17]. The seven-waste defined by lean literature is waiting, overproduction, inventory, over-processing, motion, transportation, and rework [18]. Hence, the current paper identified wastes in the precast yard and categorized them into these seven categories (Table 1).

And Figs. 1, 2, 3, 4, 5, 6, 7 and 8 summarize the seven sources of waste at the precast yard.

The wastes identified above are the major cause of slow progress at the precast yard. Hence, in the next sections, improvements are suggested keeping in mind the tool practitioners can use to minimize or eliminate these wastes and help in achieving higher productivity and hence maximize production outputs.

Table 1 Seven sources of waste at precast yard

Type of waste (With definition)	Figures showing waste at precast yard
Type of waste (With definition) **Over Production**: Producing sooner or in greater quantities than the client demands If the number of segments produced exceeds segment stacking capacity. Then, this is considered to be overproduction waste. In this case, the erection site has to be developed for segment storage purposes. This happens when the erection schedule did not match the construction schedule **Transportation**: Unnecessary movement of people and/or materials between process steps 1. Tire-mounted crane unavailability results in an unloading of rebars at the segment stacking area, which cause unnecessary movement of rebars 2. Transporting inner panels, cage-lifter, and segment-lifter with the help of a hydra or tire-mounted crane from one bay to another bay 3. Transporting bulkhead from stacking bed to casting bed location	Figures 1 and 2
Rework: Correction processes within the main process. Rework is always the result of a failure to do something right in the first place 1. Bar placed wrongly at the time of tying 2. Cutting/bending of rebars not done as per approved BBS 3. Wrong inner panels used for segment cause rework of shuttering, buffing, etc 4. Inner shutter inserted wrongly 5. The wrong bulkhead was used 6. Bulkhead alignment and level not maintained before inner shutter fixing causes reopening of an inner shutter	Figures 3 and 4
Type of waste (With definition) **Over-processing**: Doing more than the client requires. Over-processing is a form of waste that might have positive reasons for workers having high standards than the customers or employees being overly proud of their work. Even after nut-bolting, using extra turnbuckles to support formwork **Motion**: Unnecessary movement of people or parts within a process. Rebar yard location is generally outside the bay in a typical casting yard layout, which means cut and bent rebar has to come to the jig area after covering some distance means which causes unnecessary motion	**Examples of waste at precast yard** Figures 5 and 6

(continued)

Table 1 (continued)

Type of waste (With definition)	Figures showing waste at precast yard
Inventory: Too many flow units in the system 1. Segment stacked at stacking yard (SY) is considered to be inventory 2. No fronts availability for casting results in full occupancy of jigs, which further results in more cut and bend of rebars as inventory	Figure 7
Waiting: Employees or resources just sit around waiting for something to happen. Waiting is an unproductive use of time 1. Delayed in issuing materials from the store which include rebars, binding wires, etc. 2. Common inner panels for segments casting at multiple fronts result in waiting, and only one segment can be casted at a time 3. Workers are waiting due to delays in getting concrete from the batching plant	Figure 8

Fig. 1 Occupied stacking yard

4 Improvement Suggestions

The current study adopts responsiveness versus crew productivity graph, and quartile analysis to implement standardization and remove inefficiencies, and the productivity tools that are implemented in this study are OEEs, OPEs, and KPIs.

Fig. 2 Panel shifting between bays

Fig. 3 Tying blister portion on a bed

Fig. 4 Wrongly fixed panels

Fig. 5 Extra turnbuckles used

4.1 The Trade-Off Between Responsiveness and Crew Productivity

It will help in finding the optimum number of labours required in a crew to finish the job. For cutting and bending of one span (say 15 segments) assuming three different crews with different manpower strengths deployed at three different locations working on separate resources. Time taken by all the crews deployed to do cut and bend should be recorded. Average crew productivity of all the crews should be

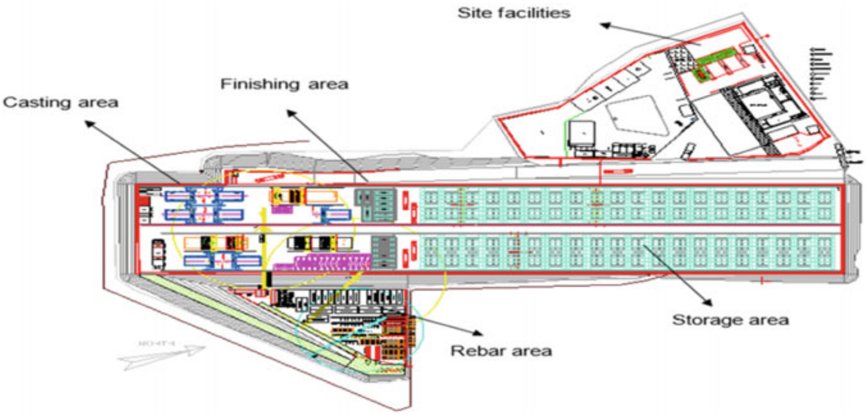


Fig. 6 Rebar yard to jig motion

Fig. 7 Segments stacked at SY

recorded throughout the process, i.e. from start to completion. Based on this, graph is plotted between responsiveness and crew productivity.

This will give the optimum number of labour required (crew capacity) to do the cutting and bending work of one span, instead of deploying additional resources (Fig. 9). Similarly, crew capacity at different locations for different works in precast yards can also be determined.

Fig. 8 Workers waiting for material

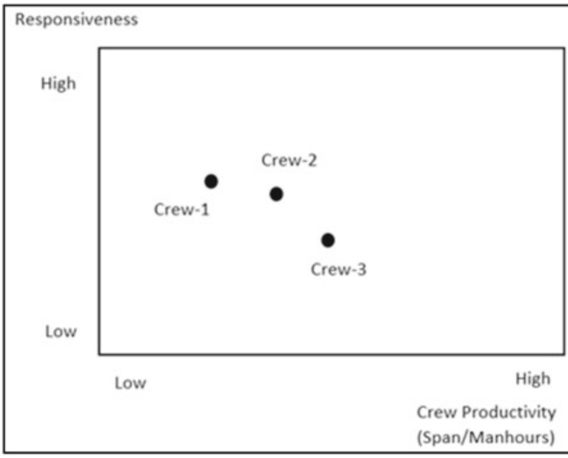
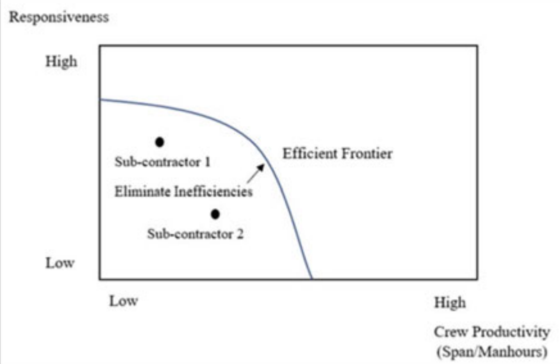


Table: Crews Capacity

Crews	Man-powers
1	8
2	6
3	4

Fig. 9 Determining the optimum number of labours



Sub-contractor	Location
1	Rebar yard-1
2	Rebar yard-2

Fig. 10 Determining efficient frontier

4.2 Overcoming Inefficiencies

In the construction industry, it is common to deploy more than one sub-contractor for the execution of similar works. Assuming two sub-contractor's crews working for cut and bend work. Time taken to complete cutting and bending by both sub-contractor's crews have to be recorded. Average crew productivity of both the crews should be recorded throughout the process, i.e. from start to completion. Based on this, graph (Fig. 10) is plotted between responsiveness and crew productivity for both sub-contractors.

This will help in comparing which sub-contractor is performing better in terms of completing the segment faster or how much it lacks from the best sub-contractor. This should be done at every site to find the best sub-contractors to do the job. And the good practices of the best sub-contractor would be transferred to the other sub-contractors.

4.3 Evaluating Proposed Redesign and Technologies

Time taken to do shutter fixing and de-shuttering for both cases should be recorded, i.e. with the current frontier and new frontier. Average crew productivity for both cases should also be recorded. Based on this, the graph between responsiveness and crew productivity is plotted for both cases.

If the new frontier graph lies above than current frontier, means with this technology responsiveness and crew productivity both are improved (Fig. 11). It can be implemented in all those activities or processes which can be improvised with the use of technologies.

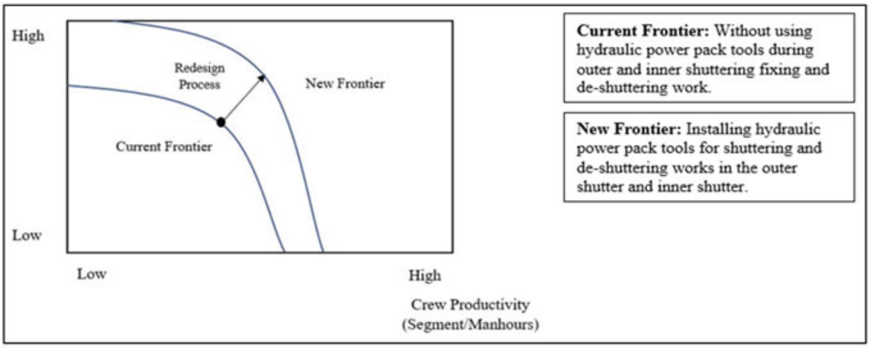


Fig. 11 Determining new frontier by redesigning process

4.4 Quartile Analysis

The main focuses of any construction site were on minimizing average processing time and minimizing idle time. For that, they do adopt some strategies, but they overlooked the approaches adopted by different sub-contractor deployed at the site. It can become important for the identification of best practices if the time differences between sub-contractors for doing the same work are recorded and evaluated. Thus, the quartile analysis compares the highest quartile performing sub-contractor with the bottom quarter sub-contractor.

4.4.1 Implementing Quartile Analysis at Precast Yard

Sub-contractors deployed at the precast yard for segmental construction will differ in the processing time to cast a segment or to complete the casting of one span. Each of the sub-contractor deployed has different ways of doing the task. Hence, collecting a sample of segmental production processing times by each sub-contractor will help in analysing variation in processing times and the reasons which cause such variations. And if the best practices from the top performers are transferred to the bottom performers, the average productivity of the work will rise.

4.5 Main Problems at the Precast Yard

Productive time data of each work are not maintained by the project sites.

Sometimes inexperienced sub-contractor is deployed for production works.

Steps in which quartile analysis can be implemented:

The first step is to record productive time data for similar works done by each of the sub-contractors deployed at the precast yard.
Plot it dramatically to compare the top and the bottom quartile at the site. This will help in determining the variation in the process.
The aim is to reduce this variation by moving the bottom quartile up to the median or to the top quartile, which ultimately boosts productivity.

5 Implementing Productivity Tools

5.1 Overall Equipment Effectiveness (OEE) Framework

OEE is a powerful tool that helps to analyse the utilization and downtime of a machine and to see the potential for productivity improvements. This framework helps in evaluating the productivity of machines and other resources. The first step is to record the total available time of the gantry crane in an excel spreadsheet. Secondly, recording idle time, time spent on maintenance, gantry breakdown, unnecessary motion, etc., to determine waste of time. Thirdly, calculating productive time. The productive time of the resource is the difference between the total available time and the waste time. The fourth step is to determine the overall equipment effectiveness (OEE) of the resources. It is calculated as the ratio between productive time and total available time. Lastly, the OEE diagram can be prepared with the help of spreadsheet data (Fig. 12).

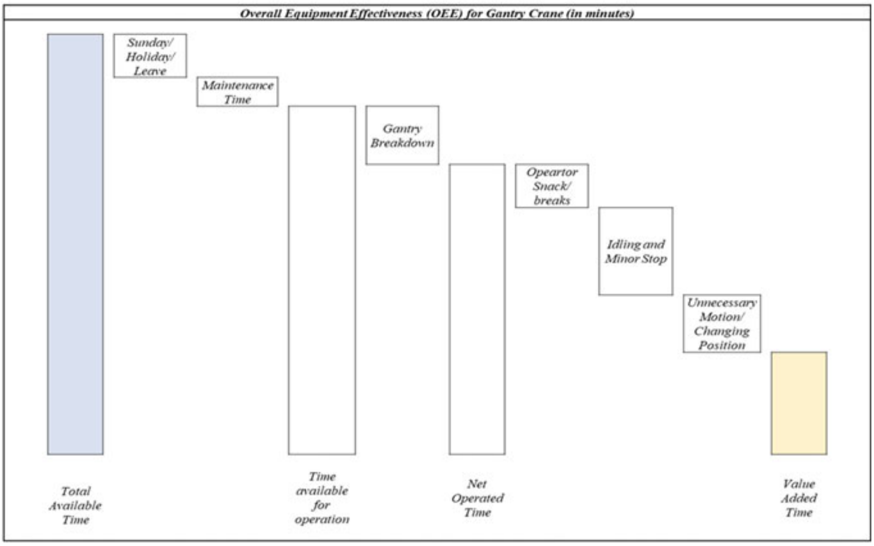


Fig. 12 OEE framework for gantry crane

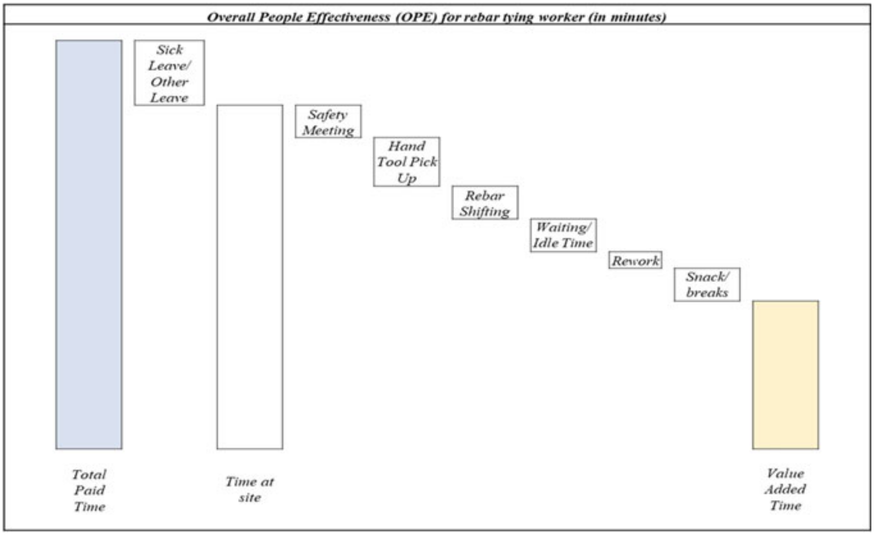


Fig. 13 OPE framework for rebar tying worker

5.2 Overall People Effectiveness (OPE) Framework

Overall people effectiveness (OPE) for each worker, working in the casting yard, can be estimated by following the steps described in the section. Figure 13 shows the value-added and non-value-added time dramatically for rebar tying workers.

The non-valued added time shown in above frameworks can vary for both machinery and worker. Hence, relevant changes can be made for calculating the value-added time for both machinery and workers.

5.3 Key Performance Indicators (KPIs)

This tool helps in visualizing the relationship between operational and financial variables. The main branch of the KPIs tree is profit. Profit is the difference between revenue and costs. Revenue in casting yards was driven by the number of segments casted multiplied by the rate of the segment. Cost is the sum of fixed cost and variable cost. Fixed cost includes equipment hire charge and staff payment. Variable cost includes sub-contractor payment, consumable material costs, and electricity bills (Fig. 14).

Depending upon financial variables at the precast site, the other branch of KPIs is added. Hence, KPIs will help in monitoring cash-inflow and cash-outflow per month and estimating the profit or loss made per month.

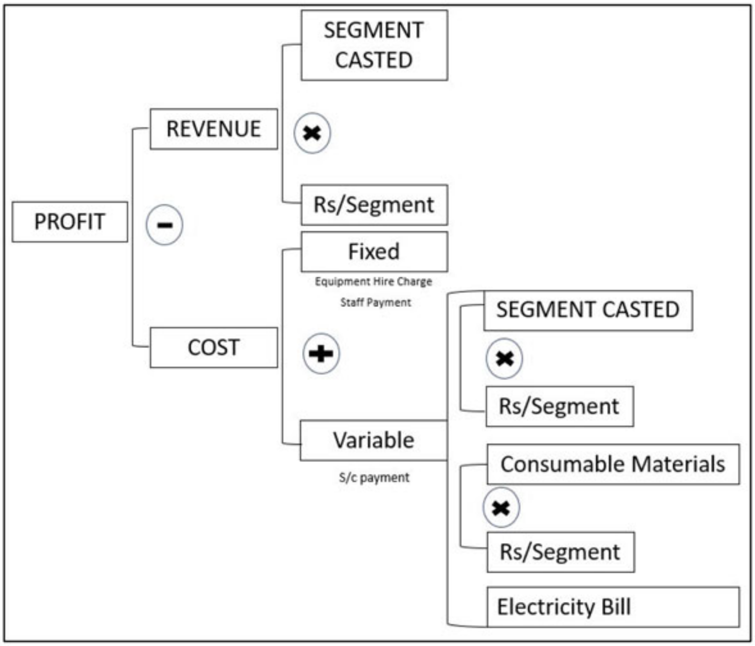


Fig. 14 KPIs tree

6 Discussion and Conclusion

This paper shows that a precast yard can employ practical concepts and productivity tools of operational management to increase productivity and hence its performance. These tools can be applied simply and easily by the precast team. This paper also emphasizes locating seven sources of waste in the precast yard. The main tools of operational management quartile analysis, OEEs, OPEs, and KPIs are discussed in brief. Overall, the paper focused on providing the guidelines in which these tools can be implemented in the precast yard to improve their efficiency and effectiveness.

The responsiveness versus crew productivity graph ensures that the site is utilizing their resource effectively. It helps in determining crew capacity, removing inefficiencies by transferring practices from best sub-contractors, helps in re-evaluating design or choosing technologies.

Quartile analysis implementation ensures that sub-contractor's approaches for executing work can be looked at while composing standard working procedures. The goal of site management should be to Fig. out how exactly the top-performing sub-contractors achieve their results and to find a way in which other sub-contractors deployed at the site for the execution of similar works can learn something from them. The variation of processing times across sub-contractors allowed seeking for productivity improvement.

OEEs diagram will show the effective time of the machine and downtime reasons dramatically. With the help of the machine's diagram, the site team can see where improvement can be provided faster. Hence, the site team must prepare an OEE framework for other machinery which they used at the precast yard. The following types of machinery are required for the superstructure construction process: Cutting machine; bending machine; backhoe loader; tire-mounted crane; gantry crane-100 T; gantry crane-25 T/40 T; batching plant (30 cum/h); transit mixers (4/6 m^3); and concrete pump with boom placer. Hence, the OEE framework should be prepared for all these types of machinery.

Similarly, OPEs framework can be implemented for every worker's working at the precast yard to determine their non-value-added work. Based on this site management can take necessary actions to enable faster construction.

The following waste at the precast yard can be minimized or eliminated by implementing these tools:

The graph between responsiveness versus crew productivity and quartile analysis helps in eliminating or minimizing rework, transportation, and motion waste.
OEEs will help in removing waiting waste.
KPIs will help in monitoring overproduction and inventory waste.

Further investigations should focus on how precast managers apply these tools at the site and how these tools benefit the project in achieving its target and thus saving from cost and schedule overruns.

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Identification and Analysis of Lean Techniques in Indian Metro Rail Projects

Sruthilaya Dara and Aneetha Vilventhan

Abstract Lean construction is now being implemented by several construction industries all over the world to increase the productivity of the projects. While endeavoring to implement lean principles, the construction industry is facing several challenges to decrease the occurrence of complexity. Urban transportation is becoming increasingly important in India, and it has become a prerequisite for economic and social success. Among urban transportation, metro rail projects are regarded as one of the most significant construction projects. There have been various studies on the technical and economic analysis of metro rail projects. But there are only a few studies on the application of lean techniques in metro rail projects to decrease the impact of complexity. The purpose of this research is to study the application of lean techniques in metro rail projects to reduce complexity and propose a conceptual framework. This study provides knowledge on the management of a metro project using lean techniques to reduce the occurrence of complexity. This research can be used successfully in metro rail projects to reduce complexity and waste, and increase productivity. The research results would help different stakeholders to put lean theories into practice.

Keywords Metro rail · Lean principles · Lean thinking · Lean production · Construction waste · Complexity

1 Introduction

In the construction industry, lean techniques aim to improve the performance of projects in terms of time, cost, and safety and also provide value to customers. The primary goal of lean construction is to establish processes that minimize waste of materials, time, and labor while increasing value [1]. Lean construction is a modern approach for designing and executing projects. This method is extremely useful for uncertain, complex, and time-bound projects. According to Howell [2], lean aspires

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to be an ideal and its ultimate goal is to improve the process. In the construction industry, lean techniques are used as a new and modern management approach to enhance productivity, increase profit and eliminate waste. Hence, the construction projects are finished within budget, on time, and with a quality level accepted by the client [3]. Lean construction, lean project management, and value engineering are some of the project management techniques that have been developed to enhance construction performance. Construction can benefit greatly from the lean production idea because manufacturing and construction processes are similar. One of the trends in the construction business with the greatest rate of growth is lean construction [4]. Applying lean techniques to the construction sector promises to enhance not only productivity but also the entire project management cycle [5]. Lean concepts have been applied successfully in the construction industry. To improve the quality of interior finishing work, it was used in the construction industry but on smaller-scale projects like residential structures [6]. These lean techniques have yet to be applied in large-scale projects like the construction of metro rails. Therefore, metro rail projects are chosen for the research objective to determine the implementation of lean techniques and their management.

2 Literature Review

India, a developing nation, meets several issues in the construction sector, including a lack of thorough and accurate historical data regarding complexities and a failure to adopt new technology for minimizing the impact of complexity factors to achieve the goals of construction projects. A modern ideology focused on managing construction production is called lean construction by creating control systems, reducing losses throughout the process, and also by initiating productive flows. This ideology was borrowed from Toyota Production System (TPS), which emphasizes waste reduction and elimination through lean production [7]. The term “lean construction” is used to describe the management strategy for achieving significant continuous improvement in the performance of a project process through the elimination of time and resource wastes that do not enhance the quality of the product or the level of service provided to the customer [8]. A series of flow conversion operations make up lean construction and is depicted the project as a series of interconnected tasks that must add value for the client [9]. According to Koskela [10] and Howell et al. [11], lean construction entails using just-in-time practices, pull-driven scheduling, lowering labor productivity variability, enhancing flow reliability, getting rid of waste, streamlining the process, and benchmarking.

3 Applications of Lean Methodologies in Construction Projects

Lean construction, according to Koskela [10] and Thomas et al. [12], entails the use of pull-driven scheduling, just-in-time (JIT) production, lowering labor productivity variability, enhancing flow reliability, getting rid of waste, streamlining the process, and benchmarking. Several additional ideas from the construction management sector are incorporated into the notion of lean construction. These ideas include product circles (PCs), business process re-engineering (BPR), concurrent engineering (CE), last planner system (LPS), total quality management (TQM), teamwork, and value-based management [13].

Many nations throughout the world have recently conducted studies on employing LPS and lean construction applications [14–16]. The project delivery system, production control, work structuring, design, supply chain, project controls, and overall construction project management have all been subject to attempts to adopt lean ideas and methodologies. Implementing two lean construction principles (benchmarking and minimizing labor productivity variability), Abdel-Razek et al. [17] concentrated on increasing construction labor productivity in Egypt. The benchmarks include the project management index, the performance ratio, and the disruption index. The intervention as a whole was presented by Ballard et al. [18] confirming the applicability of lean concepts and methodologies to the management of fabrication processes. They also presented instances of the benefits associated with better demand management, shorter cycle times, higher productivity, increased worker involvement, and increased income and profitability. The results show the usefulness of lean concepts and practices, as well as their applicability to fabricators' operations when supplying things engineered to order for building projects. Tsao et al. [19] employed lean thinking and work organization to improve the design and installation of metal door frames for a prison construction project. Koskela et al. [1]showed how to streamline and speed the construction process in their analysis of a fast-track office building project. To aid in decision making in the early stages of building projects, Marzouk et al. [20] used computer simulation as a tool to measure the impact of applying lean concepts to design processes in construction consultancy firms. A pull flow construction management software system based on the LPS was described by Sacks et al. [21] along with a collection of working mock-ups of a recommended system that has been built and tested. Alinaitwe [22]researched the effects of various hurdles on the efficacy of lean construction initiatives and then produced a graphical aid to assist decision makers in concentrating their efforts on overcoming barriers.

This study contributes to determining the effectiveness of applying lean construction principles to increase construction productivity and reduce project complexity. The study accomplished the following goals:

Investigating the barriers to approaching lean construction and the effectiveness of applying lean techniques practically in the construction of metro rail projects as a case study.

Creation of a conceptual framework through the identification of lean thinking.

4 Research Methodology

The action-based case study approach was employed as the research methodology in this study and is represented in Fig. 1. Implementation and thinking on an intervention that solves a real-life organizational problem are both possible through the use of the action research approach [23]. Metro rail construction involves inter-organizational coordination with multiple contractors, utility agencies, and political authorities. A reliable case study triangulates its data by gathering it from many sources [24]. They include participant interviews, on-site observation, project documentation, archival data, artifacts, and newspaper articles. Semi-structured interviews, site visits, and project documents were used for the case studies for understanding complexity. To comprehend complexity, 18 semi-structured interviews with stakeholders of metro rail projects were conducted and represented in Table 1. Interviews were conducted with the project manager, project engineer, quality engineers, and site engineer. Project specifications, lean tool application, coordination strategies, and management procedures were all acquired using an interview protocol. The gathered data is assessed using qualitative data analysis NVivo software to ensure validity and reliability.

To analyze the lean tool implementations during the construction of metro rail projects, a focus group discussion was organized. Focus group discussions enable interactive discussions on an issue with a group of selected participants to collect multiple perspectives and reach a consensus on the research topic Hennink [25], Leung et al. [26]. In the focus group, the impact of the application of lean concepts on the decreasing complexity of metro rail projects was discussed. Focus groups are typically conducted with a small group of 5–10 people to gain a comprehensive understanding of the research topic Hennink [25]. Therefore, eight participants are

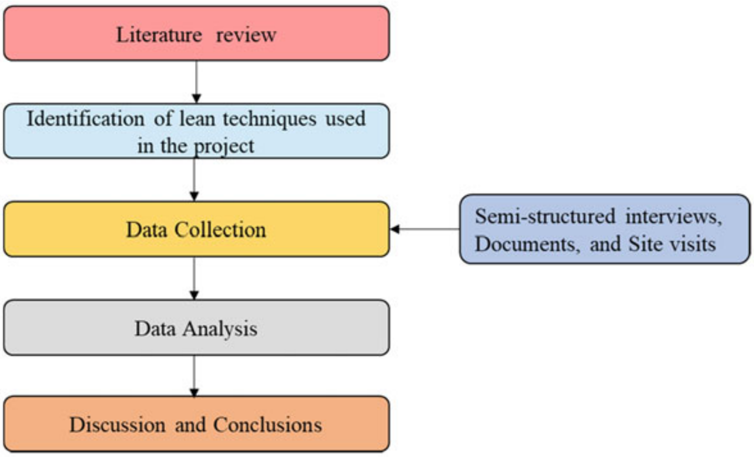

Fig. 1 Research methodology

Table 1 Demographic details

Category	No. of participants	Work experience
Project managers	3	> 10 years
Project engineers	3	> 5 years
Quality engineers	4	> 7 years
Site engineers	5	> 4 years
Contractors	3	> 4 years

considered for the discussion. The participants in the focus group discussions should share relevant experiences or backgrounds related to the issue of the study. Therefore, participants are selected from metro rail projects having profound knowledge and experience like project managers, project engineers, and quality engineers who are selected as participants having at least six years of professional experience. In April 2020, focus group discussions are conducted for an hour with the help of a semi-structured questionnaire. This ensures that all essential concerns and questions are handled during the conversations. The questions were designed to promote group discussion and the exchange of ideas on how to apply lean concepts to minimize project complexity during the construction. The discussions were ethically audio recorded, and the NVivo 11 software was used to analyze the transcriptions to ensure the validity and reliability of the study.

5 Case Study Description

To identify the lean tool applications to decrease the complexity of metro rail projects during the construction stage, the ongoing metro rail projects are selected for the case study. The complexity is a major problem in large infrastructure projects. Metro rail projects are considered to be one among them; hence, the Bangalore and Ahmedabad metro rail projects are considered for the study. Bangalore Metro Rail RT-03 project is Design and Build contract. The contract of BMRCL has phase 2 with the design and construction of a 2.8 km tunnel and two stations for 17 million USD. Ahmedabad metro rail project is a turnkey contract, and the project is divided into two phases. The phase I project is 40.03 km long, with 6.5 km underground and four stations, and 13 elevated stations, for USD 1619.3 million. This phase has two corridors, the east–west corridor with 17 stations and north–south corridor with 15 stations, linking four important areas of Ahmedabad. Phase II was approved by the Government of Gujarat (GoG) in October 2017 with a total length of 28.2 km, two corridors of 22.838 km and 5.416 km, with 24 elevated stations connecting Gandhinagar, Ahmedabad Airport, and Gujarat International Finance Tech (GIFT) city.

The most common complexities faced in the metro rail projects are acquiring the right of way (ROW), finalization of the contract, interface, integration of works by various contractors, delay in acquiring materials and labor, contractual aspects, and project management. These complexities are reduced and monitored as follows by using the conventional approach. Hence, the research suggests the following lean approach in addition to conventional methods.

6 Conventional Methods

Alignment was carefully finalized/revised with no/minimal impact on the existing structures. In line with the project schedule, right of way was also acquired sequentially to ensure less impact on the schedule.

With the requirements detailed, identifying the best contractor to tide along with the difficulties of the project was a key challenge. Even during the difficult times, all the contractors supported well to complete the project.

Various monthly review meetings are conducted regularly throughout the project to monitor the progress, identify the potential roadblocks, and plan the works accordingly to ensure the work is not hindered.

Initially, the project is divided into six stages. Continuous improvement and modifications are made from the previous experiences. The lead contractor shares the work schedule with the subcontractor to ensure a seamless flow of work during back-and-forth handover and takeover.

To ensure client satisfaction throughout work progress, certification of intermediate project milestones is established.

Various stakeholders are involved in the project; therefore, before developing the master schedule, all the stakeholders were involved in identifying the potential complexities and risks along with remedies/actions for the project. Identified complexities and risks are categorized into major, moderate, and minor. Based on all the inputs and experiences from other metros, master schedule was developed using Primavera software. Based on the key dates and milestones of the contract, all the contractors were also asked to develop detailed works schedule using Primavera and submit the monthly progress. Every contractor develops a work program and further develops extracts detailing the monthly and weekly schedule.

Overall project planning is monitored by the project control team and notifies the execution team of delays/hindrances. Project review meetings are attended by project managers of contractors along with a team of four. The contractor may take inputs from the designers and consultants.

Monthly review meetings chaired by the project director, monthly interface meetings conducted by the general consultant, and various site visits and review meetings for monitoring the wastages and progress of the project.

The project manager and core team members from the contractor's team attend the meetings. Minutes of Meetings are circulated with action points and target dates. The progress is tracked by using earned value management method, building information modeling (BIM) is used for integration of all systems in civil construction, and project progress is monitored using Primavera schedules.

7 Lean Construction Approach

A reliable work flow can be established much earlier, after identification of complexities, and on-site activities are to be implemented using a virtual platform.

Minimizing waste and maximizing the value by considering the whole project as a single unit.

The outputs offered are to be driven by pull by minimizing the waste and concentrating what is required.

More transparency has to be maintained by considering the participation of all stakeholders and involving them in the decision making for decreasing the interface problems.

The changes and modifications are to be considered at the early stages, and provisions have to be made accordingly to increase the productivity of the project and accept the possible modifications occurred.

Abundance of collaborative work is required among all the parties.

Future prospects and continuous improvement are both considered to be top priorities.

8 Application of Last Planner System (LPS) to Metro Projects

The last planner system was implemented in the metro project to assess the practical efficiency of lean construction techniques. LPS is related to the pull methodology, which plans backward while looking ahead to the project. This guarantees both performance and the dependability and reliability of work flow. When the LPS was first introduced, project engineers were asked to assign work to the site engineers, supervisors, and site crew, so that the stakeholders in site management could have appropriate-level conversations with the trade foreman in order to prevent critical issues from occurring on site. The site engineer was given a five-week look-ahead schedule and asked to prepare a reverse-phase scheduling based on the project five weeks ahead. The site engineers were instructed to carry out reverse-phase scheduling, variance analysis, and percentage plan completed charts to compare the planned and actual performance over time as percentages, and a baseline was created. After the application of LPS, the people we talked to said that "pull-planning," which is another name for the collaborative approach, is the best way to make sure that everyone knows what their roles and responsibilities are and what they can expect from each other in order to reach milestones. The last planner system goes into detail about the planned activities long before the conditions on the site can be known. Instead of trying to improve each task separately, this improves the flow as a whole. The flow is strengthened when the integrated project team uses pull-planning to schedule the work flow-related activities identified through value stream mapping because everyone in the project learns to make clear requests. This ensures that installations of structural elements are error-free and construct/install them in a safe, efficient, and standard-compliant manner. This helps in reducing the rescheduling of work; hence, the technological complexity is minimized. The weekly performance of the projects was observed and measured in percentages with number of completed percentage of events divided by total percentage of events in a phase. From the application of LPS, the transparency in the project is obtained 80% by regular communication with the stakeholders using visual management systems. This helped to reduce the organizational complexity which is caused due to interface problems. Reduction of variability is 64% by using standards communication and design methods, just-in-time, and reviewing the designs at the early stage of work. The reduction of variability has helped to minimize the environmental and organization complexity occurred due to lack of communication, delay in permissions obtained from authorities. The 55% of waste elimination was observed by reducing the non-valued activities, creating awareness to the workers about productivity loss and importance of waste elimination. The identification of non-value-added activities have helped to minimize the quality complexity. The 75% of continuous variability is obtained by monitoring the site, continuous educative seminars, and programs helped in decreasing the impact of technological complexity in metro rail projects.

9 Findings from the Case Study and a Proposed Frame Work

From the observation of metro projects, it has been discovered that the amount of construction waste has decreased to a minimum. Leading time was reduced, and a more effective way to use the workers was identified, and the quality of construction outputs was reported to be outstanding. The application of LPS has increased the labor, material, and equipment productivity with establishments of schedules and targets. The establishment of value-added events has been increased. The transparency in the project has been maintained for the effective productivity, and more than half percentage of the waste elimination has been maintained. The changes made in decision-making process has increased the information flow and has reduced the reworking and rescheduling of events. The results also show the enhancement in the work process, stakeholders, and improvements in the project productivity and performance. The application of lean helped in waste minimization, increased transparency, quality, reliability, and reduction variability. Using all of the findings, a general conceptual framework is developed to apply the same LC principles in a more comfortable manner. The overall duration of the activities can be reduced by employing lean techniques that focus on eliminating waste as well as the delays and disruptions it cause. The framework was developed to show how successfully LC practices can be integrated into metro rail construction. The framework is more effective for projects that must be accelerated but are characterized by uncertainty.

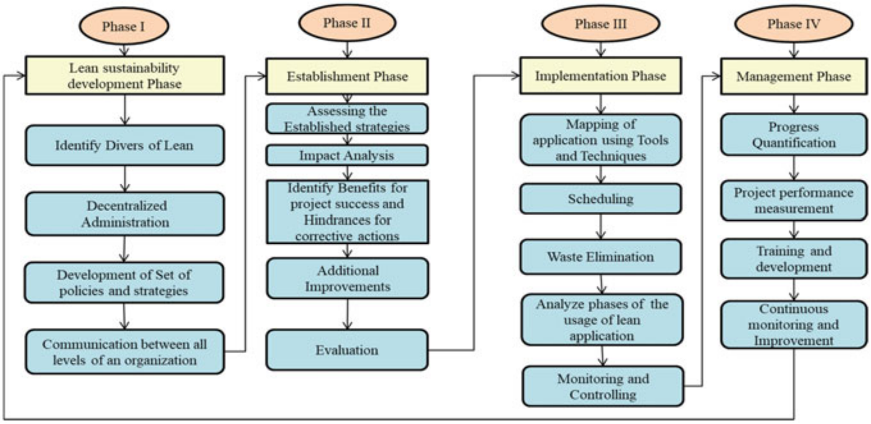

Fig. 2 Framework of lean construction

Figure 2 illustrates the proposed framework for implementation of lean in metro constructions.

10 Conclusions and Discussions

The application of lean techniques in metro construction is the most beneficial according to the present study. According to the focus group discussions, the use of lean techniques helps in reducing the impact of complexity in metro rail projects during construction. While metro rail construction is still in its early stages, efforts to implement lean construction (LC) are clearly yielding positive results. Although many countries have greatly benefited from implementing lean concepts, the accuracy of lean implementation in metro rail projects is comparatively low. The lack of adequate lean awareness and understanding is one of the most significant challenges encountered in the metro context. From the study, it is observed that the application of LPS is one critical step that could result in a significant and positive change and increases the project performance. A general framework was developed after weighing the benefits of LC practical application. From the application of lean techniques, the value technique can be used to identify waste that adds no value to the project's progress. These are mostly visible in the metro rail precast yard. Because of the rapid advancement of technology, the methods and techniques used to enhance the features of the project are changing; thus, the application of the value technique is more useful. The metro projects are inter-organizational and involve multiple organizations, and using value stream mapping to manage the flow of men, materials, and machinery during the construction phase of the metro project is beneficial and helped in minimizing the technological and organization complexity. This application of this principle aided in the improvement of the construction process and the reduction of

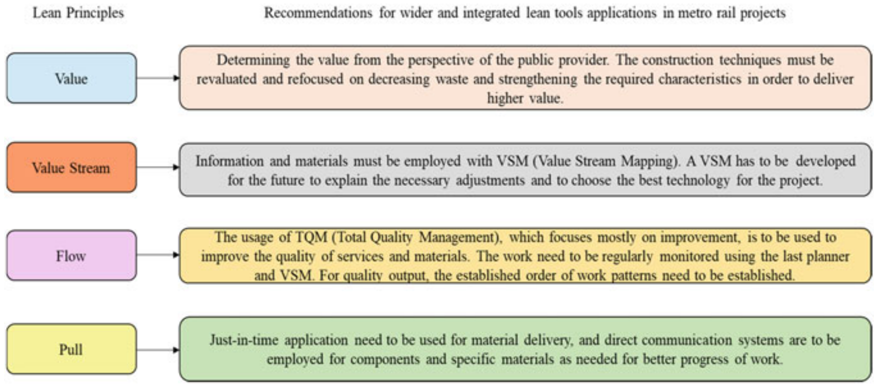

Fig. 3 Recommendations for lean tools applications in metro rail projects

waste in variable conditions. Because precast components are commonly used during the construction phase of metro projects, flow and pull techniques are used to reduce waste and delays in component delivery and have a great impact in decreasing the environmental and organizational complexity. The application of the flow principle facilitates the detection of flaws and problems. This aided in standardizing things and decreasing the delays caused by the flow and processing of information. One of the most important lean thinking principles is the pull. This aided in obtaining real-time feedback from on-site workers as well as balancing off-site work. The application of this lean technique decreased the impact of decrease in quality and helped in minimizing the technological and social complexity. More research is needed to confirm the validity and reliability of this framework. From the above discussions, the inputs obtained from focus group recommendations for lean tool applications in metro rail projects to decrease complexity is shown in Fig. 3.

11 Recommendations

According to the research study, lean construction is considered to be one of the best management techniques to control the wastages in metro rail projects.

The usage of lean techniques is advantageous in terms of cost control and value addition as it mainly focuses on the elimination of waste throughout the project cycle.

The lean techniques of six sigma, last planner, and just-in-time are the most important and are easy to apply in the metro rail projects.

The increase in the usage of lean techniques and principles will help in increasing the efficiency and quality of the project and also helps to reduce the cost and time of the project.

The use of lean techniques can reduce the total project time and cost increasing customer satisfaction and productivity.

Advising lean construction principles and techniques after considering all of their advantages and the benefits with which they may be applied to decrease the complexity of the metro rail project.

12 Future Scope

The application of lean construction concepts in the current study seeks to decrease the effect of complexity on metro rail projects. The study is limited to Indian metro rail projects. A similar study can also be conducted on the overall metro projects worldwide including underground and elevated metro rail projects. Lean approaches have been used by various construction industries to enhance productivity and improve project efficiency. However, the adoption of lean concepts is lacking in metro rail projects. Therefore, this can be used to reduce the project's complexity throughout the project cycle. Future research can also make the metro rail project less complex by making it more effective and productive, which will help to increase GDP.

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Application of Lean Principles to Improve Rebar Productivity in Heavily Reinforced Structures

Amith G. Mallya, Varun Kumar Reja, and Koshy Varghese

Abstract The goal of any construction project is to meet the objectives with the optimised cost and within the prescribed time; it is, however, noted that most construction projects fall behind schedule and, therefore, use additional resources to meet relevant deadlines, which results in cost overruns. Techniques like lean construction have been applied in the construction industry over the years with varying levels of success. This report studies the application of lean construction techniques in construction projects with heavy reinforcement, specifically dealing with the accuracy of schedules and difficulties in estimating productivity. Many of the core lean concepts have predictability as their goal; predictable behaviour improves schedule quality, which improves cross-team coordination, which in turn leads to improvement in predictability. Firstly, in this paper, literature is studied to understand the current research related to reinforcement productivity and ways to predict it. Next, efforts are made to predict productivity based on parameters defined using reinforcement design parameters. The data is analysed to understand the reason for productivity loss seen in heavily reinforced structures based on the prediction models.

Keywords Lean construction · Productivity improvement · Reinforcement · Data fitting · Revit modelling · Bar-bending schedules

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1 Introduction

Productivity of construction activities like rebar fixing is affected by various factors. In heavily reinforced structures, design of reinforcement also contributes to reduced productivity. This report tries to find a method to predict rebar productivity based on the complexity of the structure (i.e., close spacing, complex geometry, presence of openings) and implement measures to improve the same).

It was noted from the literature that productivity at a construction site was affected by numerous external [20] and internal factors [14], including the design of the structure. In particular, reinforcement design is studied in this report. As the literature does not mention productivity in heavily reinforced structures as seen in industrial buildings, nuclear plants, and bridges, this report tries to study the effect of heavy reinforcement on productivity, if any and propose measures to improve it.

The problem with the predictability of construction activities is due to several reasons like low mechanisation, environmental effect, lack of consideration for constructability in design, and minimal opportunity for design optimisation. A systemic study to understand the research literature available on reinforcement productivity in construction yielded several papers discussed in the coming section.

Therefore, the objectives of this paper are:

To assess how rebar productivity is affected by the complexity of the structure.
Develop a methodology to quantify and predict productivity based on the complexity of the structure.
Identifying bottlenecks/limiting factors affecting productivity.
Suggesting measures to tackle the bottlenecks found.

2 Literature Review

With the implementation of various philosophies, the productivity of the manufacturing industry has been steadily increasing since the start of the industrial age; the lean philosophy was first implemented in manufacturing based on the Toyota production system (TPS) in the 1980s. The term lean construction first appeared in 1992 [8]. According to Jørgensen and Emmitt [6], all methods that encompass lean construction focus on some common elements like the reduction of waste concerning the end customer expectation, managing the supply chain from a demand-pull approach, and approaching production through a focus on processes and flow. To implement these philosophies, it is important to have accurate schedules. To understand the available research on the topic, a systematic search was conducted using SCOPUS and Google Scholar search with 'rebar' or 'reinforce*', 'Productivity' and 'Construction' as keywords. From the literature, following are the five main points noted.

Productivity measurement: Accurate measurement of productivity is very important to understand the root causes for issues at the site and to understand any improvement obtained by implementing changes.

Factors affecting productivity: Productivity at construction sites can vary based on several external and internal factors though the literature suggests reinforcement design as a factor that can affect productivity, it does not detail or quantify what characteristics of reinforcement design cause productivity issues [5].
Predicting productivity: As stated earlier, productivity is affected by several factors, and it varies from site to site based on design, management, project type, etc. Thus, predicting productivity is essential for preparing proper schedules.
Productivity improvement: Many studies have suggested the use of different techniques to improve productivity, from training to the use of technology [21].

With improvements in technology, several software and hardware solutions have been developed and implemented at various sites for a variety of purposes; several studies detailed above have used machine learning, neural networks, sensors, robotics, and simulation software to deal with different challenges at the site [19, 23].

Table 1 presents the summary of all the literature and the points covered by them.

3 Problem Description and Study Details

Construction site involves multiple processes by different teams of workers, like surveying, groundwork, rebar work, formwork, concreting, finishing, etc. With an accurate schedule, each team can plan a just-in-time system reducing waste in the form of excess inventory and equipment/labour idling waiting for work fronts.

This report summarises the study on productivity variation in heavily reinforced structures. Figure 1 shows the methodology of the study, which is divided into three phases.

The first phase involves data collection and literature review to study the problem in detail, the second phase involves data fitting and validation of models developed, and the final phase analyses the model and result to get to a conclusion.

4 Data Modelling

To make a model to predict productivity, dependent and independent variables had to be defined and calculated.

From the literature, productivity is said to be affected by factors other than design. To have a good prediction model, it is required to isolate the data which are only affected by the factors that are of interest to this study, and to achieve, the following steps were taken.

The test data were collected within two weeks, and it was ensured that weather-related factors were not present in the data points.

All the data were collected from a similar elevation, thus eliminating variation due to equipment bottlenecks like cranes.

Table 1 Summary of literature

Sl. No	Name of the paper	Productivity improvement	Productivity measurement	Use of technology	Predicting productivity	Factors affecting productivity
1	A competency-based training guide model for a labourer's in construction [12]	✓	☐	☐	☐	☐
2	How to predict the rebar labour's production rate by using ANN model? [1]	☐		✓	✓	
3	Analysis of labour efficiency supported by the ensembles of neural networks on the example of steel reinforcement works [7]	☐		✓	✓	
4	Pathways for the improvement of construction productivity: A perspective on the adoption of advanced techniques [22]	✓		✓		
5	Integrated optimization of rebar detailing design and installation planning for waste reduction and productivity improvement [25]	✓		✓		
6	Modelling labour productivity rates for reinforcement works [9]	☐		✓	✓	
7	Modelling manpower and equipment productivity in tall residential building projects in developing countries [16]	☐			✓	

(continued)

Table 1 (continued)

Sl. No	Name of the paper	Productivity improvement	Productivity measurement	Use of technology	Predicting productivity	Factors affecting productivity
8	Work practices of onsite construction crews and their influence on productivity [11]					✓
9	An empirical investigation of the learning effect in concrete operations [17]	✓				✓
10	Modelling manpower and equipment productivity in tall building construction projects [15]				✓	
11	Micro and macro level analysis of labor productivity [18]		✓			✓
12	Development of a workers' behavior estimation system using sensing data and machine learning [24]		✓	✓		
13	While loop algorithm to enhance the efficiency of work sampling method in performance measurement [3]		✓	✓		
14	Evaluating the work productivity of assembling reinforcement through the objects detected by deep learning [10]		✓	✓		

(continued)

Table 1 (continued)

Sl. No	Name of the paper	Productivity improvement	Productivity measurement	Use of technology	Predicting productivity	Factors affecting productivity
15	Accelerometer-based activity recognition of workers at construction sites [4]	☐	✓	✓		
16	Use of augmented reality technology to enhance comprehension of construction assemblies [2]	☐		✓		

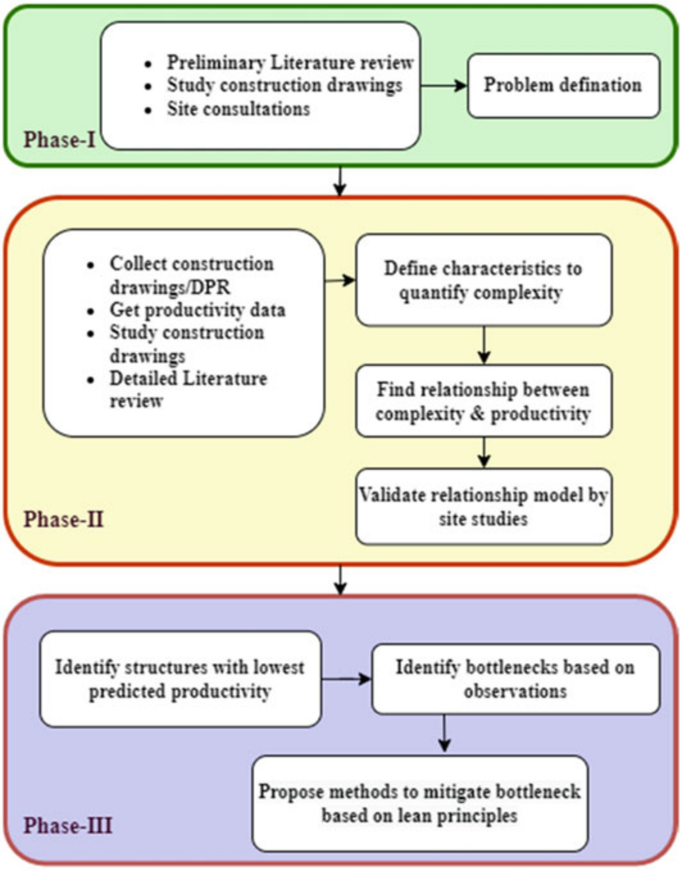

Fig. 1 Methodology flowchart

Distance between the stockpile and work area was similar for most of the data points, thus eliminating variation due to site layouts.

The data points were not affected by the lack of materials and operational delays.

4.1 Defining Complexity

Complexity is subjective in nature when comparing two structures; one can be said to be more complex than the other. But quantifying how much more difficult it is not easy; discussions were conducted with the foreman at the site. The following points were noted to be factors affecting productivity.

Diameter and length of the reinforcement, larger diameter, and long reinforcement are heavier and more difficult to handle at the site where space might be limited.

Rings and stirrups for columns and beams are more difficult to place when compared to main bars.

Openings in walls increase the number of bars and thus increase complexity.

Rework is needed when reinforcement foul with embeds openings.

Joggling of reinforcement is needed in beams to prevent fouling with reinforcement of adjacent beams and columns.

To convert these factors into a quantifiable number, from the literature, following were noted. Krawczyńska-Piechna [9] used a point system to determine a score to define various properties for rebar bending, which was used in a classification algorithm. Munshi and Saini [13] considered a metric like the weight of reinforcement per unit volume of concrete to define congestion which was then used to compare congestion between nuclear construction and normal construction. Based on literature and site experience, two parameters are suggested initially to define complexity.

Parameter 1—Density of reinforcement: This parameter is the ratio of the weight of reinforcement to the volume of concrete for the structure in question, measured as MT/cum. The weight of reinforcement is calculated based on the bar bending schedule provided by the designer or BBS procured from the steel yard. The weight of concrete is obtained by considering the structure's dimensions and openings. This parameter accounts for the close spacing of reinforcements, the diameter of reinforcements, and congestion. This parameter shall be denoted as $P1$.

Parameter 2—Nonlinearity of reinforcement: This parameter is the ratio of the number of bends of all bars to the total length of reinforcement for a given structure multiplied by 10. It is measured as bends/10 m. This parameter accounts for complexity due to stirrups/column rings; it accounts for openings and short sections. This parameter shall be denoted as $P2$.

4.2 Curve Fitting

Curve fitting is the process of constructing a mathematical function that best fits a series of data points, subject to constraints. Depending on the process, data modelling could either be parametric modelling (regression modelling) which gives a function as output and nonparametric modelling (interpolation), whose output cannot be described as a function.

5 Result Validation and Interpretation

For a given set of data points, it is possible to create multiple surfaces to determine the best fit. The predicted productivity values are compared with actual productivity data, which is independent of the test data.

5.1 Polynomial Model

After fitting the data in MATLAB, the polynomial function with the best

$$\begin{aligned} f(x, y) = {} & 0.06299 + (0.01943 * x) - \left(0.01943 * y - 0.006567 * x^2\right) \\ & + (0.00145 * x * y) + \left(0.00145 * y^2\right) + \left(0.002058 * x^3\right) \\ & - \left(0.00113 * x^2 * y\right) - \left(10^{-5} * x * y^2\right) - \left(7.5 * 10^{-5} * y^3\right) \end{aligned} \quad (1)$$

where ‘x’ refers to $P1$ and ‘y’ refers to $P2$ and f gives the predicted productivity. Figure 2 shows the plot of the function.

To test the validity of the model, productivity for eleven independent data points is compared with predicted productivity as given in Table 2.

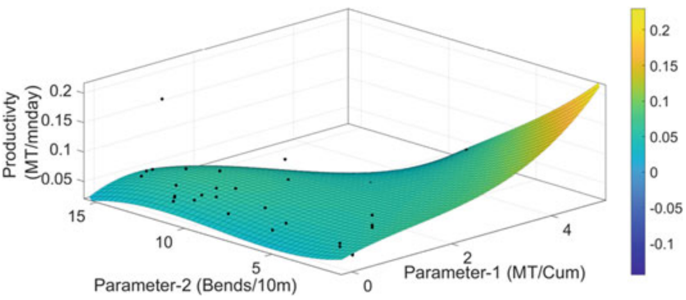

Fig. 2 3D plot of polynomial fit

Table 2 Validation of polynomial fit

Structure	Actual productivity	*P*1	*P*2	Predicted productivity	Variation (%)
Column 1	0.052	0.045546	11.35392	0.0482	7.31
Shear wall 1	0.042	0.194716	13.79791	0.047	– 11.90
Column 2	0.058	1.813522	9.676234	0.0571	1.55
Column 3	0.049	1.481419	13.77307	0.0521	– 6.33
Column 4	0.045	2.73948	8.972682	0.0451	– 0.22
Column 5	0.045	2.025198	8.142799	0.0546	– 21.33
Column 6	0.041	4.095403	8.64963	0.0351	14.39
Column 7	0.046	4.285483	8.592588	0.0363	21.09
Slab 1	0.073	0.523949	8.63839	0.0482	7.31
Column 8	0.044	0.295196	10.30573	0.047	– 11.90
Column 9	0.056	0.388892	9.881788	0.0571	1.55

From this data, it can be seen that the predicted productivity varies from actual productivity, this variation is up to 25% of the productivity, and for five of the eleven data points, the variation was within ± 10% of the productivity.

5.2 *Interpolant Model*

For the interpolant modelling, the thin plate spline method was chosen, so that extrapolation of data was possible. Figure 3 shows the plot of the surface obtained using MATLAB.

To test the validity of the model, productivity for eleven independent data points is compared with predicted productivity as given in Table 3.

The predicted productivity varies from actual productivity, this variation is up to 217% of the productivity. In only two of the eleven data points, the variation

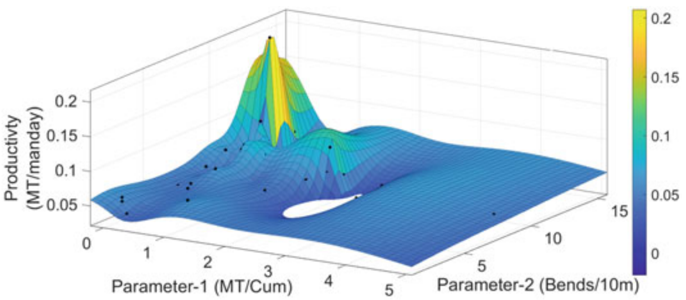

Fig. 3 3D plot of interpolant model

Table 3 Validation of interpolant model

Structure	Actual productivity	*P*1	*P*2	Predicted productivity	Variation (%)
Column 1	0.052	0.045546	11.35392	0.049	5.77
Shear wall 1	0.042	0.194716	13.79791	0.1332	– 217.14
Column 2	0.058	1.813522	9.676234	0.0481	17.07
Column 3	0.049	1.481419	13.77307	0.0745	– 52.04
Column 4	0.045	2.73948	8.972682	0.0496	– 10.22
Column 5	0.045	2.025198	8.142799	0.0047	89.56
Column 6	0.041	4.095403	8.64963	0.0603	– 47.07
Column 7	0.046	4.285483	8.592588	0.0576	– 25.22
Slab 1	0.073	0.523949	8.63839	0.0635	13.01
Column 8	0.044	0.295196	10.30573	0.042	4.55
Column 9	0.056	0.388892	9.881788	0.0685	– 22.32

was within ± 10%. It can be inferred from this that there is a larger variation in productivity when compared to the parametric model.

5.3 *Classifier Model*

From the above models, it can be concluded that predicting the exact values of productivity is difficult due to the nature of construction. It is not useful in understanding the factors of reinforcement design that affects productivity.

To better understand the data, a classification system was applied to the data and analysed to find the patterns; in this method, both the dependent and independent variable is classified into three categories, i.e., below average, average, and above average, and analysed to find any trends in the data.

Excel was used to implement the classification system, and multiple if commands were used to classify the productivity, rebar density and nonlinearity parameters into three categories based on the limits shown in the Table 4.

After classification for each pair, the percentage of data points which are below average, average, and above average is calculated and studied to find any trends. Table 5 details the result of the classification system.

Table 4 Limits used in classification

	Below average	Average	Above average
Productivity (MT/man day)	≤ 0.04	0.04 to 0.06	≥ 0.06
Rebar density (MT/Cum)	≤ 0.25	0.25 to 1	≥ 1
Nonlinearity (Bends/10 m)	≤ 4	4 to 10	≥ 10

Table 5 Classification results

Density	Nonlinearity								
	Below average			Average			Above average		
Below average	2	3	–	3	3	–	1	6	3
	40%	60%	–	50%	50%	–	10%	60%	30%
Average	–	–	–	2	5	5	1	7	4
	–	–	–	17%	42%	42%	8%	58%	33%
Above average	0	3	2	–	10	1	–	3	–
	0%	60%	40%	–	91%	9%	–	100%	–

By analysing the classifier model, some conclusions can be drawn.

For a given reinforcement density, productivity tends to decrease with an increase in nonlinearity.

For a given nonlinearity, productivity tends to increase with reinforcement density.

The following observations can explain this, data points considered in this model refer to structural elements like columns, beams, walls, and slabs, with columns and beams forming the majority of the data points collected.

In a column/beam, there are generally two types of reinforcement bars, reinforcement elements parallel to the length of the structure (main bars), and reinforcement perpendicular to the length (stirrups, rings etc.). Main bars are generally larger in diameter and are easier to fix in place as they are usually long and straight. Stirrups/rings, on the other hand, are of smaller diameter and take longer to fix in position, thus reducing productivity.

Thus, a structure with high density will have large/a greater number of main bars (as the contribution of rings to density is less compared to the main bard), and a structure with high nonlinearity will have multiple sets of rings (as main bars being mostly straight contribute less to the nonlinearity parameter).

6 Revit Modelling

The polynomial model was applied for structures planned, and probable productivity for four hundred and twenty-five structures was calculated. Based on this data, monthly plans can be suitably adjusted, so that low-productivity structures can be balanced with high-productivity structures for a given schedule.

Also, efforts can be made to improve productivity for these structures using Revit modelling, as visualising the structure from the 2D drawing was found to be difficult. Figure 4 are models developed for walls using REVIT software.

By using the Revit modelling, following benefits can be noticed:

Better visualisation of structure, reinforcement, and embeds.

Early clash detection between various components.

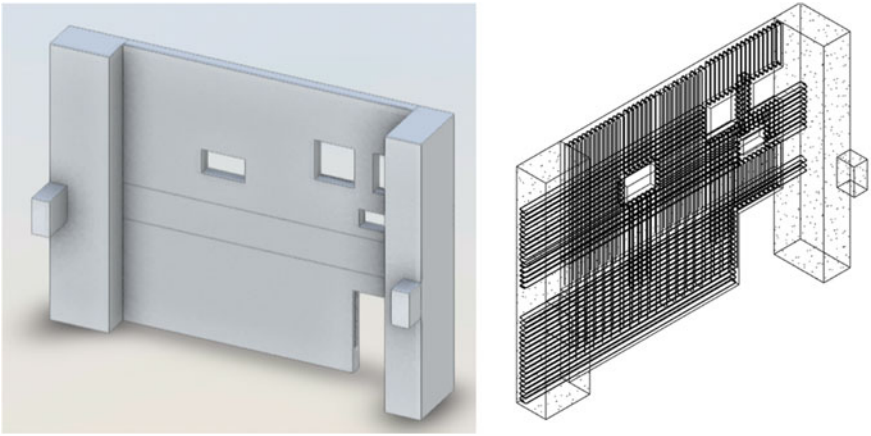

Fig. 4 Revit model

Detect mistakes/inconsistencies in drawings before the start of work.
Can automate bar-bending schedules.

7 Conclusion

From the models developed, it can be concluded that reinforcement design does affect productivity in several ways and can be predicted with some degree of accuracy. Following are the conclusions drawn from this study.

Contrary to popular belief, large-diameter heavy reinforcement (high-density perimeter) does not lead to a loss in productivity. Instead, it increases productivity.

Loss in productivity is seen when the number of bends in the reinforcement increases, so short walls, nonlinear walls, the presence of openings discontinuation in reinforcement, and presence of stirrups/column rings affect productivity, especially for structures with a density of more than 0.25 MT/cum.

The schedules can also be better designed to better balance the number of low- and high-productivity structures to achieve a reliable productivity rate, which in turn improves schedule quality.

More effort in the form of Revit modelling can be provided for structures with low predicted productivity.

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Application of Lean Technique in Warehouse Operations for Waste Reduction

Ajay K. Sinha and P. Muralidhar

Abstract The role of warehouse is very crucial in proper functioning of supply chain management system. It provides temporary storage for the goods before delivered to the end customer. In the past, it was used for storage purpose only, due to which it is considered as a cost center. But, nowadays various value-added activities like labeling, packaging, cross-docking, etc., are performed by the companies inside the warehouse. This helps in achieving better efficiency and improved customer service level within the supply chain. In this research paper, problems at various level of warehouse operations are identified at first stage. Then, at second stage, appropriate lean tools and techniques are identified and applied to eliminate them. This leads to waste reduction, enhanced productivity, and improved efficiency in the warehouse operations. Further, this research may provide insight to the companies about how to adopt and implement lean techniques into their warehouse management system effectively.

Keywords Lean technique · Warehouse · Operations · Waste reduction

1 Introduction

Lean systems are existing since 1980s in various activities like manufacturing, supply chain, warehouse, and associated activities. It has grass roots in manufacturing area and became popular due to the high success in manufacturing systems. In that there is a lot of scope for improvement in productivity and reducing the wastage in assembly line [1]. This resulted in less manual intervention in production and high automation in process which helps in achieving enhances productivity. Once the product is produced, it is stored in warehouse for some time, and then, it will be transported

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to the customer location. Currently, many organizations worldwide follow the lean practices for improving the productivity, reducing the waste, cost, and their resources. This will help in improving the quality of the output which leads to the excellence.

Lean systems can be implemented everywhere, and proper implementation of lean gives higher productivity in any sector.

Warehouse management systems is a pillar of logistics Industry. The major function of warehouse management systems are: (a) tracking the inventory, (b) layout planning, (c) labor management, (d) order processing, (e) analytics, (f) paperless documentation, (g) reliable customer service, (h) increase productivity. Implementing the lean systems in warehousing is a new experiment, but it concentrates on excessive inventory, scope for space utilization, and adding the value to the distribution process by avoiding the stock out situations. For successful e-commerce business, an efficient warehousing system plays a key role in proper distribution of goods among the customer.

The expected compound annual growth rate (CAGR) of warehousing market for FY 2021–2026 is expected to register 10%, and in FY 2022, it is estimated as 5.5%. As per the report [6], utilization of warehouse services in the sectors like FMCG, FMCD, retailing, e-commerce, etc., may increase up to 68% during AY 2022–26. The income to the country through warehousing business and its contribution to GDP is going to increase significantly in the upcoming years. As per the report [6], e-commerce, FMCG sectors will reach $120 bn. market, and proportionally warehousing business will also record the growth significantly. With huge foot print, the warehousing sector is trying to enter into tier-2 market because of the high labor cost, limited space in tier-1 market, and good distribution capabilities and to grab tier-2 market in e-commerce and allied areas. In India, the warehousing sector witnessed substantial growth in leasing the space in recent years due to active presence of FMCG and e-commerce players. Amazon, Walmart, Tata group, and Reliance companies are going to play huge role in the growth of the warehouse business which ultimately boosts to the economic growth of the country.

The above statistics shows that the warehousing business has lots of potential for expansion in India. The issues related to the operations of warehouse needs to be addressed properly for improving the productivity and efficiency. This research paper basically addresses the warehouse operational problem by the application of lean tools/techniques. More specifically, it will try to answer the following questions:

I. To identify the problems at various levels of warehouse operations.
II. To apply the appropriate lean tools/techniques for eliminating the identified problems.

2 Literature Review

The e-commerce applications are increasing nowadays due to which product life cycle span is reduced drastically and competition become more among the companies for their survival [8]. The lean network became very popular due to its success in addressing these problems faced by companies [1, 9]. This problem can be addressed to some extent by adding the innovative ideas toward the product improvement, to stay globally competitive in the market.

The term lean was coined first by Womack, Jones, and Roos in the book: "The machine that changed the world" in 1990 [16]. In this book, the authors mentioned about the success of automobile industry by implementing the lean principles [11]. The lean is nothing but doing more with less input [15]. The lean system is a mindset of the people, and they should think how we can get the results by using lean systems. Now, the lean system become very popular and could be applied to any environment. The new thing to be implemented is how various tools can be applied in the lean system related to specific sector [10]. Some of the new lean operations sector is proposed by Karlsson and Ahlstrom [4]. Whatever the way lean was implemented has proven with positive results in almost all industries [5], and the same elements will be helpful in warehouse also.

The application of lean techniques started in the year 2015 due to high demand in warehousing the products. The application and implementation started signifying from 2015 onward [12]. Very less research is done on warehouse management and lean warehousing compared to manufacturing Industry. However, implementing lean in warehouse is going to make significant difference in routine operations, reducing waste and increasing productivity during delivery periods. Implementing the lean in warehousing is quite challenging but can be done in other way because of less similarities between manufacturing and warehouse management.

The warehouse contains more IT related and manual oriented work to do with different functions as compared to manufacturing units. The success of any good manufacturing process ends with proper and effective warehousing [2]. Warehousing is an integrated part in manufacturing process. If the lean warehousing practices are implemented, then total production process becomes more effective, and overall production, storage, and shipping cost will become less [14]. The common problems where we can implement lean techniques in warehousing is handling the product, storing the product, inventory control aspects of the product, and shipping of the product. During this process of lean implementation in warehousing operations, typical common errors can be eliminated effectively [7].

3 Warehouse Operations

Warehouse is a facility used for temporary storage of goods within the supply chain. Its strategic role comprises of inventory distribution, sorting, and cross-docking which helps in providing enhanced customer service. In the past, it was generally used for storage purpose only; hence, it is considered as a cost center. But, nowadays, various value-added activities like labeling, packaging, cross-docking, etc., are performed by the companies inside the warehouse. This helps in achieving better efficiency and improved customer service level within the supply chain. The main operational activities performed in a warehouse includes receiving, inspection,

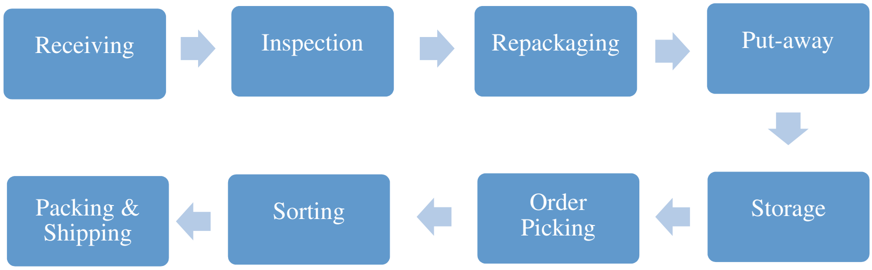

Fig. 1 Warehouse operations [13]

repackaging, put-away, storage, order picking, sorting, and packing and shipping [13] (Fig. 1).

i. *Receiving*: It is the process of order receipt of the merchandise after it has been placed. At this stage, workers ensure that the quantity and quality of the items are as per order before disbursing them to be ready for storage.
ii. *Inspection*: The procedure of inspection and quality control is performed to ensure the consistency in product quality and quantity received before storage.
iii. *Repackaging*: Repackaging is performed if the materials received exceed the storage cube requirement, or the item is received without markings that can be recognized by the systems or humans.
iv. *Put-away*: Moving goods from unloading docks to storage facilities is known as put-away. Material handling and placement are the major activity performed at this stage.
v. *Storage*: The activity of storage is influenced by the products. The volume, size, and characteristics of the products determine the type of storage that is required.
vi. *Order picking*: It is performed when the company receives customers' order. It includes picking a pallet from the bulk area storage or smaller quantities from the pick area storage.
vii. *Sorting*: The arrangement of batch picks into customers' orders is referred to as sorting. This stage involves adding picks to orders that contain multiple items.
viii. *Packing and Shipping*: This is the process of checking and packaging of the finalized orders into shipping containers. Further, shipping documents are prepared, and the merchandise are loaded into the vehicles.

Within the given warehouse operations, there exist lots of scope for committing errors while performing various duties. A total of 24 activity errors are identified within warehouse operations from various sources. The comprehensive list of activity errors/issues are mentioned in Table 1.

Table 1 List of activity errors in warehouse operations [13]

Code	Warehouse process	Problem description
X1	Receiving	Carton damage
X2		Mismatch b/w items information and freight bill
X3	Inspection	Quality defect
X4		Less quantity delivered
X5		Wrong item delivered in cartons
X6		Missing items
X7	Repackaging	Item break due to poor handling
X8		Wrong labeling on cartons
X9	Put-away	Item break during movement to storage location
X10		Item damage due to poor handling
X11	Storage	Item put in wrong shelf
X12		Storage space not optimally utilized
X13		Excess stocking
X14		Product damage during storage
X15	Order picking	Wrong item picked
X16		Delay in identifying item location
X17		Wrong quantity picked
X18	Sorting	Accumulation of wrongly picked orders
X19		Excess quantity sorted
X20		Less quantity sorted
X21	Packing and shipping	Wrong item packed/shipped
X22		Product damage due to poor material handling
X23		Error in shipping document preparation
X24		Error in packing and labeling

4 Lean Manufacturing

The concept of lean manufacturing was evolved at Toyota Motor Company during 1950–1960 in Japan. It is basically a methodology that focus on minimizing waste within manufacturing system. The main two pillars of lean system includes just-in-time inventory management and automated quality control. Though the concept of lean was started in Japan, later on, it is adopted by almost all leading automobile manufacturing companies of the world. Today, it is well accepted and practiced by almost every sector. There are five principles of lean which are considered as procedure for improving workplace efficiency. It includes defining value, mapping the value stream, creating flow, using a pull system, and pursuing perfection.

5 Seven Types of Waste

There are seven different types of waste identified under lean manufacturing system that needs to be eliminated completely [3]. They are mentioned below with brief description.

Overproduction—Producing ahead or excess of demand.

Inventory—Raw materials, work-in-process, and finished goods not being processed.

Defects—Products deviating from design specification.

Motion—Unnecessary movement of worker and machinery.

Over-processing—Excess processing performed that is undesirable.

Waiting—Wastage of productive time due to poor flow of inventory, people, and machine.

Transportation—Excessive movement of people, equipment, and inventory should be avoided.

5.1 Lean Tools and Techniques

There are many different lean tools and techniques used for improving the performance of an organization. The below mentioned list in Table 2 shows only the important tools used in improving warehouse operations.

5.2 Implementation of Lean in Warehouse Operations

In this section, the implementation of lean tools to the warehouse operations is executed to minimize the wastage. For this purpose, proper mapping of lean tools with warehouse problems are performed judiciously. Table 3 presents the mapping between various lean tools and different warehouse problems.

6 Analysis and Discussion

The mapping between identified warehouse issues and required lean tools are performed carefully. During receiving activity, the problems like carton damage and mismatch between items information and freight bill could be addressed by tools like visual management, value stream mapping, and total quality management. The problems like quality defect, quantity issue, and missing/wrong items delivered in the inspection stage could be resolved by the tools like visual management, total quality management, 5S, and value stream mapping. Under repackaging, the issues

Table 2 Lean tools and techniques used in warehouse operations [15]

Code	Lean tools/techniques	Description
Y1	5S	Technique used for organizing the work area
Y2	Value stream mapping (VMS)	Analytical tool used for visualizing and managing the materials and information flow within a process
Y3	Kanban	An inventory control system using color card to maintain continuous flow within production set up
Y4	Kaizen	An approach to create continuous improvement in the manufacturing process on regular basis
Y5	Poka-Yoke	Mechanism for detecting design error and preventing it from processing
Y6	Just-in-Time (JIT)	Pulling the parts through the production based on customer demand
Y7	Layout optimization	Optimal arrangement of workplace for minimal movement of resources
Y8	Multi-skill workers	Workers capable of performing multiple task with same accuracy
Y9	Visual management	A form of communication used to give a snapshot about the manufacturing operations
Y10	Continuous smooth flow	Method that allows work-in-process smoothly flows through all the steps of production process with no buffer in-between
Y11	Batch size reduction	Small quantity batches are used to attend high speed processing and less variability
Y12	Cross-training	Training provided to the workers on different skill set
Y13	Total quality management (TQM)	A management approach that seeks to provide customer satisfaction by delivering excellent quality product

like item breakage due to poor material handling and wrong labeling on carton could be sorted out by using multi-skilled worker, batch size reduction, kaizen, poka-yoke, just-in-time, and visual management system. In put-away process, the problems like item damage during movement to storage or due to poor handling could be addressed by providing proper layout to warehouse, using multi-skilled worker, and providing cross-training to them. Problems like item put in wrong shelf, unutilized storage space, over stocking, and product damage during storage could be minimized by using tools like 5S, kanban, poka-yoke, just-in-time, layout optimization, multi-skilled worker, cross-training, visual management, and batch size reduction. In order picking operations, the issues like wrong item/quantity picked and delay in identifying location could be sorted out using tools like 5S, value stream mapping, kanban, kaizen, poka-yoke, just-in-time, visual management, continuous smooth flow, and layout optimization. Issues like accumulation of wrongly picked order and excess/

Table 3 Mapping between lean tools and warehouse problems

Code	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13
X1									√				√
X2		√							√				
X3									√				√
X4	√	√							√				
X5		√							√				
X6	√	√							√				
X7								√				√	
X8				√	√	√			√				
X9							√	√				√	
X10								√				√	
X11	√		√		√	√	√		√				
X12	√						√						
X13	√								√		√		
X14	√				√			√				√	
X15	√	√	√	√	√	√			√	√			
X16	√						√						
X17	√	√			√				√	√			
X18	√			√	√				√				
X19	√	√							√				
X20	√	√							√				
X21	√	√		√	√	√			√			√	
X22								√				√	
X23				√	√				√	√			
X24				√	√				√	√			
Total count	13	9	2	6	9	4	4	5	17	4	1	6	2

less quantity picking are resolved by using tools like 5S, kaizen, poka-yoke, visual management, and value stream mapping. At last, during packing and shipping stage, the issues like wrong item packed and shipped, product damage due to poor handling, error in preparing shipping documents, and error in packing and labeling could be addressed by the tools like 5S, value stream mapping, kaizen, poka-yoke, just-in-time, multi-skilled workers, visual management, continuous smooth flow, and providing cross-training to the workers.

7 Conclusion

It has been already validated that the application of lean tools in manufacturing bring lots of benefits to the organization in terms of waste minimization, cost reduction, and productivity enhancement. Similarly, the implementation of lean tools in warehouse operations can bring significant improvement in the overall productivity of the facility. In this research, we tried to identify and address the various issues encountered in day-to-day warehouse operations through different lean tools and techniques. Among all the lean tools, visual management, 5S, value stream mapping, and poka-yoke could be used maximum to address the problems at first level. At second level, kaizen, cross-training, and multi-skilled workers could be used for encountering the problems. Finally, at third level, the tools like just-in-time, layout optimization, continuous smooth flow, kanban, total quality management, and batch size reduction could be used for resolving the issues in warehouse operations. In summary, this research may provide insight to the companies about how to adopt and implement lean techniques into their warehouse management system effectively for productivity improvement.

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Customizing the Last Planner System Components to Plan and Monitor Typical Concrete Cycles

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Abstract The last planner system (LPS) has been proven to be a beneficial technique in the lean construction sector for stabilizing workflow and improving the reliability of plans. To integrate LPS into the processes of an organization, its standardization and customization are prerequisites to meet the organization's specific needs and seamless data management. Real estate development in tier-1 cities in India usually demands the fast-paced construction of multi-story buildings with typical floor layouts. On the other hand, in such high-rise construction projects, delays in the concrete cycles add up and can cause the project to be delayed. Thus, it is imperative to plan and monitor each concrete cycle in a systematic way that can yield a summary of productivity analysis, resource consumption analysis, and variations analysis, along with visual and root cause analysis. As these concrete cycles usually have a duration ranging from one to two weeks, two components of the LPS—make-ready planning and weekly look-ahead planning—are required to customize and emerge into one standard template. This study discusses the adopted framework to

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prepare standard templates for different formwork systems used on different project sites of Shapoorji Pallonji Engineering and Construction. The study also discusses key findings and novel benefits that could be realized by adopting the developed framework.

Keywords Lean construction · Last planner system · Concrete cycle · Make-ready planning · Look-ahead planning · Monitoring template

1 Introduction

It is essential to support the projects for working toward targeted milestones, doing what is feasible to progress along a planned path, and figuring out alternate paths that achieve desired goals when the situation becomes complicated. Specifically, in construction projects where uncertainty is ingrained in almost every stage, reliable planning and continuous monitoring become more crucial [1, 2].

Addressing the ultimate goal of continuous improvement, the last planner system (LPS), introduced by Glenn Ballard and Greg Howell, enables projects to predict workflow with realistic planning [3]. This system emphasizes tight scheduling, documented commitments, statistical progress tracking, constraints, and variation analysis through multiple project phases, including planning, design, execution, and commissioning. According to previous studies, successful LPS implementation can result in multiple benefits, as documented in Table 1.

LPS is being utilized in construction projects in a variety of contexts as per the project-specific requirements. According to a set of historical data collected by Turner Construction on the cost share of different construction activities in the building construction, concreting activities consume ~ 23% stake in the total cost of construction [11]. Similarly, in Indian construction, Shapoorji Pallonji Engineering ansd Construction have denoted the activity share of ~ 30–35% for concreting activities in a set of existing and delivered construction projects.

Among a wider variety of construction projects, SP E&C mainly deals with the construction of building facilities. Commercial and residential real estate projects that construct multi-story tower buildings with nearly typical floor layouts hold a significant stake, around ~ 70%. As an organization, SP E&C considers the timely completion of projects while achieving the expected level of quality as some of its

Table 1 Benefits realized by previous implementations

Benefits realized	References
Optimized and reduced schedule	[4, 5]
Knowledge building and open sharing among team members	[6–8]
Better collaboration, communication, and understanding	[7–9]
Stable workflow, resource balancing, and productivity improvement	[10]

core values aiming at trust-building and customer satisfaction. Thus, if not controlled as planned, the typical floor cycles were found to be one of the bottlenecks in the construction projects, which can directly inherit significant delays along with increased cost implications affecting productivity and customer satisfaction.

To align project-level planning with ground-level execution and to integrate Plan-Do-Check-Act (PDCA) concept, LPS have been customized to address this specific requirement. Key objectives behind implementing LPS into such projects are:

Optimize concrete cycle duration up to the maximum extent,

Realistically plan the consecutive cycle based on tracked parameters and learnings from the previous cycle,

Nurture a work culture of confidence and mutual consensus among stakeholders involved in the project delivery process.

2 Customization in LPS

LPS originally included five core elements: (1) Master planning, (2) Phase planning, (3) Look-ahead planning (/make-ready planning), (4) Weekly work planning (commitment planning), and (5) Daily huddles, as shown in Fig. 1. Each of these elements focuses on "Should," "Can," "Will," "Did," and "Learn," respectively.

In a typical construction project, master planning defines project-level targets as project milestones in terms of the completion of specific activity phases in certain

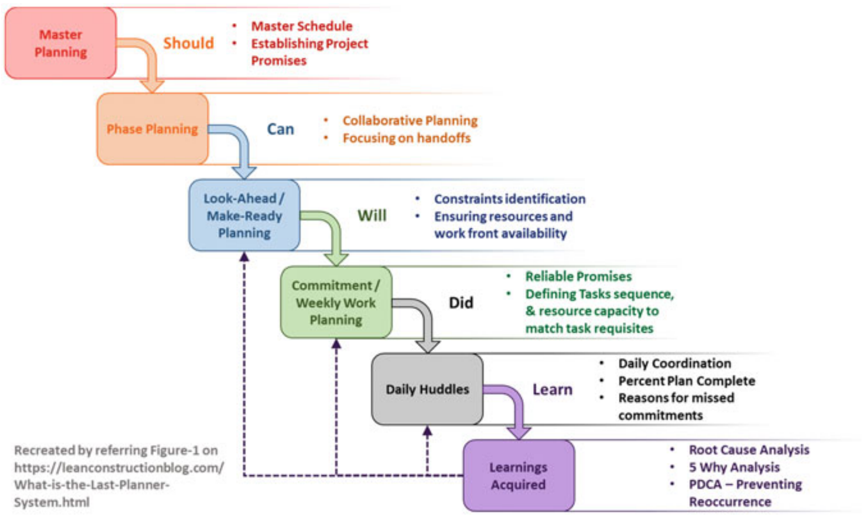

Fig. 1 Last planner system as published initially by Lean Construction Institute

decided areas of the project, e.g., completion of foundations in Tower-1 to Tower-N. Phase planning subsequently breaks the milestones into smaller objectives, including completing repetitive activities performed on multiple levels, e.g., concrete casting at level N1, completion of finishing activity at level N2, etc. Apart from that, the milestones defined in cycles in the phase-level planning usually are in the cycle having a duration of 14–20 days as per the complexity of work and defined area of the activity.

In such projects, look-ahead/make-ready planning requires an explicit activity breakdown for a better understanding for all the stakeholders involved in the planning and execution stages. Such planning shall provide activity-specific targets to be achieved each day of a cycle while taking care of the readiness of resources to be deployed in each stage of completion. Hence, the planning team shall prepare the look-ahead/make-ready planning in collaboration with the site execution team members and other critical functional representatives accountable for the cycle completion.

Now, making a weekly work plan becomes a bit challenging when a cycle is getting completed in between a week and a new cycle starts on the following day onward. From the site implementation, it could also be noticed that the remaining duration of a week post-completion of a cycle was getting faded in the planning process, and similarly, execution work was also showing similar behavior for the remaining days in such weeks. Thus, it could be identified that the LPS implementation in such projects requires a modified approach where activity planning and tracking can be recorded in terms of days and even better in terms of dayparts where working hours differ in the different time shifts. But, instead of providing targets for the week, if a plan can provide holistic targets to complete an entire activity cycle within the stipulated time frame and can also provide insights into a whole activity cycle at a time, it can be more functional for such projects. Thus, it could be identified that there is a need for a cycle plan which can integrate the functionality of the weekly work plan but can be applied for the whole cycle.

Additionally, it could also be noticed that the duration of the tasks in the activity breakdown, which caters look-ahead/make-ready planning, is required to be committed by the respective stakeholder in the cycle plan itself. Thus, it becomes necessary to integrate both of the original LPS components—the look-ahead/make-ready plan and the weekly work plan into one integrated cycle plan. To address this requirement, LPS has been slightly modified to prepare a framework that helps to prepare a set of templates for different construction activities, which typically occurs on a regular basis, and repetition of the same can be found in the significant count. As shown in Fig. 2, LPS has been customized by emerging look-ahead/make-ready plan and weekly work Plan into one integrated activity cycle plan for multi-story building projects.

During the implementation, it could also be noticed that the comparison of planning with actual tracking is also value-adding, especially when it is a grey area where consideration of activity duration depends upon multiple factors, and all are not adjustable at once.

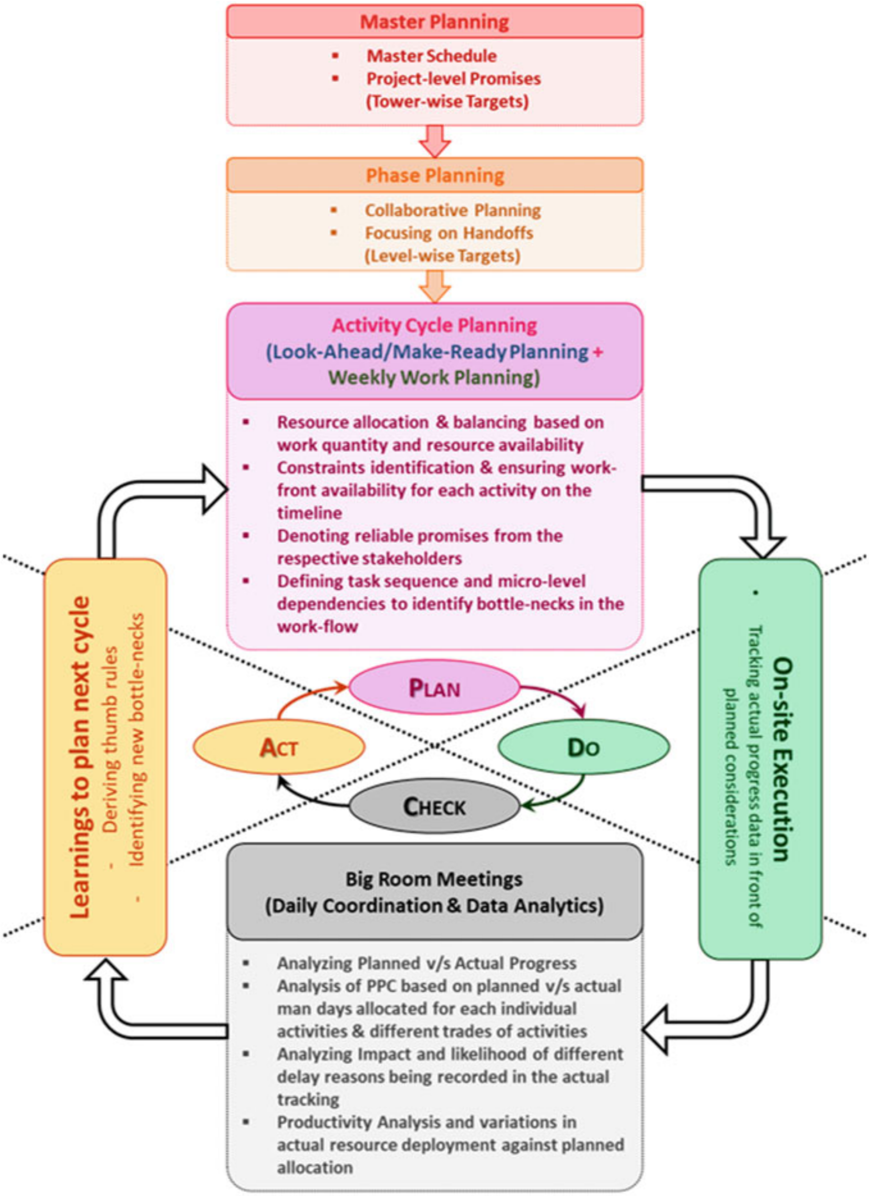

Fig. 2 Customization in last planner system for activity cycles

Finally, focusing on concreting activities, an integrated framework with standard templates have been prepared for different types of formwork system to plan and monitor concrete cycles in multi-story buildings with typical building layouts.

3 Development and Implementation Methodology

Focusing on the initial scope to prepare a set of templates for concreting activities using different types of formwork systems, two different formwork systems have been selected for the pilot study—(1) Monolithic aluminum formwork system and (2) Conventional formwork system.

To understand micro-level activities in a concrete cycle, four projects with monolithic aluminum formwork systems and two projects with conventional formwork systems have been selected. With rigorous discussions and mind storming with site teams, detailed activity breakdowns were prepared for both the formwork systems. Additionally, it was also denoted that even for the same formwork system, activity distribution can be standardized only up to a certain extent—beyond that, there should be a provision to add specific detailed activities which can impact the concreting cycle but may not be directly categorized into concrete activities.

A set of parameters was then decided to include as a part of the framework. Based on this, two different templates have been created for monolithic aluminum formwork and conventional formwork, respectively. By accommodating project-specific additional activities and customization in activity sequencing, individual templates have been prepared for all six selected projects.

As a collaborative exercise, this process has included all three levels of participation—(1) Corporate office level, (2) Regional office level, and (3) Project team level in the organization as shown in Fig. 3. A responsibility distribution matrix was developed, which highlights specific contributions expected out of cited organizational levels. The corporate office lean support team is responsible for developing and refining the framework and templates to make them more suitable and functional by addressing site-specific and generic needs. Regional office—quality and planning team is responsible for ensuring continuous monitoring and improvement during the process. They are also responsible for acquiring historical data generated parallelly during the implementation process.

Project teams are directly responsible for emerging the real meaning of the word ‘Last Planner’ by engaging execution in-charges, engineers from different disciplines, and foremen of the subcontractors working in the different trades. Planning teams on the sites are responsible for planning individual cycles based on learnings from the previous cycle data and also for managing actual data being provided by execution in-charges of different towers. Project managers are responsible for leading daily huddles and coordinating with respective stakeholders to clarify the issues on the way to progress ahead. After the collection of significant actual tracking data, the corporate office lean support team provides comprehensive analytics of the collected

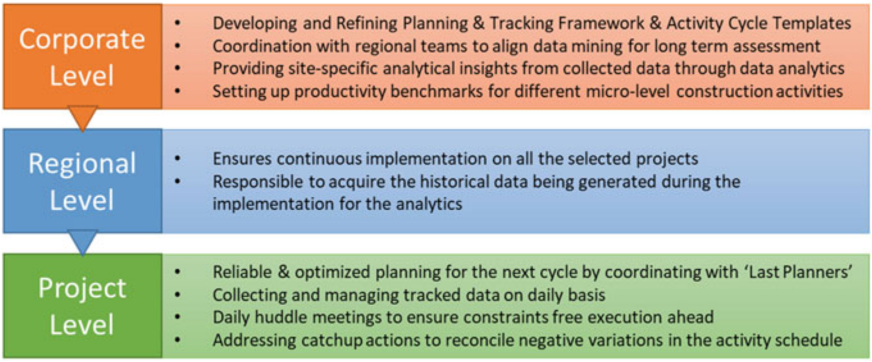

Fig. 3 Responsibility distribution matrix

data and acquired learnings to standardize thumb rules of the considerations into a set of benchmarks for the company and make them ready to use for upcoming projects.

During this study, the implementation process was carried out on six different projects, and a framework was developed to prepare six different cycle planning templates.

4 Framework Functionalities

The initial scope of the framework development focused mainly on concrete cycles. Although the framework prepared here is not limited to only concreting activities, rather it can be utilizable for all kinds of construction activities irrespective of their nature, whether linear or cyclic.

As per the objectives, the intended use of the framework was mainly to design activity cycle templates that can help 'Last Planners' with realistic planning and actual progress tracking, simultaneously providing different types of decision-making statistics. Thus, the framework has been developed in a way that can become an integrated part of company processes after certain standardization for different kinds of construction activities. The developed framework provides the functionalities below and as shown in Fig. 4.

In section 1, broader project details, cycle id, specific work front location, and work quantum in different activity trades are being accommodated.

In section 2, the cycle timeline in terms of day-half, days, and dates is accommodated.

In section 3, activity break down for a cycle with assigned trade id is accommodated.

In section 4, planning and monitoring spaces for all day-half and for all activities are accommodated in a way where users need to fill the required manpower in the planning row and actual manpower in the monitoring row on a particular day-half.

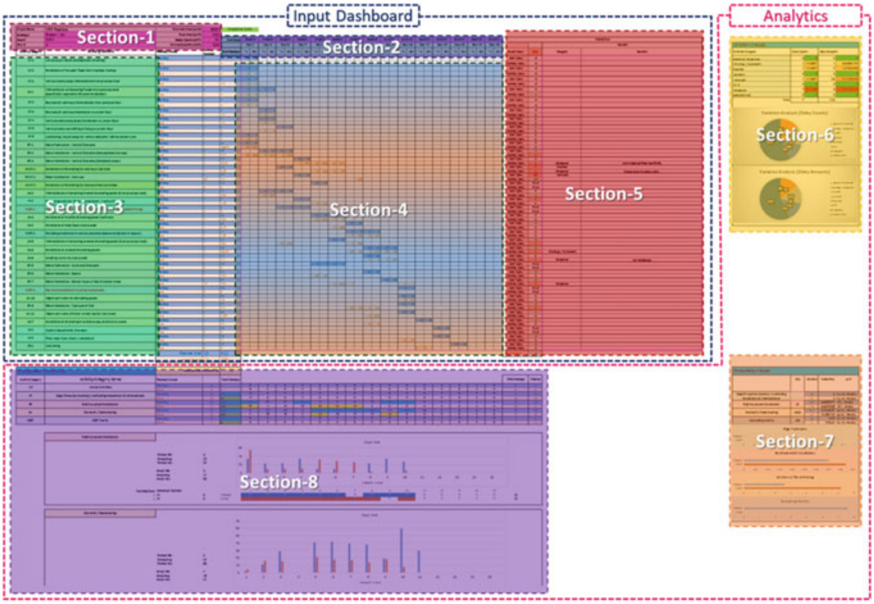

Fig. 4 Activity cycle planning and tracking framework

This section then automatically prepares a bar chart to showcase planned versus actual data.

In section 5, variations after the execution are recorded, and a provision to indicate constraints during the planning process has also been provided.

In section 6, two pie charts and an analytical table reflect the impact and likelihood of different variations being recorded in section 5

In section 7, planned versus actual productivity can be seen on a real-time basis for different activity trades participating in the activity cycles.

Section 8 provides a dynamic overview of planned manpower versus actual manpower consumed on a particular day. This section also provides statistical inferences that can critically help in resource balancing within the trade as well as across the trades.

5 Templates for Concrete Cycles

Using this framework, two templates have been formulated to plan and monitor concrete cycle activities for monolithic aluminum formwork and conventional formwork systems. The entire template for the monolithic formwork system for one of the SP E&C projects is shown in Fig. 5. In the concrete cycle activities, three primary activity trades have been considered, including (1) Formwork/shuttering activities.

(2) Reinforcement fabrication and installation activities, and (3) Edge projection/ safety net installation and uninstallation activities.

In the template, section 1 includes work quantum in terms of shuttering area (SQM), reinforcement quantity (MT), edge protection (RMT), concrete quantity (CUM), and pour area (SQM). In section 3, a detailed activity breakdown has been integrated along with given trade codes for the activities as SF for edge protection, SH for shuttering or formwork, RF for reinforcement, MEP for MEP activities, and CR for concrete pouring.

6 Benefits Realization

After the successful implementation of the customized LPS framework on four different projects having monolithic aluminum formwork, it could be noticed that all four projects reflected certain benefits as listed below:

- Before the adoption of the framework, the execution-level planning process was not addressing manpower requirement versus consumption on a daily basis and total man-days requirement versus achieved linking with productivity norms for the specific quantum of works in different activity trades. After implementation, having clarity about total and day-to-day manpower requirements, a well-planned resource balancing could be achieved in the planning of consecutive cycles.
- Initially, the delay registers being maintained on-site were only recording macro-level reasons for whole cycle delays, which were not helping to infer any specific reason/s impacting the project progress. But, after the implementation of the framework, both negative and positive both types of variations could be recorded in terms of delays and catch-ups. Thus, it started providing inference on the likelihood and impact of negative variations, and in the big-room meetings, these issues could be well-discussed and resolved by developing bound commitment records for relevant stakeholders. On the other hand, favorable variations could be registered in the learnings as the best practices which have provided optimized activity durations.
- Observing data for a collection of cycles, it could be noticed that the sites were achieving more actual productivity than the planned ones. However, the holistic cycle plan was getting extended in terms of days. But, after implementation, all the bottlenecks could be identified in terms of certain critical activities or some predecessors which are essential in the execution process, like inspections, approvals, final alignments, etc.
- Statistically, it could be noticed that around 20% of the cycle time could be optimized for the monolithic aluminum formwork system, and measurement of the benefits for the conventional formwork system is still in progress, but according to the current status of the data, it is also being expected nearer to the 20%.

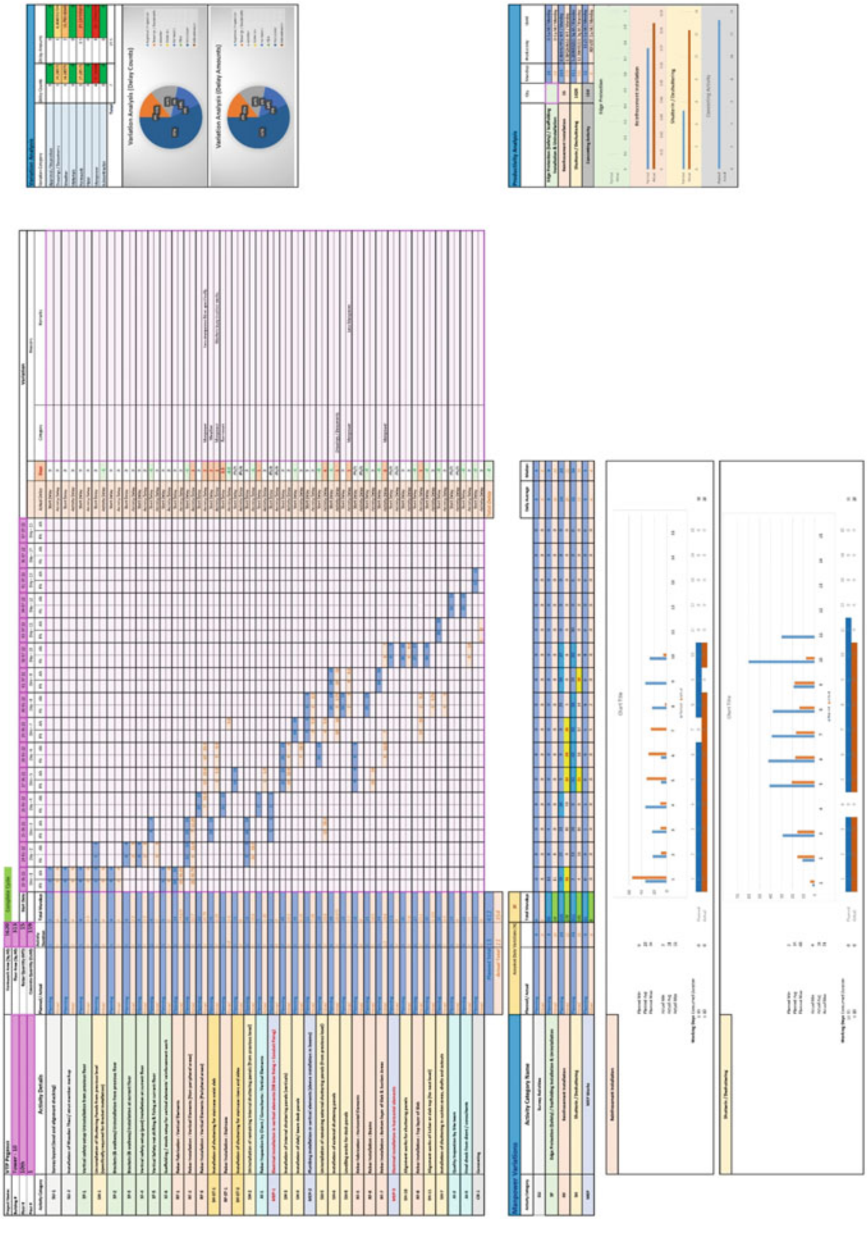

Fig. 5 Concrete cycle planning and tracking format (for monolithic formwork system)

Fig. 6 Concept for ERP-based cycle planning and tracking functionality

7 Discussions and Future Scope

As the current framework emerges two core components of the LPS: look-ahead/make-ready planning and weekly work planning, it upholds a vast potential to get integrated into companywide planning processes. Beyond that, the parametric nature of the framework allows users to utilize it for any typical cyclic activities. Thus, the same can be used to prepare multiple activity cycle planning templates similar to the one presented in this paper.

Currently, the framework has been developed using spreadsheet tools, but indeed it can be converted and integrated into a part of an ERP system which can enhance its functionalities to the next level. By integrating the same with on-site mobile applications and desktop computer-based planning tools, a fully automated and more sustainable LPS workflow can be developed. Figure 6 reflects the holistic ideology to make this more functional.

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Identification and Reduction of the Manpower Waste in Construction Using Work-Sampling Analysis

Megha S Pradeep, Parth Bhadaniya, Aritra Roy, Hemadri Reddivari, and Balamurugan Nagrajan

Abstract Delays in a construction project are directly dependent on the extent of activities performed by the workers on the site daily that do not add value to the project deliverables. To address the time and cost overruns of a project due to these, workers must be closely observed to categorize their activities. An efficient observation-based lean tool that can be used for this is work-sampling analysis. This study aims to assess the use of tour and crew-based work sampling to determine the level of manpower waste in the ongoing construction site of a commercial 3B + G + 10 high-rise building in Bangalore, India. The aim also extends further to data analysis from the obtained video samples to determine the root causes of manpower waste in the project and corresponding strategies that were undertaken to eliminate the same. The study also discusses the extent of improvement in the project execution methodology after the root causes from the work-sampling analysis has been adequately addressed.

Keywords Work sampling · Waste · Lean construction · Value stream · And Data analysis

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1 Introduction

Delays in a construction project can arise due to several factors like changes in the project scope, poor collaboration among the stakeholders, inaccurate planning, resource unavailability, etc. Among these, one of the primary reasons is the activities that often do not add value to the project deliverables [9]. In a broader context, such activities can be recognized as "waste" in lean terminology, leading to no return on investment [2].

Besides other wastes, manpower waste can be observed on-site through informal methods like random "Gemba" walks by supervisors, web cameras, etc [6, 7]. To give a more accurate analysis, these should be formally documented using statistical work sampling, which can indicate the level of manpower wastage on the site and can further be correlated with reduced worker productivity.

Work sampling involves the collection of instantaneous observations of work-in-progress, called samples, in the form of videos and other data acquisition technologies. These samples are further compiled to get the percentage of the total time period when the workers performed productive and non-productive work. Data analysis is performed on the videos to identify the activities that cause a negative impact on productivity and to focus on improvement strategies. In work sampling, the activities on the site are generally classified as value-added (VA), non-value-added but necessary (NVAN), and non-value-added (NVA) activities [1].

Work sampling can be either tour-based, which involves data collection with the observers moving throughout the site, or crew-based, where a particular crew is being observed. Further, the analysis can be done using random or periodic time intervals for both tour- and crew-based samples.

Work sampling has the edge over other observation-related time-study procedures in monitoring labors, as it provides maximum overall information in a limited time [4]. It could also be coupled with other lean tools like the productivity measurement system (PMS) to get a holistic view of the construction site's working conditions [5].

In this study, work sampling is carried out on the construction site of a 3B + G + 10 commercial building named Godrej, Indiranagar, Bangalore, India. The project involves an item-rate contract with Shapoorji Pallonji & Company Private Limited as the contractor. As the project duration is 14 months as per the contract, with a bonus of 1% of contractual value if the project gets completed in 13 months, lean implementation is essential to reduce the delays. Hence, work sampling was carried out on the site when the basement construction was ongoing below the ground level to obtain the level of "waste" in the project.

The primary objectives of this study include performing the following:

1. A Phase-1 sampling analysis to get an overall indication of the level of manpower wastage on the site.
2. A Phase-2 root cause analysis to determine the exact reasons for the reduction of value in the project and corresponding strategies undertaken to eliminate the same.

3. A Phase-3 sampling analysis to find the extent of improvement in the execution methodology after adequately addressing the root causes from the work-sampling analysis.

2 Literature Review

Data acquisition and analysis done using work sampling are significant for improving productivity in the construction project. Studies were performed on work sampling carried out by organizations in their construction processes. It is to be noted that considering the results of work sampling over a longer period with the same working conditions is not relevant for a construction project. However, work-sampling results can initiate discussions among the top management and contribute to further improvement in lean implementation [9].

Also, activity categorization is a significant step in construction work sampling. Several studies suggest different typologies for each activity categorization. Studies have defined those activities involving direct work that adds to construction as the value-adding, and the indirect preparatory activities which is essential to finish a construction unit as contributory works. Also, works that were not required to complete the end product were termed "waste" in lean terms. Jenkins et al. [3] altered this categorization as productive work, supportive work, and recoverable work. According to their study, productive or value-added works included a direct hands-on-action to physically complete a project and supportive work as any activity to maintain the former. They termed the wasted time spent on the job site recoverable work or waste. Another classification was put forward as direct-value-adding work as those which physically add value to the product and preparations as those non-value-added activities which cannot be immediately eliminated without affecting customer value. Further, activities that can be immediately eliminated without affecting customer value were regarded as "waste" in construction [8].

Based on the definitions given by several studies, a concise definition for the acting categories is derived, which is given in Table 1.

Table 1 Derived definitions for various activities from existing literature

Category	Defining parameters
Value-added or VA	Direct productive work with hands-on action contributing to the unit of work.
Non-value-added but necessary or NVAN	Supportive or essential contributory work to maintain VA or to finish the work unit, but not directly attributed to hands-on action.
Non-value-added or NVA	Wasted or ineffective time by the laborers that are non-productive and non-supportive.

3 Methodology

Firstly, as it is important to specifically mention the deciding parameters of classifying activities in the context of work sampling, this research's considerations were fixed based on the nature of works carried out at construction sites. Further, work samples were taken with proper preparation beforehand to eliminate unreliable results. The different steps taken to ensure that the video samples are a proper representative of the population are as follows:

- The selected time frame of the observation was fixed to the peak construction time between 11 am and 1 pm.
- The observation route was fixed to the areas where major work was going on and drawn on the floor plans.
- Each video's observation time was limited to 15 min for unbiased analysis.
- The number of observers were fixed to one for minimum disturbances for the workers in the site.
- Each specific activity of the site was categorized and fixed into VA, NVAN, and NVA based on several discussions within the project team and as per previous research.
- The entire process was divided into three phases: the initial phase of sampling, root-causes analysis to find the factors contributing to waste, and the final phase of sampling to detect the percentage of improvement in value addition.
- Work sampling was conducted both at the tour and crew level in the initial and final phases to get an overall indication of the value of the project.
- The analysis was also subdivided into random and periodic analyses for both tour and crew samples to increase the accuracy of the analysis.
- In crew-based sampling, an additional category was included as "No contact" to indicate that the work-front was unavailable or exited from the camera frame for a specific duration.

Hence, a total of eight analyses of work samples were involved in this study for waste indication and improvement, where the considerations for activity classification are as given in Table 2.

Also, as discrete categorization is an essential factor in work sampling in construction to get unbiased results, each site activity observed in the study was grouped into the broad categories given in Table 2. This detailed activity categorization is given in Table 3.

The detailed methodology adopted in the study, represented as a flowchart, is shown in Fig. 1.

Table 2 Considerations for activity classification adopted in this research

	Considerations
VA	• All micro-activities that are directly performed to accomplish macro-activities that can generate **revenue through the client** (e.g., concreting, finishing activities, etc). • All micro-activities that are directly performed to accomplish macro-activities, which are an **essential predecessor to the revenue-generating macro** activities (e.g., shuttering installation, scaffolding installation, safety-setup installation, etc).
NVAN	• All micro-activities which are ***not part of*** any revenue-generating/essential predecessor/element-making or finishing kind of macro-activities **but are essentially required to perform any of the micro-activities discussed in the section above** (e.g., material shifting from site-store to work-front, asset shifting from one work-front to another work-front, accessories level temporary installations, etc). • All micro-activities which are **required to realign deviated contract measures** or **to rectify repetitively occurring issues** (e.g., execution errors, dimension mismatch, quality issues, pouring of tie-bar holes, cheeping of excess concrete, etc)—without which work cannot proceed ahead **irrespective of contracting company is liable to pay an additional amount for the same.** • All micro-activities which are not directly dealing with the progress of the work but are **necessary to convey knowledge** for execution (e.g., discussions of GFC, delivering instructions, etc).
NVA	• All micro-activities which are not directly linked with any construction activities and are not even required for the execution progress (e.g., Idle standing or sitting, talking unnecessarily, roaming on the work-front or on-site without any purpose, etc).

Table 3 Detailed activity categorization

Category	Godrej site activities
VA	Slab reinforcement tying, rebar fabrication, scaffolding installation, formwork installation, waterproofing
NVAN	Communicating at the site, shifting rebars, holding the staff, chipping concrete, shifting tools
NVA	Roaming around, sitting idle, standing idle

4 Computational and Root Cause Analysis of Work-Sampling Videos

4.1 Phase-1 Sampling Analysis

4.1.1 Tour Sampling

In Phase-1 tour sampling, 13 activities were identified to occur in the site, categorized into VA, NVAN, and NVA, with five, five, and three activities in each category respectively. Both periodic and random sampling analyses resulted in a more significant proportion of VA activities, followed by NVAN and NVA. An average proportion of

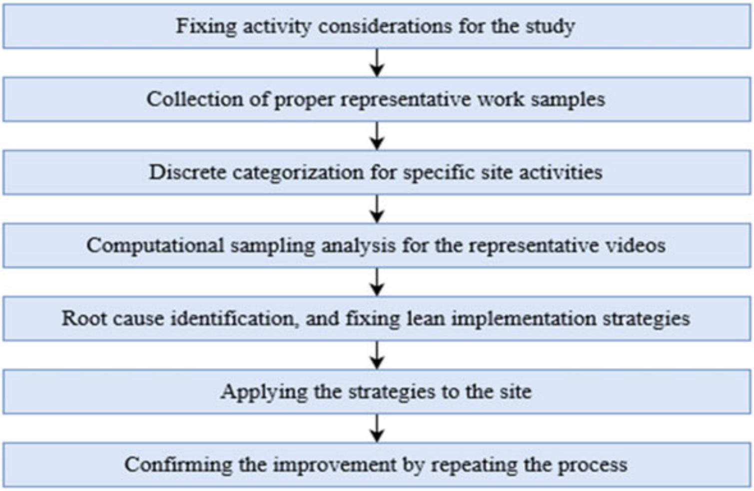

Fig. 1 Detailed methodology

44%, 25.71%, and 30.29% were estimated as VA, NVAN, and NVA, respectively as shown in Fig. 2.

The major five activities in tour-based random sampling which resulted in maximum percentage contribution are slab reinforcement tying, rebar fabrication, roaming around, standing idle, and scaffolding installation. Tour-based periodic sampling identified these as slab reinforcement tying, rebar fabrication, roaming around, shifting tools, and standing idle. Hence, the significant contribution for non-value-addition was found in the activities like roaming around, standing idle, etc. It

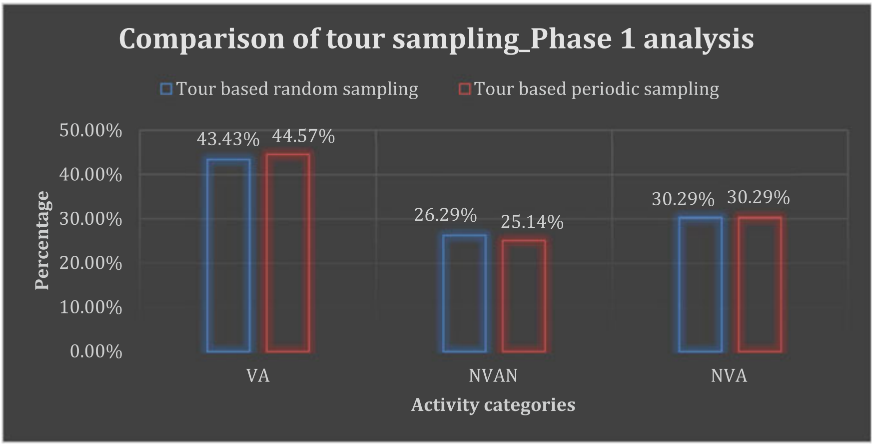

Fig. 2 Comparison of tour sampling in Phase-1 analysis

was identified that the focus should be on the measures to eliminate these activities for efficient lean implementation.

4.1.2 Crew Sampling

Reinforcement tying work was observed for crew-based sampling, which resulted in an overall proportion of 67.10, 22.89, and 8.66% for VA, NVAN, and NVA, where "No contact" contributed to an average of 1.34% of the analysis, as shown in Fig. 3.

4.2 Phase-2 Root Cause Analysis

As more than an average of 20% of the activities in tour-based sampling belonged to NVAN, the strategies were primarily focused on eliminating activities contributing to this category. Activities like shifting tools, transporting rebars, etc categorized as NVAN were addressed using 5S techniques such as arranging the required elements near the work-front. This eliminated the need for workers to shift frequently so that they could be deployed to other positions, which required more value-addition.

It was also noted that the NVA category had an overall percentage contribution of more than 30%. Activities like roaming around, standing idle, etc were addressed using proper supervision, such that workers were shifted to crews involving value-added work. It was also analyzed that other root causes, like waiting for materials, etc., also lead to laborers remaining idle during working hours. This was also eliminated to a great extent by using proper instructions given to the site team and subcontractors.

Another reason contributing to labor waste in crew sampling was the deployment of extra workers that were unnecessary. In Phase-1 video analysis, nine workers were

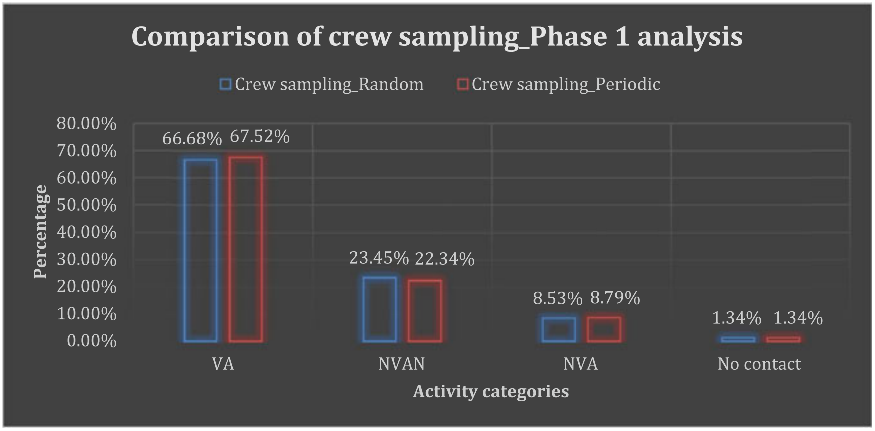

Fig. 3 Comparison of the crew-based sampling in Phase-1 analysis

involved in the tying reinforcement crew, of which eight were working on the same side of the slab. This resulted in congestion and ultimately contributed to an increase in NVAN, where workers had to frequently shift their places for rebar tying and getting tying wires. This led to deploying a reduced number of six laborers for the work in a systematic allotment to different slab positions. This was also aided by the provision of tying wires and tools near the work-front using 5S.

4.3 Phase-3 Sampling Analysis

4.3.1 Tour Sampling

In Phase-3 tour sampling, periodic and random sampling analysis resulted in an increased proportion of VA activities followed by NVAN and NVA. An average of 66.59%, 26.12%, and 7.28% were estimated as VA, NVAN, and NVA, respectively, as shown in Fig. 4.

In Phase-3 tour sampling, the four major activities that resulted in maximum percentage contribution are scaffolding installation, slab reinforcement tying, formwork installation, rebar fabrication, and shifting rebars in random and periodic analysis. Hence, a significant contribution was found to shift from NVA activities to those that belonged to VA.

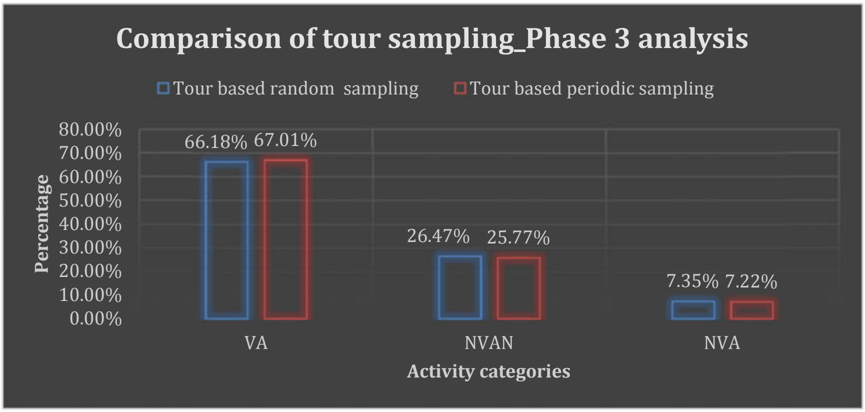

Fig. 4 Comparison of tour sampling in Phase-3 analysis

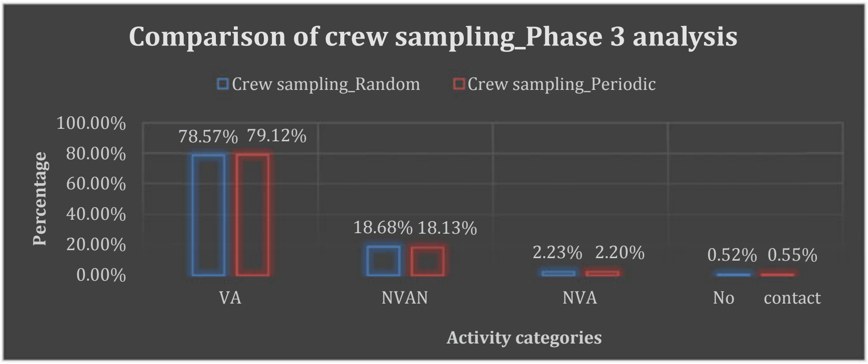

Fig. 5 Comparison of crew sampling in Phase-3 analysis

4.3.2 Crew Sampling

For crew-based sampling, an overall proportion of 78.84%, 18.40%, 2.21%, and 0.53% was observed for VA, NVAN, NVA, and No contact categories respectively as shown in Fig. 5.

5 Conclusions

It was found that an overall increase of 22.59% was found in the value-adding work category for tour-based sampling through proper lean implementation. There was an evident decrease of 23.01% in non-value-added activities through proper management of workers. However, there is a need to further reduce non-value-added but necessary activities through lean principles as the overall percentage remained approximately the same for this category. In crew-based sampling for reinforcement tying, value-addition was found to increase by 11.74%, with NVAN and NVA decreasing by 4.49% and 6.45%, respectively.

It is to be noted that work sampling functions as a lean tool for getting an approximate indication of manpower waste on the site. Also, the percentage of non-value-added work has a strong negative correlation with worker productivity. However, a positive correlation between value-added work and productivity cannot be ascertained as the crews could be involved in rework, which is a hidden waste. The study can also be further improvised by coupling a productivity measurement system and work-sampling analysis for a better view of the waste determination in the site.

Acknowledgements We are glad to have completed this research on lean implementation with proper coordination with various teams at Shapoorji Pallonji Engineering & Construction and the associated subcontractors.

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Employing Linear Scheduling Method and Supply Chain Principles for Optimizing Storage Demand

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Abstract This paper is based on the Statue of Equality—Dr. Babasaheb Ambedkar Memorial in Mumbai. The Mumbai Metropolitan Region Development Authority (MMRDA) conceptualized this project, which was awarded as a Design and Build (D&B) project to the Shapoorji Pallonji Engineering and Construction (SPE&C) company. According to preliminary drawings, the statue will stand 137.3 m tall, making it the world's third-largest statue after the Statue of Unity and the Spring Buddha Temple. Because this is a one-of-a-kind project, the design and construction phases present unprecedented challenges. As the project is of a substantial scale, the space available for material storage and equipment mobility must be carefully managed. The project site being in the densely populated Dadar region led to logistic constraints due to a lack of adequate storage space. As the critical path method (CPM) has been proven to be less effective in modeling repetitive or linear projects, the linear scheduling technique is often used to represent such activities graphically. Thus, using the linear scheduling method (LSM), comprehensive logistic planning of all processes involved in the erection of structural steel ribs was prepared to devise a dynamic representation of storage requirements. The LSM prepared using the critical path network is then optimized to address the apparent bottlenecks by improving

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collaboration and employing supply chain management principles. Similarly, as this project involves multiple stakeholders having different roles in all phases of the project, a responsibility matrix was developed to map the risks to different stakeholders. This matrix would aid in identifying entities accountable for dealing with certain shortcomings during the project's lifespan.

Keywords Linear scheduling method · Supply chain management · Storage optimization · Responsibility matrix · Productivity alignment

1 Introduction

Project scheduling and monitoring are currently carried out using the conventional critical path method [1]. This method has limitations in scheduling linear, repetitive projects where LSM can offer significant advantages in easy visualization and tracking [2]. As CPM does not consider the spatial aspects, it cannot effectively model the repetitive tasks occurring at different locations. In such projects, LSM allows effective planning and scheduling of project activities concerning time and location. With an increase in the scale of the model, the CPM method becomes very complex due to a high number of project activities and interdependencies, making it difficult to understand and communicate effectively using CPM schedules. In contrast, LSM is an effective tool to visually communicate the project objectives with all team members, including those who lack knowledge of planning and scheduling.

In the case of linear scheduling, the steps followed include preparing the linear flow diagram in the as-is condition from the CPM schedule. Then, the spatial conflicts between the activities can be removed by shifting activities to ensure continuous workflow and resource continuity.

Due to predecessor constraints between different activities, this will increase the project duration. Waste in this schedule can be easily seen in the form of excessive buffers. Further optimization can be done to reduce these wastes by synchronizing the production rates. This can be done by increasing the crew size or improving the productivity of existing crews.

The Dr. Babasaheb Ambedkar Memorial is coming up on sprawling 12-acre land at the erstwhile Indu Mill premises. Its main attraction will be a 25,000 square feet stupa around a pond. The design involves 2.5 lakh square feet of construction work. The MMRDA was appointed as a Special Planning Authority by the Maharashtra Government for the development of the memorial, and Prime Minister Narendra Modi unveiled a plaque to mark the laying of the foundation stone.

A 350 feet high bronze statue of Ambedkar placed on a pedestal of 100 feet height (total height of 450 feet), accessed by a spiral ramp, is the main feature of the memorial. The pedestal houses a dome in Buddhist Architectural style resting on 24 structural steel ribs. Along with this, a 1000 capacity auditorium, exhibition halls, research center, lecture halls, library, conference halls, meditation center, parikrama path, souvenir shops, waiting room, canteen, administrative office, toilets, landscaped area, gardens, parking, etc., form part of the memorial.

Structural steel ribs must be fabricated and bolted to insert plates around the core wall of the pedestal to support the architectural dome. Each of the 24 ribs weighs approximately 40 metric tons and spans more than 35 m in length, which cannot be feasibly transported to the site. Thus, to keep the length of trailers less than 30 m, trailers with 35 metric ton capacity were utilized, and the ribs were brought in three segments to the site. Initially, the site had the capacity to hold three ribs (120 Mt.) which, by adjusting the site logistic plan, could be increased to five ribs (200 Mt.). Multiple hydra (pick and carry cranes) machines are required for segment unloading and on-site assembly. Following assembly, the whole rib is lifted and maneuvered to the spot for erection using a high-capacity crane.

The entire rib erection activity, from material procurement to rib erection, is divided into detailed milestones for planning using the linear scheduling method (Fig. 1).

Firstly, after receiving approvals, a material indent is generated by SPE&C to the steel manufacturer for material procurement (A). This material is delivered as raw sheets at the Daman fabrication unit (B). Material delivery begins 45 days after the order has been placed.

The fabrication process at this unit includes cutting, welding, metallization, painting, and quality inspection (C). Backward planning is needed to ensure the rib manufactured and transported corresponds with the erection sequence (D) (Table 1).

The fabricated segments can then be transported to the site using trailers. One trailer can only be loaded with only two segments. Thus, to ensure that with each

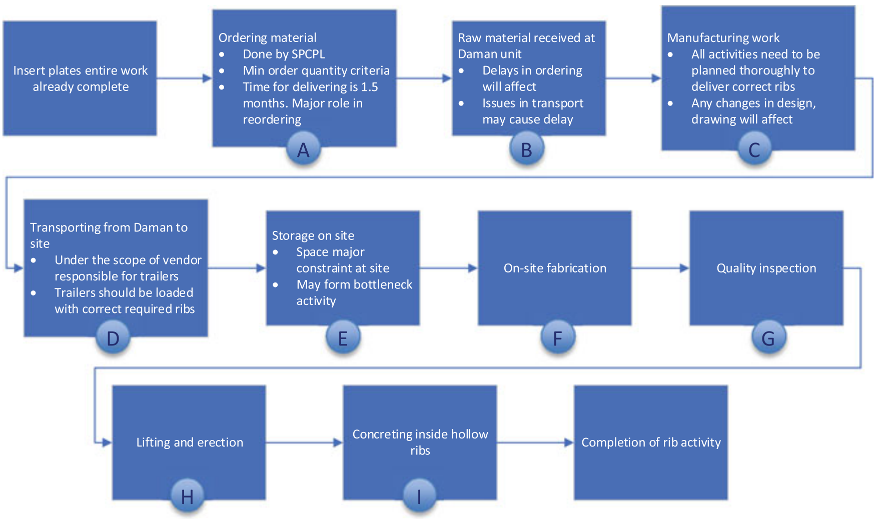

Fig. 1 Supply chain of rib erection activity

Table 1 Segment transportation sequence

1st batch	Trailer1	R1A, R1B
	Trailer2	R1C, R2C
2nd batch	Trailer1	R2A, R2B
	Trailer2	R3A, R3B
3rd batch	Trailer1	R4A, R4B
	Trailer2	R4C, R3C
4th batch	Trailer1	R5A, R5B
	Trailer2	R5C, R6C

load, one rib material is delivered at the site, two trucks shall be dispatched at once (D).

The segments on delivery are unloaded using hydra machines. As the site is located in a densely populated region, space for storage is a significant constraint (E). Such constraints cannot be handled using conventional CPM planning techniques. In such cases, LSM possesses the additional benefit of providing a dynamic visual depiction of storage requirements based on the transit schedule.

The segments are subsequently welded together on-site with special provisions for handling the segments (F). A thorough quality inspection follows this to avoid lapse during manufacturing (G).

The assembled rib is then raised and secured in place with a crawler crane. Crawler crane mobilization and scaffolding arrangements must be completed before this activity. To balance the loads, an erection sequence is needed, wherein ribs are erected in opposite directions alternatively (H).

Lastly, after the ribs have been secured in place, concrete will be poured into the hollow ribs in three layers to provide additional stability (I). This will complete the rib erection activity. During the whole process, multiple constraints are needed to be foresighted, as documented in Table 2.

2 Literature Review

The construction sector is shifting from conventional construction techniques to modular building systems. If construction supply chains are to support this transformation, they need to be modified and strengthened using an adapted logistics system. Factory manufacturing and inventory management can be adapted to capture the logistics of modular construction, covering the three common tiers of operation: manufacturing, storage, and construction. Previous studies have indicated that construction site delays constitute the most significant cause of schedule deviations [3].

Repetitive scheduling using conventional methods suffers from many drawbacks due to forced resource continuity assumptions that increase time and cost. Moreover,

Table 2 Foresighted constraints

Transit to site	Width of road	Congested roads in Dadar, having a width of 3.5 m, cannot provide a sufficient turning radius to transport trailers of more than 30 m in length
	Axle load	An entire rib weighing 40 Mt. cannot be transported on suburban roads due to maximum axle load limitations
Site logistics	Storage	A maximum of five ribs (200 Mt.) can be stored at the site
	Equipment allocation	The movement of cranes needs to be planned due to limited access space
Methodology	Two segments (A and B) are welded before transit	During transit in trailers, A-B segments have to be planned together as they are welded at the fabrication yard
	Rib erection sequence	The farthest rib with respect to crane movement is erected first. For stability, ribs are to be erected in opposite directions alternately
	Uniqueness of ribs	A spiral rod passes through ribs at different positions. Thus, all segments have different weights and dimensions
	Manufacturing speed	The speed of manufacturing need not be increased as it is limited by erection activity
	Erection speed	Due to limited space for crane movement, erection speed cannot be increased further and forms the bottleneck activity

it leads to an increased work in progress (WIP), that is, inventory of units due to the unit's idle time between successive activities. Interruption-based scheduling techniques reduce the project duration. However, they do not address the WIP inventory and its repercussions. Yet, work breaks in discrete, repetitive projects can expedite the construction process. Accordingly, a repetitive scheduling system that can generate a schedule with minimum WIP, cost, and time while maintaining a continuous flow of resources is needed to deliver repetitive units cost-effectively.

For this purpose, a pull batch-based repetitive scheduling model was developed and studied using a low-income housing development project case study. This model integrates pull production and batching concepts to reduce time, cost, and WIP. For instance, using the optimization model, it was observed that the cycle time of the last batch was 137 days, whereas, using the conventional scheduling technique, the construction cycle time was 434 days. Although this model reduces time and WIP, it may result in higher resource idle costs due to pulling action between batches. This research shows the benefit of merging lean principles with construction scheduling methods, encouraging the further application of lean principles in construction [4].

This paper focuses on implementing the linear scheduling method, along with supply chain management techniques, on the Babasaheb Ambedkar Memorial project to develop a seamless process flow and optimize the storage requirement by mapping all constraints between stakeholders to achieve synergy at all levels in the project.

3 Current State LSM

All the activities are plotted according to the standard productivity rates with respect to a common unit of work, here considered as a metric ton of rib. The horizontal axis represents the number of days, whereas the vertical axis represents the unit quantum of work. The slope of each activity line indicates the production rate for that activity. As a result, the steeper the slope, the higher the production rate leading to faster activity completion. It can therefore be assumed that in an ideal production system, all activities should have identical production rates, resulting in parallel flowing lines. The overlap between activities indicates that the succeeding activity cannot proceed unless the preceding activity is complete. This indicates that the succeeding activity needs to be delayed owing to a lack of work-front availability, which is a waste in terms of idle time. The horizontal gaps between two activities indicate large time buffers, which increases the work in progress, a type of inventory waste. Wastes present in the system can therefore be easily identified using such graphic illustrations.

Thus, by plotting the LSM for the entire rib activity, as shown in Fig. 2, it is identified that the activity may suffer from time and cost overruns due to the overlap between the manufacturing and transportation activities. Simultaneously, as shown in Fig. 3, it is also identified that even under ideal conditions, this schedule cannot be followed as it requires peak storage of almost 400 metric tons, whereas the available storage capacity at the site is 120–200 metric tons.

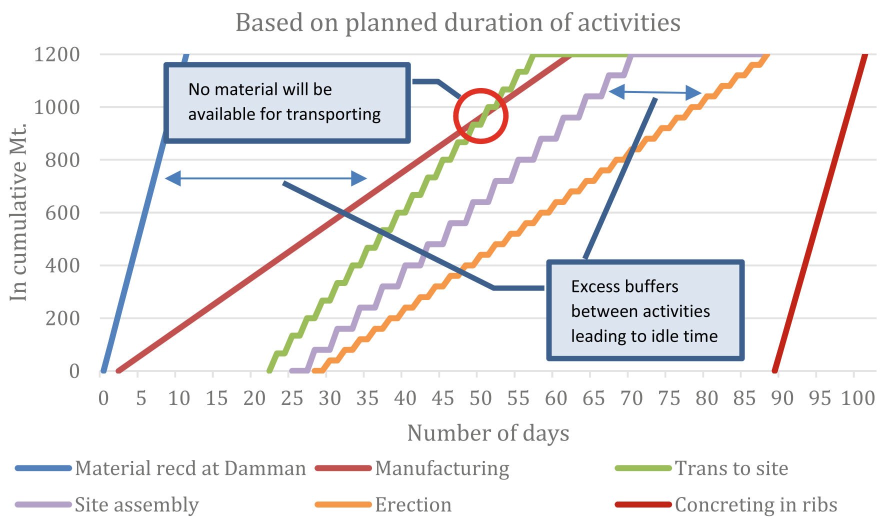

Fig. 2 As-is LSM

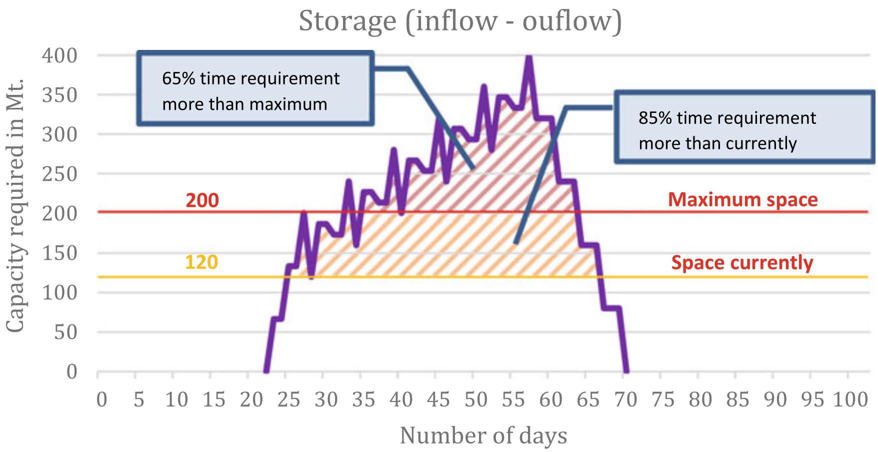

Fig. 3 As-is storage curve

It can be seen that the storage demand is higher than the maximum capacity for more than 65% of the duration. This mainly occurs as the production rates of transportation, site assembly, and erection activities are not synchronized, thereby increasing inventory waste continuously. That is, the material delivered at the site in unit time is higher than the handling capacity of the on-site fabrication team. Thus, raw material keeps getting stacked at the site. Further, the time required for the erection of assembled ribs is higher than the time taken for on-site fabrication leading to the stacking of assembled ribs.

4 Optimization Techniques Adopted

4.1 Optimizing Storage Requirement

The space available for material storage at the site is 120 metric tons, and by making specific additional arrangements, storage space of up to 200 metric tons can be made. Based on the current state of LSM, it can be seen that the peak storage requirement is 400 metric tons. It can be seen that if planning is done only using the critical path method, it will lead to excessive material stacking beyond the available capacity requiring a delay in the project. Thus, to synchronize the production rates of transportation and on-site fabrication activities, the batches are transported alternately in two and three days instead of only two days previously. This helps to ensure the work-front is continuously available for transportation activity as the time buffer between each batch increases. As the production rates of transportation and on-site fabrication can be seen almost parallel now in Fig. 4, this helps to reduce inventory waste. Thus, it can be seen in Fig. 5 that the peak storage requirement falls to 175 metric tons from 400 metric tons, which is below the maximum available storage space.

It needs to be kept in mind that having no inventory is not the best possible solution because if inventory is very low, that may lead to time delays due to the unavailability of material. However, if the inventory is very high, that may reach the maximum capacity leading to high work in progress (WIP). From the storage curve, it can be inferred that the optimization needs to be done in such a way that the

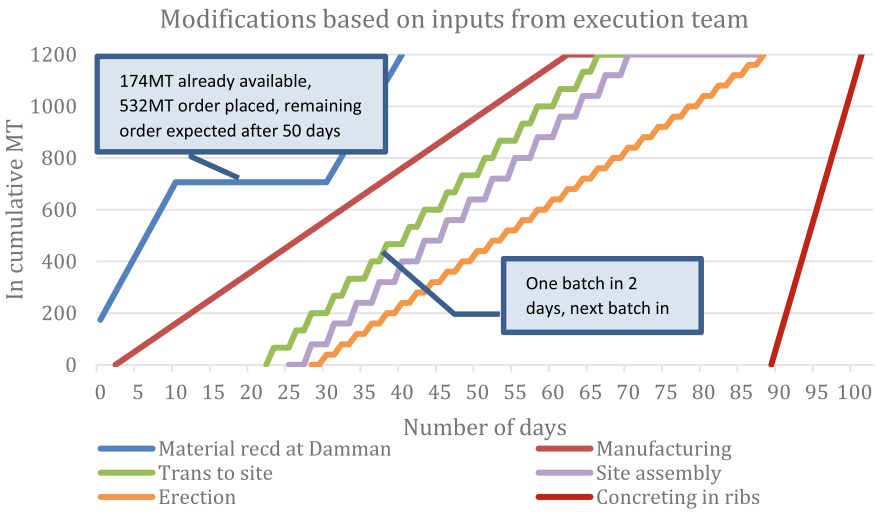

Fig. 4 Modified LSM

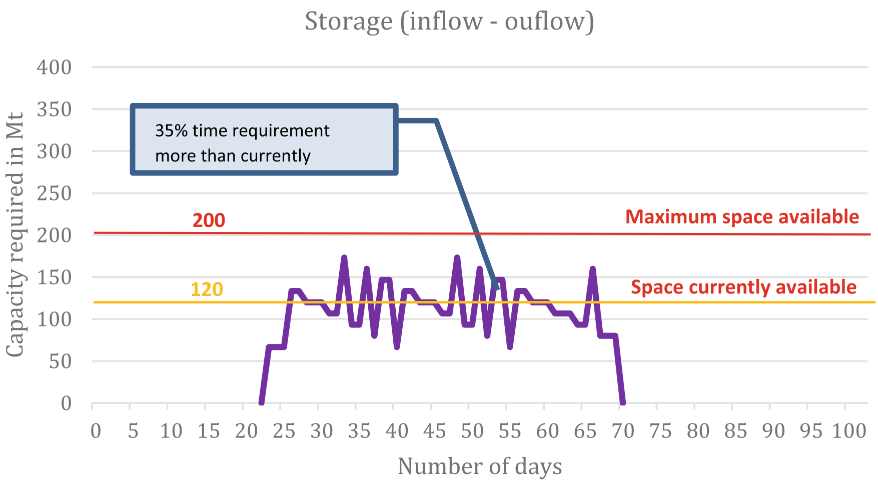

Fig. 5 Modified LSM storage curve

requirement is close to the available capacity, avoiding excess WIP and, at the same time, providing an adequate buffer in case of delays in material delivery.

5 Reducing Buffers by Improving Collaboration

Considerable time buffers between two activities are generally provided in the construction industry due to the high uncertainties involved in completing each activity. These time buffers can be seen as horizontal gaps between two activities. If the constraints associated with various activities are documented in advance and mapped to corresponding stakeholders based on their responsibility during various phases of the project, it would aid in mitigating the risks involved in the project. For this purpose, a responsibility matrix, as given in Table 3, was developed, identifying all the risks in different activities, and this was assigned to the stakeholders responsible for handling them. As Shapoorji Pallonji has a wide range of departments, each responsible for handling different functions, the designation of the person responsible for handling the constraint in Shapoorji has been mentioned. Thus, this matrix would also help to streamline the internal processes within Shapoorji and develop an automated workflow system in the future for the organization.

6 Improved LSM

In this LSM, only 22 ribs are considered for transporting to the site and erection, as the space of the remaining two ribs is required to provide access to heavy lifting equipment. Thus, they are planned to be erected after the cladding work of the statue starts. The buffer between procurement and manufacturing is also utilized by ordering material in two separate batches by accounting for the minimum ordering criteria and the time required for the material delivery. This helps to reduce waste directly by reducing the duration of invested capital.

Further, by adopting the suggested optimization techniques, the production rate of transportation, on-site fabrication, and erection is made nearly similar. This allows for reducing the idle time of crews due to the unavailability of work-front to a minimum. Also, the storage requirement is optimized to its minimum value by trial and error method using the dynamic representation of storage capacity. This helps to keep the inventory costs to a minimum, allowing a form of just-in-time manufacturing. It needs to be noted that as the time buffers have been reduced to a minimum, all the stakeholders need to actively participate in mitigating all the risks identified in the responsibility matrix, as given in Table 3, with consideration of all the constraints mapped across the supply chain as shown in Fig. 6. This will help establish synergy among all entities and avoid conflicts, as all responsibilities have been assigned well in advance.

Table 3 Responsibility matrix

				Stakeholders responsible for constraint														
Sr no.	Activities	Constraints	SPE&C											D&B consult.	Subcon Str: Steel	Supplier Str Steel	Ext QC	Client, PMC
			Executives	Procurement	Planning	Finance	Commercial	Store	Execution	HSE	QA/QC	P&M	D&B					
1	Completion of insert plate fixing																	
2	Material indent																	
2a		Time of order	Director Operations, Reg. Head	HO/Head, RO/Head			RO/Head											
2b		Time of approval	Reg. Head		RO/Head		RO/Head											
2c		Quantity of order	Reg. Head	HO/Head	RO/Head		RO/Head											
2d		Unit price variation																
3	Material delivery (Daman unit)																	
3a		Issues in material transportation		RO/ Manager	Site/ Manager, RO/ Manager										✓	✓		
3b		Payment issues	Reg. Head			RO/ Head	RO/Head									✓		✓
4	Fabrication																	
4a		Change in design, drawing/scope Sync between											D&B/ Manager	✓	✓			✓
4b		erection and fabrication schedules	Project incharge		Site/ Manager				Site/ Manager						✓			

(continued)

Table 3 (continued)

				Stakeholders responsible for constraint													
Sr no.	Activities	Constraints	SPE&C											D&B consult.	Subcon Str: Steel	Supplier Str Steel	Ext QC	Client, PMC
			Executives	Procurement	Planning	Finance	Commercial	Store	Execution	HSE	QA/QC	P&M	D&B					
4c		Payment issues	Reg. Head, Project incharge			RO/ Head	RO/Head											✓
4d		Skilled manpower	Project incharge						Site/ Manager						✓			
5	Trans from Daman to site																	
5a		Issues in material transportation	Project incharge		Site/ Manager										✓			
5b		Sync betweenmaterial delivery and execution teams							Site/ Manager						✓			
6	Storage on site																	
6a		Site space management			Site/ Manager				Site/ Manager						✓			
6b		Heavy lifting equipment	Regional Head, Project incharge		Site/ Manager		RO/ Manager		Site/ Manager	Site/ Manager		Site/ Manager, RO/ Manager						
7	Onsite-fabrication + QC																	
7a		Safety during monsoon							Site/ Manager	Site/ Manager					✓			
7b		Skilled manpower	Project incharge		Site/ Manager				Site/ Manager						✓			

(continued)

Table 3 (continued)

				Stakeholders responsible for constraint														
Sr no.	Activities	Constraints	SPE&C											D&B consult.	Subcon Str: Steel	Supplier Str Steel	Ext QC	Client, PMC
			Executives	Procurement	Planning	Finance	Commercial	Store	Execution	HSE	QA/QC	P&M	D&B					
7c		Quality issues							Site/ Manager		Site/ Manager						✓	✓
7d		Approvals									Site/ Manager		D&B/ Manager					✓
7e		Payment issues	Regional head. Project incharge			RO/ Head	RO/Head											✓
8	Lifting and erection																	
8a	(HD for ribs, Cuplock for the statue)	Scaffolding arrangements	Project incharge		Site/ Manager				Site/ Manager	Site/ Manager					✓			
8b		Logistics planning for lifting equipment	Project incharge		Site/ Manager				Site/ Manager	Site/ Manager		Site/ Manager			✓			
8c		Force majeure																
8d		Skilled manpower	Project incharge		Site/ Manager				Site/ Manager						✓			
8e		Payment issues	Regional head. Project incharge			RO/ Head	RO/Head, Site/ Manager											✓

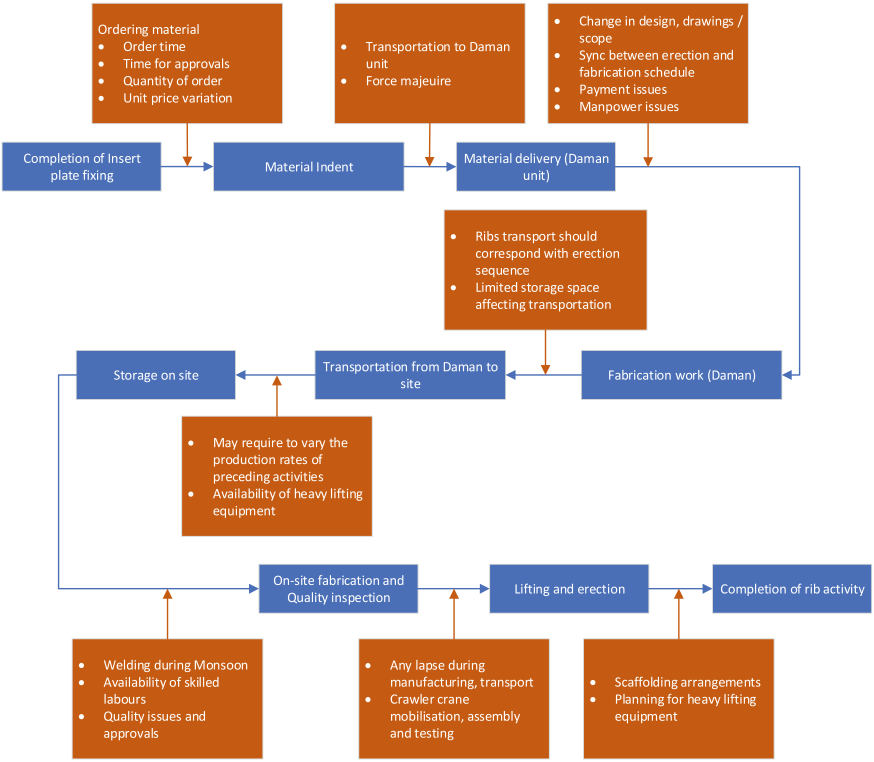

Fig. 6 Constraint mapping along the supply chain

7 Future Scope of Work

7.1 Monitoring Template

The optimization tools employed help to optimize the storage demand within the well-defined capacity limit and further improve the planned schedule of the activities by ensuring continuous workflow and synchronized production rates. LSM can also be used to track the progress of such repetitive tasks by providing a real-time visual representation of the activity progress, as shown in Fig. 7. The planned schedule of activities can be taken as a baseline, and the actual progress can be superimposed on this schedule to identify the delays and incorporate their impact on the remaining activity duration. The horizontal distance between the baseline and the actual progress at any point indicates the delay in the activity. Such a template can also be used to compare the optimal demand with the actual storage requirements, as shown in Fig. 8.

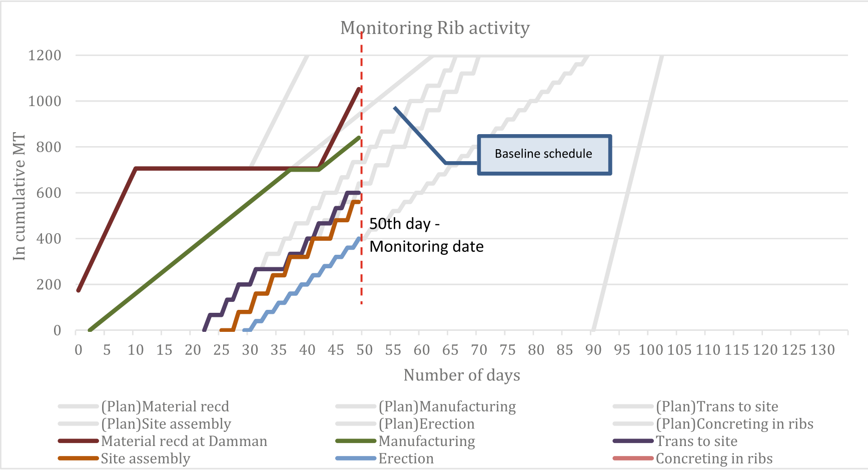

Fig. 7 Monitoring LSM template

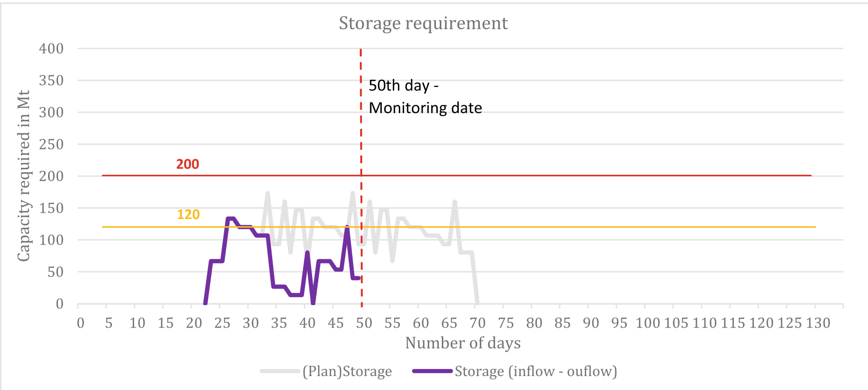

Fig. 8 Monitoring template storage curve

8 Integration of LSM and Last Planner System

Integrating the last planner concept and LSM can improve the coordination problem between subcontractors. As in LSM, the activities are positioned in a time and space format, along with the production rates in the form of the slope of the lines. This representation can facilitate 'What-if' analysis. In LSM, the repetitive activities are represented as same line segments, and the work continuity can be verified and manipulated according to requirements using the last planner system.

9 Optimization Using Heuristic Algorithms

There is literature available on utilizing heuristic algorithms in linear scheduling methods for optimizing the inventory and minimizing the duration considering the impact on resources and idle time. However, they are available in raw form and require detailed analysis and testing before starting their application in the construction industry.

10 Conclusion

The LSM charts plotted for the different scenarios depict the improvements made by the optimizations suggested. In the first case, the data obtained from the conventional bar chart schedule is converted to the LSM chart, and the constraints are identified. In the modified LSM, lean concepts of continuous workflow and pull planning were employed to achieve resource continuity. This leads to an increase in the cycle time of the activities as they are spread out to utilize the total float available.

As given in Table 4, this LSM is further optimized with reduced time buffers and synchronizing the production rates of the activities to reduce the project duration. This reduces the excess WIP present in the system and allows for an increase in the utilization factor of the resources, thereby reducing idle time. This reduces the project duration by more than 20% of the original schedule leading to significant savings in the indirect project costs, including rents of heavy machinery and equipment. It can

Table 4 Conclusion

Section	Total activity duration	% Time reduction	Peak storage requirement	% Savings in space	Techniques adopted	Remarks
As-is LSM	101	–	400 Mt	–	–	Significant delays, Excessive storage requirement
Modified LSM	101	0.00	175 Mt	56.25	Ensuring continuous workflow, resource continuity	Activity duration is high, and very large buffers between activities
Optimized LSM	80	20.79	133 Mt	66.75	Synchronizing production rates, reducing buffers	Requires high collaborative effort

also be noted that the peak storage requirement falls more than 65% as compared to the initial case making it feasible to execute the project under tight space constraints.

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Optimizing Timeline of Parallel Finishing Activities in High-Rise Building Projects Using Linear Scheduling

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Abstract Optimization of schedule in a construction project contributes significantly in reducing waste in terms of time and cost. To achieve this, novel methods like LSM or linear scheduling methods should be adopted in construction projects involving repetitive activities. This study creates templates for optimizing the timeline of selected parallel finishing activities of a 2B + G + 32 & a 3B + G + 24 tower of a residential apartment complex located in Bangalore, India. The paper also presents sample data entries to the templates and linear scheduling graphs to demonstrate its working. Further, the reduction in duration for activity completion in both towers is discussed, and optimized linear graphs are presented for the same.

Keywords Linear scheduling · Waste · Lean construction · Optimization · Standardization

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1 Introduction

Construction project monitoring is one of the most critical tasks [1]. Multiple technologies have been explored for this purpose [2–4]. Linear construction projects are either those with constant repetition of a unified network of activities throughout the project or projects that are linear due to their physical layout [5, 6]. These two categories are generally termed repetitively linear or physically linear projects. The second category involves representative projects like tunnels, roads, etc., and is also known as transportation-type linear projects [7].

The linear scheduling method is a graphical approach that can be used as a practical and visual tool for use in construction projects with repetitive activities. Conventional methods like CPM or Gantt charts can be substituted with the linear scheduling method (LSM), which can be used to visually represent the construction project [5].

An LSM graph typically involves time on one axis and project progress on the other. It is to be noted that time and progress can be on either axis, depending on the layout that makes more sensible data analysis. For example, in the case of a high-rise building, the vertical axis can represent progress, as it can be correlated with the different rising floors on the building. It would be in the other layout for a highway project, where the horizontal axis can be termed coincidental with the physical linear layout of the project [8].

In this study, the project consists of a 2B + G + 32 and a 3B + G + 24 tower of a residential apartment complex with eight flats per floor in Bangalore, India, where the construction is ongoing, and finishing activities are yet to be started. The project is named Towers 6 and 7, Parkwest, and involves a lump-sum contract with Shapoorji Pallonji & Company Private Limited as the contractor. It was proposed to adopt a linear scheduling optimization approach for the finishing activities for on-time project completion as a part of lean implementation. Hence, two sample templates applicable to high-rise building projects were prepared with respect to the selected finishing activities of the towers for linear scheduling.

Hence, the primary objectives of this study include performing the following:

1. Creation of LSM templates for optimizing the timeline of repetitive activities.
2. Performing trial data entries to demonstrate the working of the templates.

2 Literature Review

Optimization of schedule in a construction project has become an important research topic over the last few decades. Delays in a construction project can arise due to several factors like changes in the project scope, poor collaboration among the stakeholders, inaccurate planning, resource unavailability, etc. [8–11].

However, it is apparent that a construction project manager would not be able to perform several trials of project schemes on the same construction site, irrespective of the type of project. It is due to the fact that construction projects, in general, are one-time processes.

Hence, there is a need for proper pre-planning to achieve an optimized timeline with corresponding resource deployment. In other words, with the help of a pre-scheduled project timetable, planning managers can determine the optimized construction scheme by adjusting the schedule [12]. To achieve this, novel methods like linear scheduling can be adopted in addition to conventional methods like CPM.

Compared to conventional network schedules, the linear scheduling method provides a graphical schedule that is more straight forward and easy to understand. When linear scheduling is used for repetitive activities, the delays and corresponding locations of the work in progress on any given day can be easily determined from the graph [8].

Researchers have also focused on developing a standardization while depicting a linear scheduling graph. Vorster et al. [5] reviewed linear scheduling to show the need for a standard format for the same. A proposed standard format for linear scheduling with symbols like bars, lines, blocks, etc., along with recommendations covering this and the methodology to be used were presented.

It is to be noted that some studies have also presented new scheduling methods for repetitive projects by integrating different methods. Salama et al. [7] integrated linear scheduling and critical chain project management methods by introducing a framework for scheduling repetitive projects after accounting for constraints of resource continuity and uncertainties associated with activity durations. However, the method could be made more generic to be applicable to more project types.

In short, linear scheduling as a practical and visual tool for use in construction projects has been a widely researched topic in the past decades due to its advantages. However, more simple, expandable, and generic formats have to be explored, for easy application of linear scheduling in sites, concerning lean implementation. Hence, this study proposes a generic template in Microsoft Excel that can be easily expanded, as it is cost-effective compared to other commercial linear scheduling software like TILOS and Turbo Charts.

3 Methodology

The detailed steps undertaken for optimizing activity timelines are as follows:

- Firstly, the repetitive activities for which the optimized schedule is to be prepared were identified as the finishing activities for Towers 6 and 7, Parkwest.
- Further, the planning team prepared detailed schedules for both towers for the same, which involved the estimated duration and baseline start and finish dates for each task.
- The schedule for Tower 6 involved finishing activities as block masonry, waterproofing, sunken drain piping, cinder filling, cement plastering, gypsum plastering, railing works, and granite coping works for all 32 floors of the tower.

Table 1 Standard productivity values adopted in the study

Activity name	Standard productivity	Unit
Block masonry	10	m^2 per man-day
Waterproofing	5	m^2 per man-day
Cement plastering	12	m^2 per man-day
Gypsum plastering	12	m^2 per man-day
Railing	10	Rmt per man-day

- The schedule for Tower 7 involved finishing activities as block masonry, railing works, granite coping works, waterproofing, and cement plastering for all 24 floors of the tower.
- As the scope of the study is limited to the preparation of sample templates, it was necessary to constrain the number of activities in the schedules. Hence, activities like block masonry, waterproofing, cement plastering, gypsum plastering, and railing works were identified for Tower 6 and given their respective activity IDs as A01, A02, A03, A04, and A05. For Tower 7, these were block masonry (A01), waterproofing (A02), cement plastering (A03), and railing works (A04).
- These activities were assumed to have a finish-to-start relation for both towers.
- The number of typical floors under consideration was limited to five for both towers: Floors 12, 13, 14, 15, and 16.
- Further, a set of standard productivity values were fixed and adopted for the finishing activities considered. The standard values adopted in this study are as given in Table 1.
- Further, sample optimization templates were created in MS Excel, and trials were performed to demonstrate their work.

The detailed methodology adopted in the study is shown in Fig. 1.

4 Creation of Optimization Templates and Trials

The optimization templates were prepared in MS Excel, with the provision for entering respective quantities for the finishing activities as per the estimation. The automated template then generates the total man-days required for each finishing activity, as per the quantity estimate and the standard productivity norms.

Further, the planned duration as per the pre-planned schedule has to be entered for each activity, for which the production rate and minimum manpower required per day to achieve the targeted schedule gets generated.

Finally, the optimization duration has to be entered, for which the optimized production rate and manpower requirement per day are generated. According to the optimized manpower requirement per day, the planning team can deploy the resources to complete the project.

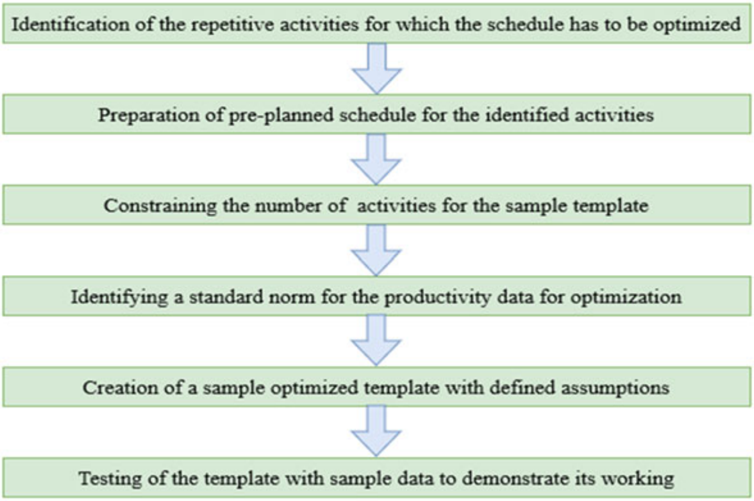


Fig. 1 Detailed methodology in the study

The linear scheduling optimization templates for Towers 6 and 7 are shown in Figs. 2 and 3.

A sample trial has been performed for both templates to demonstrate the work.

The following are the formulas and model calculations involved in the template's working.

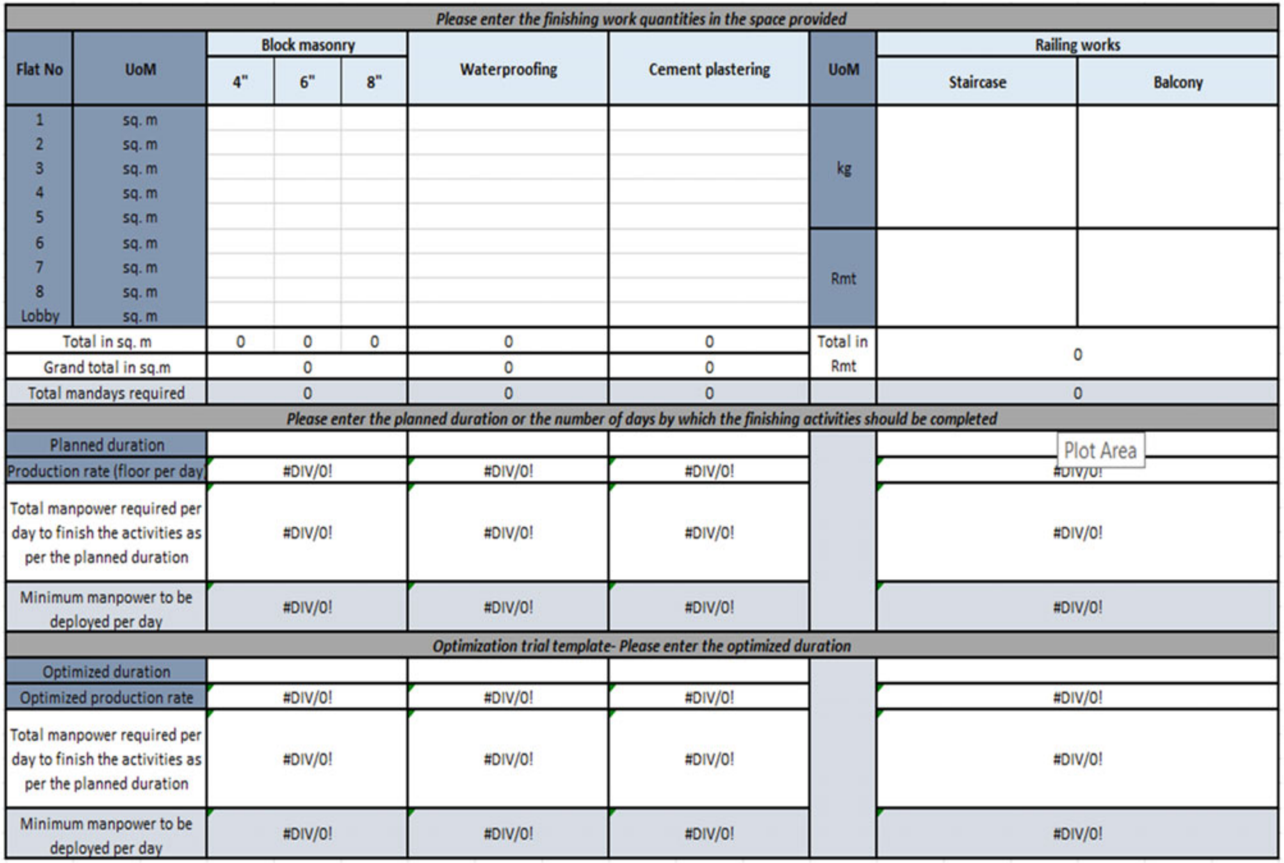
- Unit production rate (UPR) = 1/Planned duration (for each floor)
- Production rate (PR) = UPR × Qty. of work
- Daily manpower requirement = UPR × Total Mandays

As per the pre-planned schedule, the planned durations for the finishing activities of block masonry, waterproofing, cement plastering, gypsum plastering, and railing works were 20, 15, 7, 16, and 15 days, respectively, for both towers. The templates generate the planned unit production rate in floor per day as 1/20 = 0.05, 1/15 = 0.067, 1/7 = 0.142, 1/16 = 0.0625, and 1/15 = 0.067, respectively. Also, the minimum manpower to be deployed per day to achieve the pre-planned schedule for the finishing activities is generated as 4, 7, 3, 8, and 1 for both towers. (e.g., in block masonry, the standard productivity value is 10 m^2 per man-day, and the total quantity of work as estimated is 675.1 m^2. Hence, the total man-days required is 675.1/10 = 67.51 man-days, where UPR is 0.05/day. Now, as the daily manpower requirement is 67.51*0.05 = 3.3755, the template generates the minimum manpower to be deployed as 4 after rounding off using the INT function of Microsoft Excel).

Now, against the pre-planned duration, it is also required to enter the optimized duration of activity completion, which is targeted at 7 days for each activity in both templates.

Please enter the finishing work quantities in the space provided										
Flat No	UoM	Block masonry			Waterproofing	Cement plastering	Gypsum plastering	UoM	Railing works	
		4"	6"	8"					Staircase	Balcony
1	sq. m									
2	sq. m									
3	sq. m							kg		
4	sq. m									
5	sq. m									
6	sq. m									
7	sq. m							Rmt		
8	sq. m									
Lobby	sq. m									
Total in sq. m		0	0	0	0	0	0	Total in Rmt	0	
Grand total in sq.m		0			0	0	0			
Total mandays required		0			0	0	0		0	
Please enter the planned duration or the number of days by which the finishing activities should be completed										
Planned duration										
Production rate (floor per day)		#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	
Total manpower required per day to finish the activities as per the planned duration		#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	
Minimum manpower to be deployed per day		#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	
Optimization trial template- Please enter the optimized duration										
Optimized duration										
Optimized production rate		#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	
Total manpower required per day to finish the activities as per the planned duration		#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	
Minimum manpower to be deployed per day		#DIV/0!			#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	

Fig. 2 Optimization template for Tower 6



Please enter the finishing work quantities in the space provided									
Flat No	UoM	Block masonry			Waterproofing	Cement plastering	UoM	Railing works	
		4"	6"	8"				Staircase	Balcony
1	sq. m						kg		
2	sq. m								
3	sq. m								
4	sq. m								
5	sq. m								
6	sq. m						Rmt		
7	sq. m								
8	sq. m								
Lobby	sq. m								
Total in sq. m		0	0	0	0	0	Total in Rmt	0	
Grand total in sq.m		0			0	0			
Total mandays required		0			0	0		0	
Please enter the planned duration or the number of days by which the finishing activities should be completed									
Planned duration								Plot Area	
Production rate (floor per day)		#DIV/0!			#DIV/0!	#DIV/0!		#DIV/0!	
Total manpower required per day to finish the activities as per the planned duration		#DIV/0!			#DIV/0!	#DIV/0!		#DIV/0!	
Minimum manpower to be deployed per day		#DIV/0!			#DIV/0!	#DIV/0!		#DIV/0!	
Optimization trial template- Please enter the optimized duration									
Optimized duration									
Optimized production rate		#DIV/0!			#DIV/0!	#DIV/0!		#DIV/0!	
Total manpower required per day to finish the activities as per the planned duration		#DIV/0!			#DIV/0!	#DIV/0!		#DIV/0!	
Minimum manpower to be deployed per day		#DIV/0!			#DIV/0!	#DIV/0!		#DIV/0!	

Fig. 3 Optimization template for Tower 7

The production rates are generated as 1/7 = 0.142 floors per day, along with minimum manpower to be deployed to achieve the optimized duration. The minimum resources required to be deployed for block masonry, waterproofing, cement plastering, gypsum plastering, and railing works gets generated as 10, 14, 3, 17, and 1, respectively, for both towers (e.g., in block masonry, the daily manpower requirement is 67.51*0.142 = 9.6443, and the template generates the minimum manpower to be deployed as 10 after rounding off using the INT function of Microsoft Excel).

The optimization templates for both Towers 6 and 7 are shown in Figs. 2 and 3, respectively.

Also, the optimization of production rates and resources for both towers are graphically represented in Figs. 4 and 5, respectively.

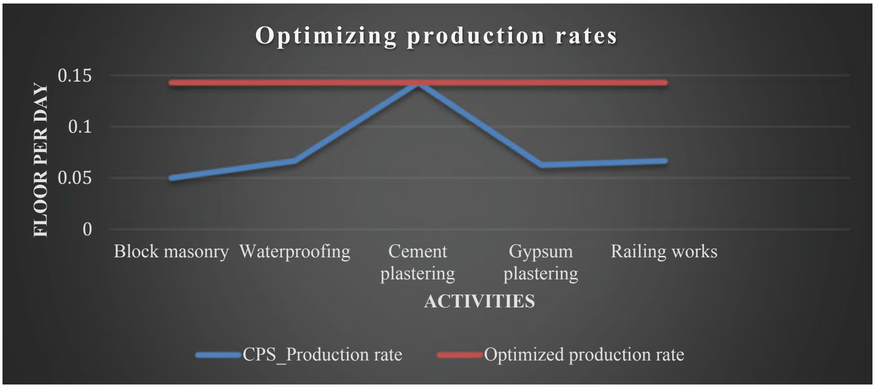


Fig. 4 Optimizing production rates for the towers using the template

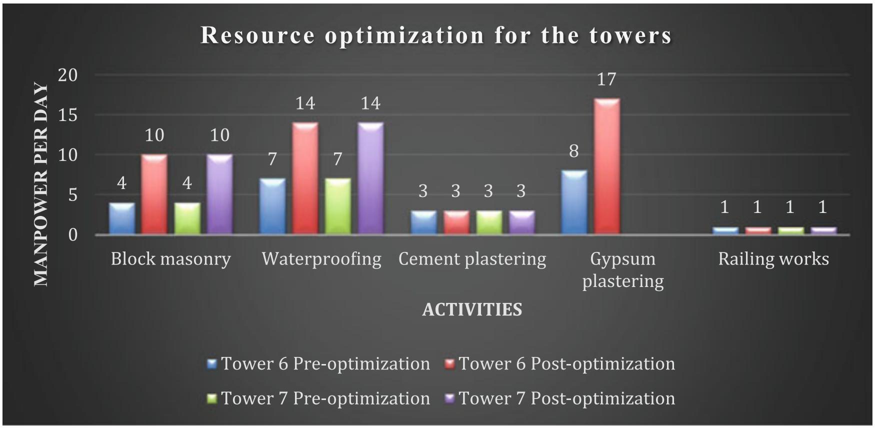


Fig. 5 Optimizing resources for both towers using the template

5 Linear Scheduling Optimization

As per the optimized production rates and resource deployment generated using the templates, the linear scheduling graphs can be prepared for both towers. As per the graphs, it is found that the total estimated duration for completion of finishing activities is 153 and 137 days for Towers 6 and 7, respectively. It is found that the schedules for the activities involve time wastage, represented by the horizontal lines in the graphs.

This is solved using the optimized resource deployment, after which the linear schedules are prepared. As per the optimized graphs, the total duration for completion gets reduced to 63 and 56 days, respectively, for Towers 6 and 7. The optimized linear scheduling graphs have parallel lines for each activity, as no time wastage is involved.

The linear and optimized scheduling graphs for Towers 6 and 7 are shown in Figs. 6, 7, 8, and 9, respectively.

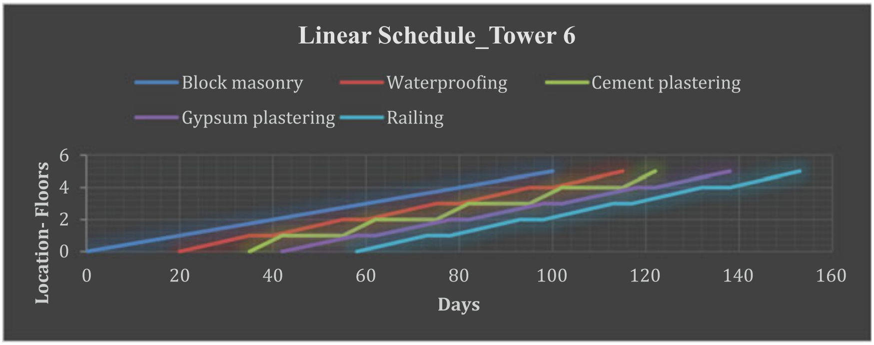


Fig. 6 Linear scheduling graph for Tower 6

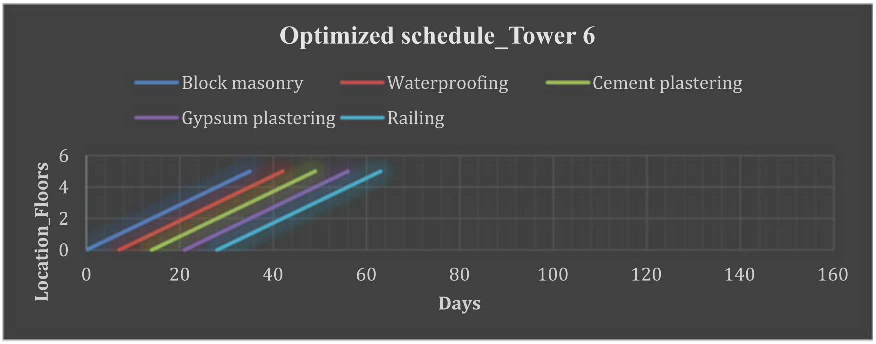


Fig. 7 Optimized linear scheduling graph for Tower 6

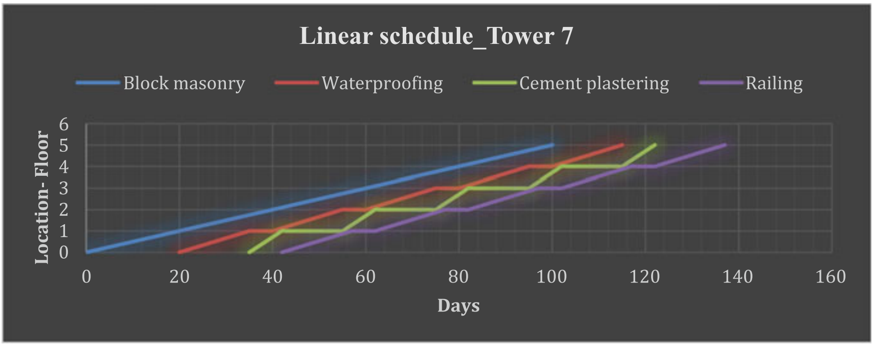


Fig. 8 Linear scheduling graph for Tower 7

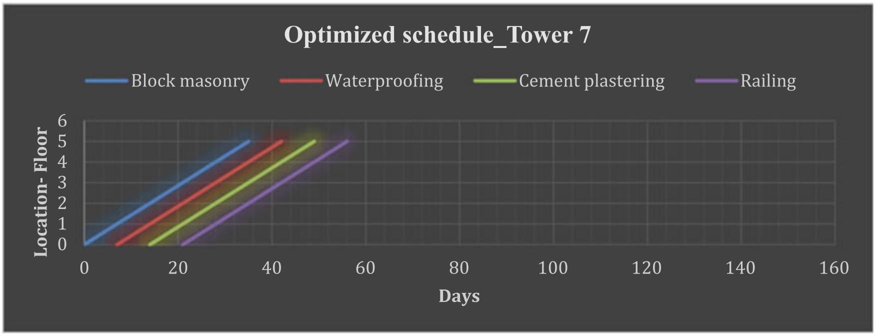


Fig. 9 Optimized linear scheduling graph for Tower 7

6 Conclusions

It is found that production rates and resource deployment can be automatically generated using the created optimization templates. As linear scheduling software such as TILOS and Turbo Charts are costly options for organizations from an implementation point of view, the created MS Excel template is a better cost-effective option. It is evident from the graphs that preparing an optimized linear schedule for finishing activities can reduce the total estimated completion duration for the projects. Reducing time overruns in a project significantly contributes to an efficient implementation of lean construction. Hence, using linear scheduling method for repetitive activities can achieve the same.

It is to be noted that the scope of the templates can be further improvised when more finishing activities are involved. The template can be modified by adding graphic libraries similar to that in linear scheduling software like TILOS. In other words, creating more advanced optimization templates could be the future scope of work.

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Assessment of Last Planner® System Maturity and Engagement of Participants by Linguistic Action Perspective Approach—A Case Study

Ragavi Prabaharan, Karthikeyan Sundaralingam, Tamilnathan, and Mohanbabu

Abstract Its high time to monitor the implementation of the Last Planner® System (LPS) and the participant's engagement at project sites to examine commitment management. As LPS highly involves collaboration and coordination among the project's participants, there is a need to study the "People" element at every stage, which eventually helps the team to analyse and assess the organizational transformation. In this study, the authors used the "Linguistic Action Perspective" (LAP) or "Language Action" approach developed by Retamal et al. (Exploring the relationship among planning reliability (PPC), linguistic action indicators and social network metrics. IGLC 28—28th annual conference of the international group for lean construction 2020, pp 109–118, 2020) for assessment purposes. This paper follows a case study approach. The project's scope is the construction of a medical college building and associated development works. The findings highlight that the organization should consider "Engagement" as an important component while implementing Big Lean tools like LPS and Big Room since it helps them to sustain the Lean implementation throughout the project. By emphasizing the importance of people's commitment and engagement, the team will focus on the areas that need more improvement to analyse interpersonal relationships at work and to achieve productivity.

Keywords Linguistic Action Perspective (LAP) · Last Planner® System (LPS) · Lean Construction

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1 Introduction

The productivity factor in the construction industry has not increased as in other industries [1]. A proper technique should be adopted to improve productivity, and efficiency can be increased through better planning and standardization of technical and operational workforces at the project sites [2]. Hence, "Lean Construction" tools are being adopted by many projects site across the world. One of the common Lean tools implemented in the projects is the Last Planner System (LPS). LPS is a planning, monitoring, and control Lean tool developed by Glenn Ballard and Gregory Howell in the year 1992. It was developed for the collaborative planning process and highly reliable workflow. Construction industries need Lean tools to standardize and strengthen workers' capacities and reduce project variability and uncertainties; as mentioned, it is a collaborative planning process, and it highly demands project participants' involvement. The engagement and commitment towards the LPS implementation have a huge role in sustaining it in the projects. This paper discusses the assessment of LPS implementation maturity and engagement of participants in the "Big Room" by the "Language Action Perspective" approach.

2 Background of the Study

2.1 Last Planner System at Project Sites

The company started to implement the Last Planner® System in its projects in the year 2013. Though LPS was widely implemented in many of its projects, the effectiveness and benefits were not attained to the fullest by the project team, and hence, it is always necessary to understand the level of implemented tools' maturity; however, it depends on the depth at which the tool is implemented at the project sites and also its type [3]. Therefore, the project team decided to assess the maturity level of LPS implemented in its project and to identify the positive and negative indicators that influence the commitment and engagement of participants in the "Big Room" meetings.

2.2 Selected Project

The project's scope is the construction of the Medical College Building and associated development works and bulk services. The authors conducted this study on one of its company's ongoing EPC projects. As EPC project involves multiple stakeholders, the authors perceive that it would be an appropriate one to study the "Engagement of participants" and "Assess the LPS" to get more precise results. Further, one of the authors is the senior planning manager of this selected project which helped to validate certain components of the study from a practitioner's perspective.

3 Literature Review

Last Planner System in India

Last Planner System (LPS) has been implemented across many countries, including India; however, the implementers are unable to realize its benefits due to various reasons that are associated with the implementation process, such as fragmented Lean implementation technique, resisting nature of the participants and lack of skill and knowledge [4]. Furthermore, there is a lack of a framework to assess the LPS components at the project sites to track the activities and assess the maturity of LPS [5]. In addition, the gradual implementation of LPS in Indian project sites highly demands research and study in evaluating the effectiveness of implementation and engagement of the participants involved in the project as LPS is often implemented in the middle of the Indian projects. Consequently, there is inadequate time and focus given to initial training to build the appropriate culture and mindset effectively, and this often leads to participants struggling with LPS skills [6]. However, the project taken into study has started to practice LPS at its earliest stage with proper training for the participants.

4 Study Objective

The purpose of this study is to assess the LPS implementation in a project site through a maturity assessment sheet developed by Centre of Excellence in Production Management (GEPUC) and measure the participants' engagement by Linguistic Action Perspective" (LAP) or "Language Action" approach developed by Retamal et al. [7] to understand the maturity of Lean implementation at site and take remedial actions based on the study results for sustaining the same.

5 Study Methodology

Since it is a case study, the authors adopted a diversified research approach involving extensive literature reviews from conference proceedings like the International Group of Lean Construction (IGLC) and the Indian Lean construction conference (ILCC). The authors selected the longitudinal-holistic case study methodology to understand the LPS maturity and the project participants' engagement and conceptualize its theories. Furthermore, the methodology section includes a 3-step strategy to measure the improvement in the commitment and engagement of project participants by the Linguistic Action Perspective (LAP) approach [8].

5.1 Linguistic Action Perspective

The reliability depends on the controlling dependencies and commitments between the practitioners. Therefore, the management and control of commitments are the two important factors to be considered while monitoring the engagement of participants. To improve commitment management in planning meetings, Macombe and Howell [9] proposed the "Linguistic Action Perspective" approach based on a "Speech Act Theory" [10]. Commitment management involves four stages (1) Preparation of a request, (2) Negotiation and Agreements; (3) Execution and Declaration of Compliance; and (4) Acceptance and declaration of satisfaction; hence, it has been included in the assessment process for the better reliable results of the study.

5.2 Three-Step Strategy

(1) LPS Assessment sheet: To assess the maturity of the LPS implementation in a project by worksheet developed. **(2) LAP Indicators:** To measure and analyse the engagement of the participants in the weekly Big Room meeting by the key indicators (positive and negative) defined by Retamal et al. [7] for the Linguistic Action Perspective. **(3) Notebook for Planners:** To analyse the commitment by assigning a notebook for planners developed by Salazar et al. [11]. The assessment was carried out at regular intervals, i.e. week 1, week 3, and week 5.

6 Research Tasks

Step 1: Assessment of Last Planner System Maturity

The assessment worksheet developed by the Centre of Excellence in Production Management (GEPUC) was used to measure the implementation level and assess the maturity of LPS at the project sites. This worksheet helped the practitioners to track the implementation level of multiple practices and activities that are followed at the site [12]. Also, it helps the project team to assess and evaluate the LPS maturity. The percentage of LPS maturity is the average of the indicators.

Three colours are used to indicate the maturity levels: red, yellow, and green. The red colour corresponds to the low level of LPS maturity, yellow corresponds to the medium level, and green corresponds to the high level of maturity. The assessment sheet of LPS maturity for week 1 is given in Fig. 1.

MATURITY OF THE LAST PLANNER®			
Project	Construction of Medical College Building at Jipmer Campus, Karaikal		
Data Filled By	Project Planning Manager		
Date	30.07. 2022		
	Initial Plan	**Is it?**	**Quality**
36%	The master Plan is followed at the site	Yes	Regular
	It is reviewed periodically	Yes	Regular
	It is streamlined	Yes	Poorly
	It is reported	Yes	Regular
	The milestone plan is prepared, and it is published	Yes	Regular
	It is complemented by the layout	No	-
	It is sustainable, and the standards of the organization are met	Yes	Poorly
	Look Ahead Plan		
0%	Look ahead Plan is followed at the site	No	-
	The look ahead Plan is reviewed weekly	No	-
	Monitoring of milestones against programming goals	No	-
	Management of Restrictions		
0%	Restrictions record exists	No	-
	The record is measured	No	-
	The record is tracked	No	-
	Indicator for managing restrictions for noncompliance exists	No	-
	Weekly Meeting		
30%	Pre- preparation for the meeting	No	-
	The meeting structure and agenda are followed	Yes	Regular
	Active participation of the Last Planners	Yes	Poorly
	Meetings will be held every week	Yes	Regular
	The goal of the meeting is clear	Yes	Poorly
	Causes of noncompliance analysis		
40%	CNC exists in the meeting	Yes	Regular
	Accumulated CNC is recorded	No	-
	CNC is recorded every week	Yes	Good
	CNC is analyzed every week	Yes	Regular
	CNC is published	No	-
	Corrective measures		
33%	Corrective measures are taken in the meeting	Yes	Regular
	It is recorded	Yes	Regular
	It is monitored	No	-
	Reliable commitments		
17%	The Last Planner's Commitment	Yes	Regular
	Quantities and resources are analyzed to achieve the proposed goal	No	-
	Responsibility comes with their plan proposal	No	-
	Visual management		
75%	It is followed at the project site	Yes	Regular
	It is updated	Yes	Good
	Phase plan		
0%	It is prepared	No	-
	It is updated	No	-
	Commitments are recorded	No	-
	It is monitored	No	-
	Visible panels are implemented at the site	No	-

Fig. 1 LPS maturity assessment sheet of week 1

Measurement and control of indicators			
19%	Attendance Record	Yes	Regular
	Concrete Advance Curve Chart is followed at the site	No	-
	The yield Curve Chart is followed at the site	No	-
	Graph of Yield Curves of Key Items by subcontract	No	-
	Graph of Compliance with Progress Commitments (PPC)	Yes	Good
	The causes of Noncompliance Chart is followed at the site	No	-
	The indicators are updated	No	-
	They are published	No	-
Last Planner meetings			
42%	Weekly meeting	Yes	Good
	Punctuality of the Last Planner	No	-
	It is followed consistently	Yes	Regular
	Adequate space is available	Yes	Poorly
	The use of mobile phones, and PCs 'in the meeting is respected	Yes	Poorly
	Refreshment for the comfort of the participants is provided	Yes	Regular
Participants' Commitment			
75%	Full attendance during the meeting	Yes	Good
	Taking up the subject is supported in the event of staff rotation (inductions, procedures, formats, etc.)	Yes	Regular

Fig. 1 (continued)

Step 2: Linguistic Action Perspective Indicators

LAP indicators were used to measure attentiveness and control management of commitments in the weekly work planning. Furthermore, this measures the positive and negative LAP actions defined by Retamal et al. [7, 8], which are given in Table 1.

Based on the above-proposed indicators by Retamal et al. [7, 8], the authors have measured the commitment of the meeting participants. Table 2 shows the measured LAP (+) and LAP (−) indicators of week 1.

Table 1 LAP (+) and LAP (−) indicators

LAP indicator	Positive or negative indicator
Arrives on time	Positive
Take notes	Positive
Check mobile phone	Negative
Mobile phone rings	Negative
Talk by mobile phone	Negative
Leave the room	Negative
Walkie talkie rings	Negative
Talk by walkie talkie	Negative
Does not speak in the meeting	Negative
Does not look at the person who is speaking	Negative

Table 2 Observation of LAP (+) and LAP (−)indicators of week 1

LAP indicator	Positive or negative indicator
Arrives on time	No
Take notes	Yes
Check mobile phone	Yes
Mobile phone rings	Yes
Talk by mobile phone	No
Leave the room	No
Does not speak in the meeting	No
Does not look at the person who is speaking	No

Note Some of the indicators perceived inappropriate by the project team were neglected

Step 3: Notebook for Planners

To measure the participants' commitment in the Big Room meeting, the planners used the "Notebook for Planners." This notebook has a checklist that encloses the PPC, Declaration of Compliance and Satisfaction, and other parameters. It was developed by Salazar et al. [11]. For example, Figs. 2 and 3 show the Measurement of Participants' (Civil Team) Engagement at Weekly Work Planning-Weeks 1 and 2.

NOTEBOOK FOR LAST PLANNERS											
Name	XXXX	Measurement Start Date: 30.07.2022					Measurement End Date: 13.08.2022				
Position	Planning Engineer	Symbology			-- (Very low)	- (Low)	0 (Mean)	+ (High)	++ (Very High)		
					W: Well	N: Normal			P: Poor		
Week 1							Week 2				
Who asks for it?	Activity/ Task	Sector	Day (AM to PM)	Task Priority	Clarity in Petition (Request)	Negotiation & Agreement	% Completed	PPC	Declaration of Compliance	Declarat-ion of Satisfac-tion	Comments
Name & Position				--, -, 0, +, ++	W- N- P	W- N- P	%	Does it comply?	Yes/ No	Yes/ No	
XXXX-Senior Engineer	Column Reinforcement	Civil	8.00 AM to 6.00 PM	++	W	N	100%	Yes	Yes	Yes	-
	Column Formwork	Civil	8.00 AM to 6.00 PM	++	W	N	100%	Yes	Yes	Yes	-
	Column Concrete	Civil	8.00 AM to 6.00 PM	++	W	N	100%	Yes	Yes	Yes	-
	Staircase Reinforcement Type 1	Civil	8.00 AM to	++	W	N	100%	Yes	Yes	Yes	-

Fig. 2 Measurement of participants' engagement in weekly work planning-Week 1

Week 2							Week 3				
Who asks for it	Activity/ Task	Sector	Day (AM to PM)	Task Priority	Clarity in Petition (Request)	Negotiation & Agreement	% Completed	PPC	Declaration of Compliance	Declaration of Satisfaction	Comments
Name & Position				--, -, 0, +, ++	W- N- P	W- N- P	%	Does it comply?	Yes/ No	Yes/ No	
XXXX-Senior Engineer	Roof Slab Formwork	Civil	8.00 AM to 6.00 PM	++	W	N	100%	Yes	Yes	Yes	
	Roof Slab Reinforcement Work	Civil		+	W	N	0%	No	No	No	Similar work in other area was not completed and so labour can't be engaged
	Staircase Type - 2 Column Concrete	Civil		++	W	N	0%	No	No	No	Machinery Issue
	Staircase Reinforcement Type - 2	Civil		++	W	N	0%	No	No	No	Similar work in other area was not completed and so labour can't be engaged

Fig. 3 Measurement of participants' engagement in weekly work planning-Week 2. *Note* Considering the page limit, the authors have shown the notebook filled by the civil trade alone for weeks 1 and 2

7 Results and Discussion

7.1 Evaluation and Improvement Process

The above 3 steps were followed at the site for 5 weeks, and the team measured all the parameters in weeks 1, 3, and 5 to analyse the evolution of the project after implementing the 3-step strategy. The evaluation process was carried out by analysing the LPS maturity level, increase in PPC, and commitment management using LAP indicators. The planners used the LPS notebook at the site, and the detailed information about the indicators was filled in and submitted to the planning manager. Furthermore, the Lean facilitator at the site measured the positive and negative indicators. The results of all the indicators the participants of the meeting filled are given in Table 3.

LPS Maturity Level: From the results, it can be seen that from weeks 1 to 5, there is a gradual improvement in the LAP indicators. The LPS maturity level of the project was very low before strategy implementation; hence, in week 1, LPS maturity level was 31%. Over a week, there was an increase in the LPS maturity level.

LAP Indicators: The positive and negative LAP indicators were used to measure the behavioural assessment and engagement of the participants. Initially, the LAP (+) was low, but it continued to increase once it became a regular assessment practice at the project site. Some of the common LAP (−) indicators observed among the

Table 3 Results of indicators

Project	Indicator	Week 1 (%)	Week 3 (%)	Week 5 (%)
Hospital building	LPS maturity level	31	44	69
	LAP (+)	63	70	79
	LAP (−)	38	30	21
	PPC	69	76	88
	% of compliance negotiation and agreements	50	60	90
	% of declaration of compliance with the commitment	20	70	90
	% of fulfilment declaration of satisfaction	20	80	100

meeting participants were arriving late to the meeting room and checking their mobile phones often. These two indicators were addressed to the participants on how it affects the performance of the collaborative planning process, and hence requested not to repeat further in future meetings.

PPC: In terms of PPC, there was an increase from weeks 1 to 5. It was observed from the evaluation and analysis that the LAP indicators and notebook for planners helped the participants to improve their commitment to their planning process. LAP (+) and LAP (−) indicators helped the team analyse participants' engagement in Big Room and Notebook for Planners, helped the planners get clarity on their work planning, and also the importance of commitment; both of these parameters enhanced the PPC gradually.

8 Conclusion

Though LPS was implemented at many project sites in India, the level of its implementation, maturity, commitment, and engagement of participants weren't explored in depth elsewhere. Sustaining an approach is more important than its implementation; concerning the current Indian construction industry scenario, the level of Lean implementation in the construction field is very low [13]. Hence, every project team must do a study on the same. This study was carried out on one of the company's projects and used a small sample study for 5 weeks. Furthermore, the 3-step strategy has increased the participants' commitment and enhanced their involvement in the weekly work planning. The 3-step strategy developed by Salazar et al. [11], Retamal et al. [7] and framed by Fabian Retamal et al. [8] was adopted by the authors for this study. However, some portions and parameters perceived to be inappropriate to the project's nature by the project team were neglected. Therefore, the authors and the project team have planned to develop new patterns by adding more variables and do a pilot study to examine the implementation and produce more reliable results in the upcoming projects.

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Development of Deployment Framework to Overcome the Challenges in Sustaining Lean Implementation in Construction Projects—A Company's Multi-site Case Study

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Abstract Implementing Lean in construction projects is challenging for many project teams, but sustaining them is even more challenging, as the projects involve more human dynamics (different stakeholders). This paper describes a company's multi-site case study in understanding the challenges to sustaining Lean in its projects and developing a deployment model to overcome the same. A survey was conducted on eight projects, and a total of 22 practitioners (Lean Mentors, Champions, and Facilitators) from each project attended it and revealed the challenges and the critical success factors (CSF) to overcome the challenges in Lean sustainment. The findings show that lack of awareness and knowledge of Lean among the stakeholders, more implementation period, and lack of coordination between the participants of the projects are the primary areas the team should work on to sustain Lean Implementation. In addition, consistent top and mid-management support, training for project's stakeholders, frequent meetings (daily and weekly) with project participants, technology-based approaches, and reward/incentive schemes were revealed as the CSF.

Keywords Lean Construction · Lean Implementation · Critical Success Factors (CSF) · Organizational Culture

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1 Introduction

Since the construction sector is dynamic and encompasses a range of parties, such as government agencies and stakeholders, the projects face several uncertainties. Lean construction has aided the projects in conquering these uncertainties through its numerous concepts and principles. Furthermore, Lean thinking is a new strategy for managing the construction industry that specifies objectives for the process delivery while also improving sustainability [1, 2]. Lean construction has assisted the project teams through its concepts like the Last Planner System (LPS): for strategic planning, Value Stream Mapping (VSM): to identify the value and non-value-adding activities through a mapping process, and 5S: for organizing the project site.

Though India started its Lean journey in 2008, it still faces many challenges in "Sustaining" it. This paper describes the significant challenges in sustaining the Lean journey of a company for many years and also reveals the CSF to overcome it through a developed deployment framework.

2 Background of the Study

The company started implementing Lean in its projects in 2013, with support from IIT Madras as a knowledge partner. Though the team initially faced challenges in the implementation process, they witnessed considerable benefits through its ten years of journey. But, over the years, the team started to perceive the challenges in "Sustaining" Lean implementation. Hence, this multi-site case study was carried out on eight Lean implemented projects of the company to identify the challenges of the same.

In each project, there are Lean mentors, champions, facilitators, and horses (Last Planners). In addition, to monitor and review the implementation process, there is a separate WhatsApp group for the teams, where all the project's daily PPCs, Lean-related events, and meetings are updated regularly. Furthermore, monthly meetings for project teams are conducted with panel members with more experience in Lean construction to review the project's progress in Lean implementation.

Despite all these functions, the project team could endure that the progress was under par, and the vital rule of Lean, "Keeping up Promises," has not been achieved in many portions of the project. So, the Lean Team and the Lean Coordinator oversaw the causes, identified the challenges, and discussed them in the following sections.

3 Literature Review and Theory

3.1 Challenges in Lean Implementation in Construction Projects

After surveying more than 140 construction professionals across the globe, the challenges to implementing Lean construction were found to be similar in the global context, and the challenges in developed countries like the UK are experiencing more social and cultural related barriers [3], which are very common in developing countries like India [4]. The authors classified the challenges into seven categories while considering the current state of Lean implementation in the Indian construction industry.

3.2 Management Challenges

To deploy and sustain any new approaches, there needs strong support from the top management. Also, top management has a significant role in successfully implementing innovative strategies [5]. Lack of top management support is considered a substantial barrier to sustaining Lean implementation in projects. The inadequate client and supplier involvement in the Lean implementation impacts the project's delivery as the Last Planner System (LPS) highly involves collaboration. The top management has the responsibility and competency to bring the stakeholders in this process to sustain the implementation throughout the project.

3.3 Financial Challenges

For a successful implementation and sustainment of Lean projects, there is some exigency of adequate funds from the management to motivate the workers and employees [6]. Financial challenges involve the cost involved in conducting special training programs and making employees attend conferences, courses, and examinations on Lean, providing incentives and reward systems based on the worker's performance [7, 8]. Implementing Lean practices in projects requires significant investment by the organization, but if the workers and employees return to the previous behavior, it can be sustained over time [9].

3.4 Educational Challenges

Educational challenges include a lack of understanding, knowledge, and awareness of Lean construction [10]. Education on Lean construction and awareness, especially among the stakeholders and clients involved in the project, is the first and foremost step toward successful implementation and can lead to a sustainable journey. Education is vital as it helps the practitioner understand the concept clearly and frees them from the misconception that "Lean is a difficult one to deploy." It could be seen that most of the resistance and reluctance the people have shown to adopt such new practices is due to their poor understanding, knowledge, and awareness of Lean construction.

3.5 Technical Challenges

Technical challenges directly affect the Implementation of Lean Construction (e.g., reliability, simplicity, flexibility, and benchmarking) [11]. Also, a lack of integrity in the production chain, which includes clients, suppliers, and stakeholders [7], acts as a technical challenge in the projects. The long implementation period in some of the projects is due to the time taken to select the suitable Lean concept to deploy, train the new workers and employees, manage to change in working culture, and conduct evaluations to identify the areas which need further improvements [6].

3.6 Human Attitudinal Challenges

Sustaining new concepts and approaches in projects is not an easy process. It takes more time to change from conventional practices. The challenges often arise due to human attitude, behavior, and mindset; this includes unwillingness to change or adopt new practices, lack of coordination, and lack of self-motivation [12], which are considered to be significant challenges for sustaining Lean in the project sites.

3.7 Cultural Challenges

Cultural barriers are identified to have a significant impact on Lean sustainment. Establishing an organizational culture with a mindset of waste elimination can promote the Lean philosophy [13]. Culture determines the acceptance and rejection of ideas or processes and whether an organization can be sustained in a competitive environment [14]. Lack of contractor engagement hinders the Implementation of Lean practices [15]; also, it has more impact on the sustainment part of it.

3.8 Government Challenges

Bringing Lean into the national agenda has more challenges because it merely depends on the ruling government bodies of the Nation. However, regulations in government policies can help construction organizations sustain Lean implementations in projects. Hence, most management perceives that the Government's support has more influence on Lean implementation and sustainment. In addition, government agencies should have a supporting role by devising the necessary policies that encourage the adoption of Lean construction; also, it should commence with applicable policies that could provide critical support to make lean methods feasible in projects [16]. The sub-factors under each category are restricted due to the ILCC's page limitation norms.

4 Research Methodology

The research methodology adopted was Design Science Research. It includes three stages problem identification, solution design, and evaluation [17]. This study deals with the challenges and enablers for sustaining the Lean journey of a company. First, the challenges were identified through a literature review.

Many pieces of research were carried out to identify the challenges/barriers to Lean implementation, but none have explored the "Sustainment" part and solution framework for it; hence, a deployment framework is developed that aims at the CSFs to sustain Lean in the projects for the long run. The challenges were assessed by surveying the experts practicing Lean in 8 different company projects, and virtual interviews were conducted with them to determine the CSFs and develop a deployment framework.

5 Identification of Problem

The review meetings and discussions helped the project team resolve the constraints, but it wasn't enough to find out the actual reason/root cause of the major challenge, which is the "Sustainment of the Lean Journey."

6 Survey

The study adopts a deductive approach using a questionnaire survey to identify the significant challenges for Lean sustainment. The authors have used this approach to determine the facts, opinions, and views relating to the respondents. First, the

Table 1 Profile of the respondents

No of years of experience in construction	No of years' experience in lean construction	Designation			
		DGM (deputy general manager)-projects	Project manager	Planning manager	Execution head-projects
> 20	> 5	2	4	4	1
< 20	< 5	2	4	4	1
	Total	4	8	8	2
	Sub total	22			

framing of the questionnaire was limited to semi-structured close-ended questions to identify the challenges in sustaining Lean projects. Then, a virtual interview was conducted to find the CSFs to overcome those challenges, as the respondents could give their suggestions and relative measures.

7 Profile of the Experts

The study was conducted on the company's 8 Lean implemented projects. Over 22 respondents (Experts), including Lean mentors, champions, and facilitators, were selected to attend the survey. The profile of the respondents is given in Table 1.

8 Result

After analyzing the survey results, it was found that the major challenges for Lean Sustainment are related to educational, technical, and human attitudinal aspects, which are, (1) Lack of awareness, (2) Lack of knowledge of Lean construction among the client and sub-contractors, (3) More implementation period, (4) Lack of understanding, and (5) Lack of willingness among the participants.

As major identified challenges are related to the educational and technical domain, the team decided to take necessary actions that encourage and consider it an essential part of implementation and sustainment. Hence, a framework/sustainment plan inspired by Bhawani et al. [18] is used as a base and starting point, which is later amended according to the authors' research and study need. This framework was developed by the authors that help the project participants overcome the addressed challenges. Furthermore, the survey results were discussed with the panel experts, and a virtual interview, more of a brainstorming session, was conducted to identify the CSF to overcome these challenges, and the CSFs are summarized in Table 2.

Table 2 Critical success factors to overcome the challenges

Critical success factors
Consistent support from top management
Training for project participants (Clients, suppliers, and sub-contractors)
Frequent review meetings (monthly and weekly) with clients, suppliers, and sub-contractors
Technologies and tools like software make the implementation easier and faster
Reward systems and incentives based on the individual's performance
Starting the Lean implementation with small concepts like "5S" to build the "Lean Culture" easily
Government policies that encourage the adoption of Lean construction in projects

9 Developed Framework

The authors have developed a deployment framework considering the addressed challenges and critical success factors by the Lean practitioners in the company. It comprises five steps as follows (Fig. 1).

Step 1-Educate and Train: As Lean is a long-term philosophy, the initialization of implementation should be strong enough to tackle any challenges which are expected to come in the future. Hence, before commencing the implementation, proper training and education should be provided to the participants of the projects. As identified through the survey, the major challenges for Lean sustainment fall under the education category, and therefore, the authors have developed a framework that starts the implementation by prioritizing education and training. **(1) Educate:** To

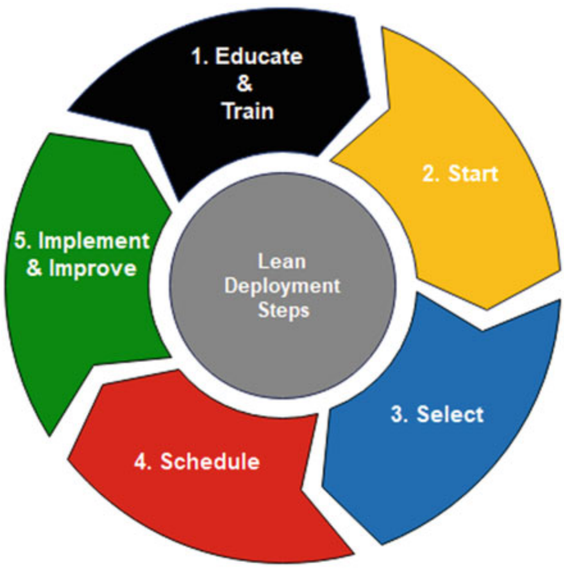

Fig. 1 Lean deployment plan for sustainment

make all the internal participants of the project attend NPTEL Course on "Lean Construction basics" (mandatory). **(2) Train:** Conduct frequent and regular internal Lean training by experts on Last Planner System (LPS), Big Room, 5S, and VSM (Both internal and external participants). **(3) Continuous Learning: Conference and Programs:** Attend Lean Conferences (ILCC, IGLC), Webinars by ILCE, LCI, etc., (All the internal project participants, External participants—optional). The top management's involvement and commitment are highly to make the stakeholders attend these training and engage them in forthcoming sessions.

Step 2-Start: **Initial Kick-off meetings:** After providing the necessary training, "Initial Kick-off meetings" should be finalized and intimated to the project participants. At this stage, the team can discuss the following areas, (1) Finalizing the project's conditions of satisfaction (P-COS), and also, the client needs should be included in the (P-COS) scope, goal, and key performance areas. (2) Embedding the project's value proposition in the Lean deployment plan. (3) Identifying the Lean champions to manage the Lean implementation.

Step 3-Select: (1) Selection of method: Selecting the methods according to the project's nature is very important. It is not always necessary to adopt the same method in all projects; various other methods can be implemented based on the project's scope, value, and other influential factors. For instance, at any given critical path activity in a project, it is advisable to make the decision based on Choosing by Advantages (CBA). At this stage, the project team can discuss and brainstorm on investing in software tools and technologies. The project team can adopt a method for each project category, such as design development, decision-making, and problem-solving**. (2) Communicate:** The project head/ leaders should communicate the selected method with the project's participants. Selection of method should be based on the following area, (i) Scope and Goal-Conditions of Satisfaction (COS), (ii) Cost-(Target Value Design), (iii) Design and Process Development-Value Stream Mapping (VSM), (iv) Information Management-(Big Room, BIM,.), (v) Decision-making-Choosing by Advantages (CBA), (vi) Problem-solving (PDCA—Plan-Do-Check-Act), 5 WHY analysis).

Step 4-Schedule: The training should be provided to the external participants based on the selected methods. Furthermore, training for external participants should be scheduled to educate and make them aware of the chosen methods. Finally, final kick-off meetings should be scheduled to start the implementation process of the projects.

Step 5-Implement and Improve: (1) Implement: The project team can start their selected method with a "Pilot study" if they aren't sure about the same outcome, which applies to any investments in software tools. Furthermore, they can start their implementation with small Lean tools like "5S" to build the "Lean Culture" within the projects. **(2) Improve:** Conducting frequent review meetings with project participants is very important as this can help the project team to evaluate themselves in the implementation stage. **(3) Lean Excellence award:** Rewards and incentives can be given to the practitioners based on their performances to motivate the workers initially. **(4) Follow-up:** It should be carried out to ensure the implemented methods are on track.

The model is developed and evaluated by the organization’s experts, and hence, the authors believe that if these steps are appropriately deployed, then it will potentially improve the effectiveness and sustainment of Lean implementation within the projects which are facing similar challenges and constraints.

Furthermore, considering the page limit of the paper, the authors have described the deployment plan theoretically rather than in an elaborated pictorial representation of each step.

10 Discussion

Though the company started its Lean journey a decade ago, sustaining it is not an easy task for the team due to the dynamic nature of the projects. Hence, the authors have developed a deployment plan for Lean sustainment in the projects. As identified through this study, the major challenges faced by the project teams are “Lack of awareness and knowledge on Lean construction among the clients and subcontractors.” As the Last Planner System (LPS) is implemented in most projects, it requires “Collaborative Planning.” Hence, the clients’ and suppliers’ involvement are much needed. Nevertheless, concerning the Indian construction industry, the awareness and knowledge of Lean construction are limited to only Lean implemented organizations. Therefore, it is challenging for the project team to coordinate and work with stakeholders who have little or no knowledge of Lean; this, in particular, has more impact on sustaining the implementation; consequently, the implementation process gets delayed. Therefore, “Educate and Train” is the first step for Lean implementation. Conducting Lean Training for the stakeholders can help to overcome this challenge, and also, it would enhance a better collaborative work culture. After the commencing and project study, the participants can start their implementation at the sites. Regular review meetings should be followed with the clients and stakeholders, as this could help them to identify the pain areas, and also, it will act as a regular follow-up platform. Reward systems like incentives, and recognitions based on the performance of the individual, are revealed as one of the success factors, as this can be a motivating factor element to the employees and the workers. But it is also believed that incentives can only make the project players involved in the implementation process more effective, and it won’t help the team in the long run, especially in sustaining it. Furthermore, practitioners feel that technology-based approaches like software which serve as a simple interface for the project team to achieve their needs, including PPC, Constraints, coordination trades, etc., can help them to implement and sustain Lean better. Therefore, top management support also significantly impacts Lean sustainment to achieve all the above-mentioned success factors. Furthermore, the Government should bring policies and establish a national agenda that enhances the adoption of Lean construction in Indian projects [4]. Lean should be included in contract conditions to make it mandatory as this could help the project team to overcome the significant challenges, which are lack of awareness and knowledge on Lean.

11 Conclusion

As a Lean practitioner for over ten years and one of the ILCE's charter members who have accomplished and studied the experiences of various Lean projects across the nation, the authors believe that the study's outcome can considerably represent a generalized problem in the Indian construction industry. Sustaining Lean is very challenging in projects, as it involves collaborative working with people from different domains. Without awareness and proper training, bringing them to work in a Lean environment is not easy. Hence, as discussed earlier, the top management and Government should take further actions to overcome this challenge. Regardless of all the challenges stated in this paper, the enhancement of Lean implementation through technology and digitization is imminent. Consequently, the institutions connecting academia and industry can contribute to work on the assessment of Lean implemented organization's maturity level and develop a framework that helps practitioners to deploy and Sustain Lean for the long run.

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Lean Implementation: A Never-Ending Journey of a Company

Ragavi Prabaharan, Mohanbabu Subramanian, Jaisankar, Tamilnathan, and Suresh Kannan

Abstract Lean implementation in India found its roots a decade ago. Many pieces of research have been done on areas like Lean tools, Barriers to Lean implementation, and even a lot more case studies were carried out on the same, but the "Lessons learned, strategic choices the team made, organizational culture transformation experienced by them after introducing an innovative concept like Lean into their projects" haven't explored elsewhere. Therefore, the authors describe a company's Lean journey to give an outline of the team's decision-making and strategic choices while deploying the Lean concept in their projects. The results suggest that implementing Lean in any project highly demands a "Change in mindset" of the people involved and also describe how decision-making and strategic choices have played a vital role in successful project implementation. Further, the findings suggest that implementing Lean is a never-ending journey, and attaining success requires people's involvement and commitment throughout the project.

Keywords Lean construction · Lean implementation · Organizational culture

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1 Introduction

The company started its Lean journey in the year 2012; the decision taken by the managing director to stand out from the accustomed curve was the best that the team could ever have to visualize and realize the benefits attained through implementing Lean. In addition, Lean can act as a strategy or conceptual tool to make the construction processes more standardized; hence, it is high time for the construction industry to adopt it. The challenges and hurdles the team initially faced, the pain areas, and the action plan to overcome them are discussed in the following sections. This paper depicts the events and the Lean implementation with a timeline pattern. A qualitative approach is used to provide a deeper understanding of the strategies taken by the company during the implementation. Furthermore, the team's decision patterns and problem-solving techniques are explained broadly. The main objective of this paper is to give an overview of the steps involved in Lean implementation and the strategic choice taken by the top management. The authors have adopted a storytelling approach to convey the parameters mentioned above for easier understanding and delivery of the content.

2 Lean Implementation in Projects

Although Lean construction found its roots in 2008 in India, the construction industry still faces many challenges in various areas. Only a few companies have adopted Lean in their projects; hence, the maturity level, while concerning to the Indian context, is still at the first stage, "Practicing of Lean." Introducing any new approaches, innovations, or changes in the regular practicing pattern, there would be some resistance from the project players. Therefore, "Culture change" is challenging for such innovative approaches, but this could be tackled with the top management's proper education, training, guidance, and support. There are several frameworks and deployment models developed by academicians and consultants, but when it comes to real-time implementation, many driving factors influence preventing it.

Successful implementation of any new approaches relies on top management's commitment. Many contextual factors and decisions which are taken by the management have significant effects and influence the implementation processes. Hence, it is always important to overlook the decisions taken and strategies followed by the top management. Furthermore, the organizational culture, workforce management, and other key factors which influence adopting the best practices are merely emerging from the top management. Hence, the study of infrastructural decisions is always important to understand the multiple ways that the company is taking to implement Lean in its projects successfully, and also it helps to understand the adjustments and improvement areas that a team should consider and look upon which are needed at various levels of the journey.

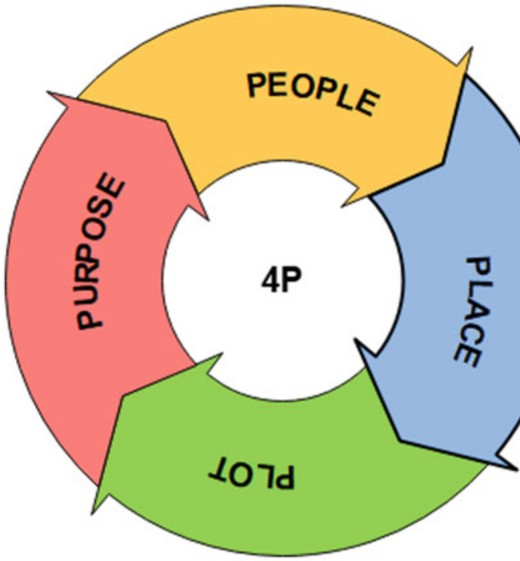

Fig. 1 "4Ps" of business story-telling

3 Study Methodology

This paper presents exploratory research to deliver the lessons learned by the construction company based on their experience. As mentioned earlier, a qualitative approach is used to understand the challenges, contextual decisions, strategies taken, and events with an open-minded interview.

The authors have used a timeline approach to describe the company's journey. Furthermore, the data, reports (internal review), and publications were used to recall the events and details. A business story-telling approach was adopted, a process involving causality that needs to have a clear goal and message [1]. The authors have adopted this approach to narrating the events and other facts in a more realistic way; also, stories will enable the readers to understand and convey the message succinctly. The four main elements "4P" of the business story-telling given in Fig. 1, which are "People," "Place," "Plot," and "Purpose," are used to precisely describe the situational context.

4 The Lean Journey

The company was founded in 1956, started its journey as a small contractor by undertaking and supervising the construction of irrigation systems, and developed as one of the notable EPC contractors in the nation. Over the years, the company has gone through various challenges and pain areas to achieve and manifest its goals. The firm's two major criteria for leading the front are quality and excellence. Furthermore,

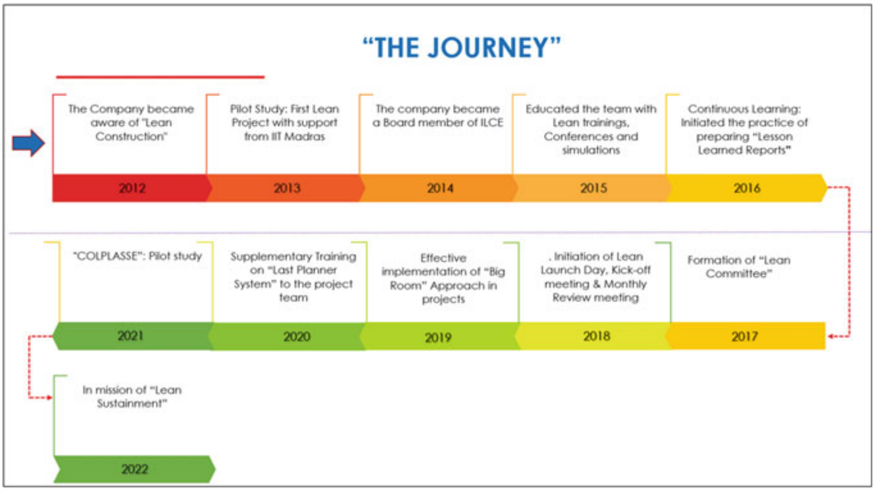

Fig. 2 Lean journey

"Continuous Improvement and Learning" have always been part of the company's mission and vision. The timeline of the company's Lean journey is shown in Fig. 2.

4.1 2012: Begun

In 2012, the company constructed a facility for IIT Madras and nurtured a good relationship with them. The term "Lean" was introduced by one of the professors and well-wishers of IIT Madras. Being a knowledge partner, IIT Madras encouraged the company to take part in the initiative that various construction industrialists of the nation established. Eventually, the awareness of "Lean Construction" was widened by the company's managing director widened the awareness of "Lean Construction," who firmly believed that construction processes should be standardized and appropriately documented. In the same year, the firm formed a team of Lean enthusiasts to learn and attain knowledge on Lean Construction; consequently, Lean training was given to them with support from the knowledge partner (IIT Madras).

4.2 2013: Learn

The company joined hands as a corporate member of the Institute of Lean Construction Excellence (ILCE) in April 2013. As mentioned earlier, the guidance was provided by the knowledge partner IIT Madras and the consultant "Nadhi Infotech." ILCE developed a team of experts and consultants from academic and industry domains. The various steps which the company has taken to reach the next level in its maturity level in "Awareness and Understandings on Lean" are explained below.

Step 1: A one-day workshop on Lean Construction was conducted at IIT Madras in May; it was organized by the project managers and other key members of the company. Through this workshop, the team learned and understood. A group of experts (Professors IIT Madras) presented the workshop and explained the concepts to the team members.

Step 2: A successful implant training was conducted by IIT Madras to the team, which was initiated in June 2013. "Lean and BIM champions" were identified through this training to make the implementation process much more effective and to take the Lean concepts to the rest of the company's team. Under the guidance of the IITM expert, the identified BIM champion was initially made to study the Revit, and Navi works to understand the basics of BIM, and eventually, the champion underwent training on 3D, 4D and 5D modules.

Step 3: A "Pilot Study" was planned to be carried out at one of the company's projects after the training sessions. The project's scope involves the construction of three major buildings: Super Market, Weekly Market, and International Convention Center. The study was started with the supermarket building in June. A group of Lean mentors, Lean and BIM Champions, Last Planner, Overall Lean document controller, Productivity improvement supervisor, and two Postgraduate students (1 for work sampling management and 1 for BIM) were identified, and their respective works were assigned to them.

Step 4: Following the formation of a group, the implementation started in the same month and was practiced for 10 months.

4.2.1 Method Selection

The proper selection of the Lean method is essential before commencing the project. Therefore, the team had a brainstorm with the Lean experts and selected the appropriate methods, namely Value Stream Mapping (VSM), Last Planner System (LPS), and Work Sampling (WS), for implementation.

Method 1: Work Sampling (WS) has helped the team to identify the Value added (VA) and Non-value added (NVA) activities more precisely. After implementing WS, the team identified 39% VA and 29% NVA, in which the scrap percentage of rebars drastically reduced from 5.98% to 0.29%; eventually, this increased the overall productivity by about 30%.

Method 2: Furthermore, the slab cycle time was reduced from 45 to 30 days after the implementation of the Last Planner System (LPS), and thereby, the overall project delay has been reduced by 15%.

Method 3: The team observed the "motion" waste in brick masonry activity, and hence, Value Stream Mapping (VSM) method was selected for the same.

> Before commencing VSM, the average productivity of mason was 0.27 cum/day; after the implementation, the productivity improved from 0.70 cum/day in, which the overall improvement was about three times [2].

Therefore, method selection and the strategies taken by the team are important as they enhance waste management, productivity, and system improvement in the project.

4.3 2014: Build

In 2014, the company became one of the Board of Directors in ILCE. After witnessing the benefits of Lean implementation, the management decided to start it in all its forthcoming projects. The full-scale implementation was started at the TRIL project (Construction of two IT buildings) at Chennai, Taramani. The implementation started with training for all the participants of the project. This was the very first project for the project team to hire a separate Lean consultant. One Lean consultant and a guide (Implementation helper) from the same consulting company joined in this process and helped the team from teaching the basics of Lean to successfully implementing it at the site. They guided the project team to form a group that included Project Manager, Planning Engineer, Planning Manager, Frontliner, and the execution team.

The team applied Location-Based Management System (LBMS) and “Big Room” concepts in this project. Both of these concepts were very effective; in particular, the “Big Room” concept enhanced the planning process and helped the team address the pain areas and resolve the constraints very efficiently. Initially, before implementing the Lean approach, the construction of toilets in the two IT buildings was delayed; hence, the team did a mock-up study on one toilet out of 84 to understand and identify the root cause behind it, and eventually, they identified that the cycle time to complete one toilet had taken about 90 days due to various vendors, suppliers, and sub-contractors’ involvement and improper planning of activity sequences. After the LBMS implementation, it was reduced to 45 days, how was it possible for the team? They implemented “Big Room” at the project site. A large configurable room with an occupancy of more than 20 participants was chosen to conduct the meetings. It created a collaborative environment and helped to address the issues and root causes of the project participants who couldn’t complete the task as planned. Through Big Room implementation, the team comprehended how effective collaborative planning could bring such considerable changes in the outcome of the process.

4.4 2015: Educate

Proper education and training significantly influence the successful Lean implementation; hence, the company has taken specific steps, which are discussed below.

4.4.1 Simulation to Educate

The top management has taken several steps to educate and spread the awareness of Lean Construction to the internal employees by making them attend conferences and training programs; eventually, they were fortunate enough to connect and build a relationship with one of the best international Lean experts from the UK, Mr. Alan Mossman (Principle of "The change business"). He visited IIT Madras for a Lean workshop and conducted a simulation called "Villego" on "Last Planner System," which helped the team to understand the process of LPS and also the importance of the Lean principles like "No Blame Culture," "Keeping up the promises" and "Respect for People." Furthermore, the simulation involves the concept of "Learn by Playing," which is the first reason it has bought a significant impact and change within the team.

The management decided to invest its fund in educating the employees and believed that this would result in a good change in the implementation process and help the team to build the "Lean Culture." Hence, the team bought a "Villego Simulation Kit" from Mr. Alan Mossman to educate the internal project teams.

4.5 2016: Continuous Learning

The team strongly believed in the motto of "Continuous Learning." Veraciously speaking, not all Lean projects were entirely successful at the initial stage when the company started to implement Lean on its own. It faced many vicissitudes in its journey. The team was pushed into a very strenuous situation and learned many lessons. They started to work on the areas, where they were falling behind and initiated the practice of preparing the "Lesson Learned" reports after the closure of all Lean implemented projects. In these reports, the challenges which were faced by the team during implementations and the steps and actions taken to overcome the same were enclosed. This really helped them to review their Lean implementation level and assisted them in improving the pain areas more effectively.

4.6 2017: Line-Up

The company started its Lean committee to make decisions on the Lean progress. The committee was composed of managers from all the regions where the projects were carried out. The regional managers are responsible for the proper Lean implementations in their respective region's projects. The project managers and team were encouraged and supported to attend various conferences and Lean programs to acquire and maintain knowledge of Lean Construction. Furthermore, they were encouraged to publish papers at Lean conferences like IGLC and ILCC. The team published papers on various areas like waste generation and controlling techniques, Lean Culture, and Process Improvement [2–4], respectively.

4.7 2018: Improvise

The involvement of the HR department has started, and their contribution helped the team to move to the next phase of implementation. They made the Last Planner System (LPS) mandatory to implement it all the projects. The standard LPS format was set up and followed from the year 2018 to till date. In the case of remote projects, "Digital Training" for the project participants and the new employees was started as well. The HR team has taken the following steps for the successful Lean implementation at the project sites, (1) "**Lean Launch Day"**: At this event, all the project participants like sub-contractors, suppliers were invited to attend it with the motive of spreading the awareness on "Lean Construction" and also, all the labors were invited to this event; furthermore, a separate interaction session was arranged to communicate with about the event in their native language, (2) **Kick-off Meetings:** Following the Lean launch day, kick-off meetings were conducted, in which the project team will discuss the project scope, goals, key performance areas. Also, the responsibilities will be assigned to the respective functional heads of the project. Identification of Lean Champions, Mentors, and Facilitators was carried out at these meetings, (3) **Review Meeting:** To monitor the progress in Lean implementation at sites, monthly review meetings were practiced. The review process was accomplished by the panel members (Top management), (4**) Rewards and Incentives:** Based on the individuals' performances (PPC achieved), incentives and rewards were given to them; this became a motivating factor to the employees and helped the team to some good extend in the project's outcome.

4.8 2019: Implement

To bring the collaborative planning culture within projects, one of the projects took a remarkable step to achieve the same. The team made an agenda which includes the

Daily Huddle meetings at 7 PM and every Saturday weekly meetings by 6 PM and strictly followed it at the site. Initially, the team faced many challenges in making it a practice; later, they made it through consistent teamwork. The project's scope involves the construction of ISPAT PG Institute and Super Speciality Hospital at Rourkela. The team was actively involved in the planning process and consistently followed the Big Room approach. As a result, weekly PPC increased from 40 to 75%. Furthermore, it helped the project team in improving planning reliability and productivity.

4.9 2020: Train

Last Planner System (LPS) is one of the Lean tools which was majorly implemented in all the projects. Only the team who are traveling with the company since 2012 were aware of Lean concepts and its implementation; hence, the management supported the new employees and other project teams to attend the international workshop on LPS by Mr. Alan Mossman, which was conducted by an IIT Madras incubated company EPMCR at IIT Madras. It helped the team to understand "What Lean Construction is? And how does it work?

4.10 2021: Recognition

The company employed a separate person (Lean Coordinator) to look after all the Lean-related works like implementing Lean at new projects, providing training, conducting review meetings, and all the research works like conducting case studies and preparing research papers to publish in the well-reputed journals and conferences, and also representing the company as ILCE volunteer. In one of the projects, the team did a pilot study with an effective software tool, "COLPLASSE," on the Last Planner System. It was developed by a Professor (IIT Madras); he and his project assistant helped and guided the team to implement it in the real-time project. The team benefited from it, and they are working on the areas which need further improvisation and to be incorporated into the software tool. At ILCC'2021 event, the team presented 5 papers on the following areas, Lean implementation benefits: Slab cycle time reduction [5], Adoption of Value Stream Mapping (VSM) for precast slab casting process [6], A comparative study between LPS and COLPLASSE implementation in project sites [7], Enabling Lean culture [8], and VSM adoption for reduction of "I" girder cycle time [9]; furthermore, 4 posters were presented, in which one of the posters which describe the "Reduction of cycle time in "I" girder erection by implementing VSM," won the first best poster award.

4.11 2022: R&D

A research and development (R&D) team was formed to work along with the Lean Coordinator to improvise the existing process and develop a separate "Lean Deployment Plan" for the "Lean sustainment" in the projects. To understand the difficulties and challenges in Lean implementation, the team conducted a survey within the Lean projects, in which 22 practitioners composed of Regional Head (Lean Mentor), Project Managers (Lean Champion), Planning Managers and Engineers (Lean Facilitator), and execution team (Lean Horses) were selected to attend the survey and give feedback on their Lean implementation experiences. After reviewing the results, major of the practitioners demanded technology-based approaches for successful Lean implementation at the site, especially for LPS. Considering the necessity, the team discussed it with top management to take it further. The management has now decided to take support from its sister concern an end-to-end software solution company to work on the practitioners' needs.

5 Discussion

The company started its Lean journey in the year 2012 and faced many challenges and benefits as well through Lean implementation; as the company's motto is "Continuous Learning," it never stopped its Learning process at any stage of its journey; instead, it formed a potential team to overcome all those challenges with consistent teamwork and hard work. The company is working on many areas to move on to the stage of its Lean maturity model; furthermore, the team will work together to achieve this goal.

6 Conclusion

The authors used the business story-telling methodology to give visibility to the readers about the decision-making and the strategic choices the company has taken toward Lean implementation. This study indicates that the work environment and understanding the need of the practitioners are more important for implementing the new approaches within a project; these two factors were found to be the study outcome as well. This study would guide the new Lean practitioners on making strategic choices and how they would reflect in the project's outcome.

Acknowledgements The authors would like to thank the company's Managing Director, Regional Heads, and the HR Team for their valuable contribution and support in sharing their Lean journey and experiences.

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Improvement of Segment Casting in Balance Cantilever Viaduct Using LPS

Javed Sayyad and Das Shanbhag

Abstract The project under discussion includes construction of access-controlled Nagpur-Mumbai Super Communication Expressway (Maharashtra Samruddhi Mahamarg) in the state of Maharashtra. The expressway comprises Viaducts, Iconic bridges, Tunnels, etc. The under-construction expressway will reduce the travel time between Nagpur and Mumbai by 4 h as stated by Union transport Minister Shri. Nitin Gadkari. Package-14 of the expressway is awarded to Afcons Infrastructure Ltd. The organization with strategic goals to reduce wastage, improve productivity and better planning is implementing lean construction tools across its project sites. Over the years, lean construction tools have been applied to simple as well as complex construction projects to manage the projects effectively and complete the project in time. In this study, an effort is made to implement the Last Planner System (LPS) for the segment casting activity in viaduct to understand the effectiveness of the system and the impact it has in timely completion of activities. The study shows if all the aspects of LPS are implemented sincerely, the system can help in process improvement which in turn leads to activity time cycle optimization. It also discusses the challenges involved in the implementation of Last Planner system.

Keywords Lean construction · Last Planner System (LPS) · Process improvement

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1 Introduction

The 701 km long access-controlled Nagpur–Mumbai Samruddhi Expressway connects two important cities of Maharashtra. The design speed for the express way is 150 km per hour, however, the speed on the expressway will be restricted to 120 Kmph. Aimed to reduce the travel time between the two major cities in the state, the expressway will serve for the overall development and prosperity of the region.

Construction Package-14 which is located in district Nasik and Thane is a challenging job due to its geographical location in mountains and heavy rainfall area. Package-14 has viaduct (balance cantilever structure), and it is spanning over a valley and connects the two adjacent mountains. The viaduct comprises two parts LHS and RHS, maximum length of viaduct is 1295 m which is on RHS side and the maximum height of pier is 61 m. Refer Table 1 for the detailed scope.

The superstructure of viaduct consists of cast in situ box segments. The segments are 17.5 m wide and casted in length of 5 m (Refer Fig. 1). To cast the segments a special type of formwork arrangement, i.e. Cantilever Form Traveller (CFT) is designed and fabricated. The CFT is assembled on ground in parts and these parts are erected above the pier head with the help of crane. With the help of CFT, segments are casted on both the sides of pier head (refer Fig. 2). Once segment casting and cable stressing is completed, CFT is shifted to the next segment casting position.

Table 1 Scope of work of viaduct

Sr. No	Description	LHS side	RHS side
1	Length of viaduct	1275 m	1295 m
2	Number of foundations	13 Nos	13 Nos
3	Number of piers	13 Nos	13 Nos
4	Segments	210 Nos	210 Nos

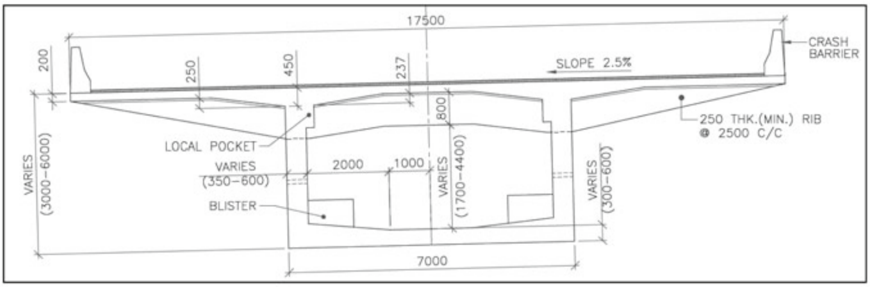

Fig. 1 Typical cross section for segments

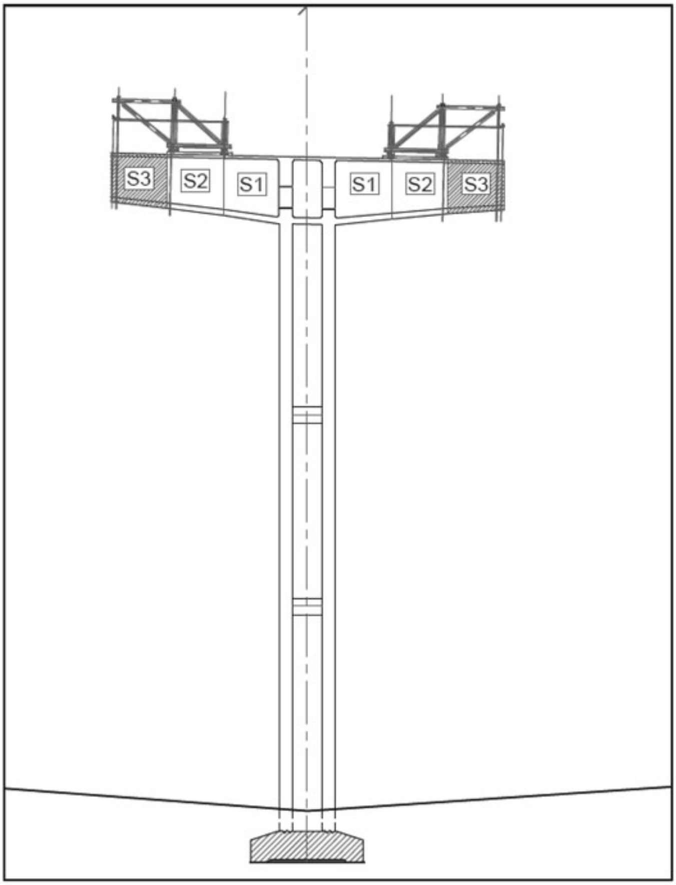

Fig. 2 Segment casting by CFT

Segments S2–S9 are casted sequentially on both side of pier (refer Fig. 3). After completion of segment casting, CFT is lowered to ground in parts and re-erected on next pier with the help of crane.

As per base line schedule, viaduct is on critical path. Therefore, timely completion of viaduct is important to complete the project in time. The superstructure of viaduct is the most challenging part and superstructure on LHS side is completed first followed by RHS side of viaduct. To complete the segment casting in time, 12 CFT pairs are deployed. Therefore, at any given moment, a total of 24 segment work fronts were in progress. Monitoring of activities at all 24-work front was a challenge (Fig. 4).

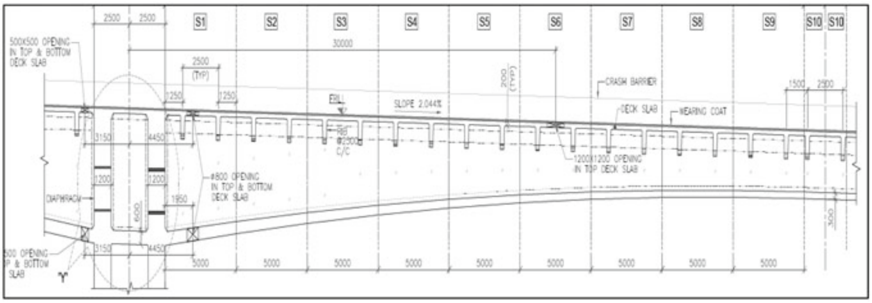

Fig. 3 Longitudinal sectional elevation of segments

Fig. 4 Segment casting by CFT on either side of pier

2 Implementation of LPS

To ensure detailed planning and monitoring of all the activities, implementation of lean construction tool was decided. Last Planner System® which is one of the tools to stabilize the work flow and to have reliable plans was proposed to implement. The Last Planer System has been proved effective in construction project management and monitoring the efficiency of planning [1].

LPS provides a platform for collaborative approach in planning and monitoring of the activities. The objective was to ensure that there is no slip is segment casting progress and the target dates are achieved.

The last planner system has three components look ahead planning, commitment planning and learning [2]. In look ahead planning, sequence and rate for work flow are decided. The last planners are the ones who control the workflow. The execution engineer and foreman, supervisors are the last planners involved in the planning. The last planners shall evaluate all the possible constraints in advance before making any commitment to prevent the uncertainties affecting the plans [3].

Implementation of LPS can help make better assignments to the workers through continuous learnings and corrective actions and to cause the work flow smoothly in best achievable sequence and rate. Re-planning and sequencing shall be done when the activities do not go as per the plan [1] (Fig. 5).

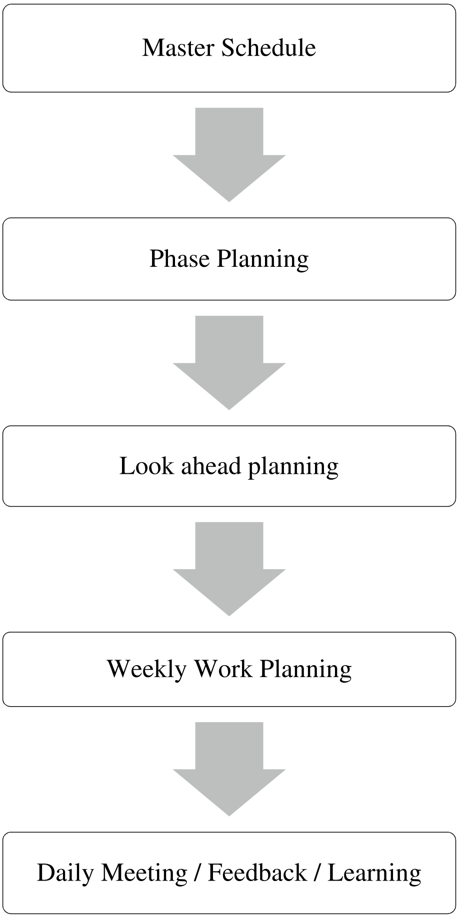

Fig. 5 Key components of last planner system

Training sessions are arranged at site to introduce LPS to all the last planners and to ensure the active participation and have collaborative efforts. Training sessions have lasting benefits in implementing new management strategies [4].

3 Master Schedule

A detailed construction schedule was prepared for all the activities of viaduct in primavera P6 PPM software. Four construction milestones were set, namely completion of foundation works, completion of pier, completion of segment casting and the finishing works in viaduct.

4 Phase Planning

Cast in situ segment casting using cantilever form traveller was a challenge. After a detailed study and multiple discussions with the key stakeholders, a list of activities involved in segment casting works and the sequencing of all these activities was decided. Refer Fig. 6 for details of activities involved in segment casting works.

After sequencing of the activities, productivity and time for each activity were decided based on discussions with experienced individuals working in construction field. So, on the basis of the decided sequence, productivity and time for each activity, we arrived at 12 days average time cycle for casting of segment. These 12 days are arrived considering the sequential activities and excluding parallel activities.

There are 9 numbers of segments to be casted on each side of a pier, i.e. the segment casting will repeat 9 times. For monitoring purpose, the cycle time of segment casting is considered to start post the concreting of a previous segment to successive segment concreting.

To discuss the finalized sequence and time cycle of segment casting with the last planers, workshops were arranged on ‘Segment Casting Works’. Following points were discussed and elaborated during the workshop.

Introduction to CFT components and CFT operation procedure.

Method statement for segment casting works.

Sequence of activities and time cycle for each activity in segment casting works.

All the engineers and supervisors were trained with Virtual Reality (VR) model prepared for CFT operations. The VR model gives step by step guide to CFT operations.

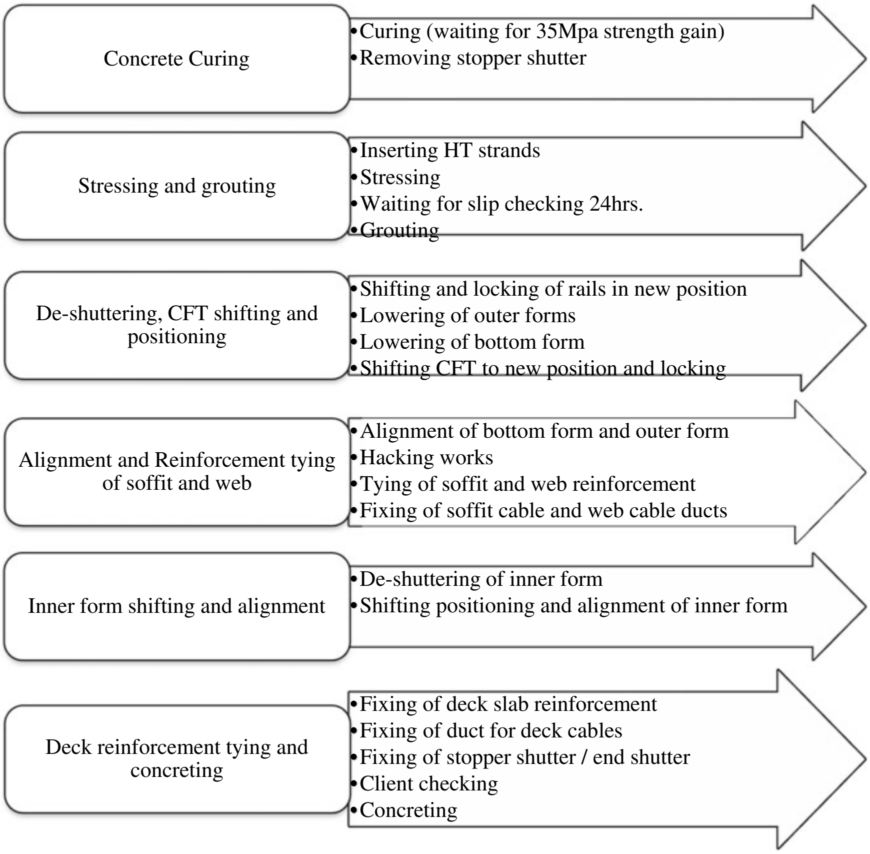

Fig. 6 Activities involved in segment casting work cycle

5 Look Ahead Planning

Look ahead planning controls the work flow of the project. For segment casting works, six weeks look ahead plan was prepared considering the sequence and cycle time of 12 days. The plan gives number of segments to be casted in each week for the next six weeks. Following activities were governing the six weeks look ahead planning for the 24 segment casting locations,

Completion of pier head.

Completion of fabrication of CFT and availability on site.

Time required in ground assembly of CFT components.

Time required in erection of CFT component above the pier head.

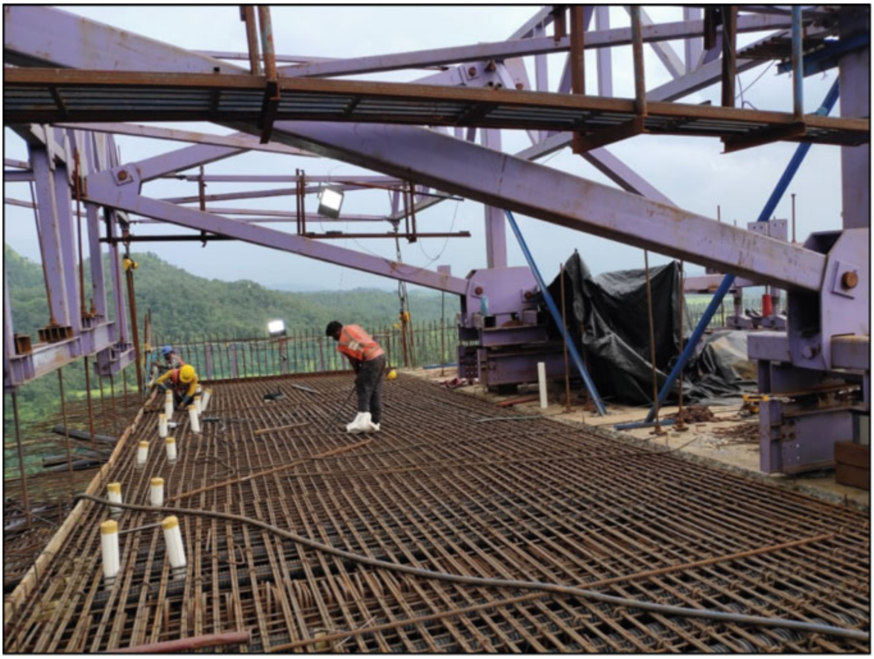

Fig. 7 Reinforcement tying in progress

Critical pier location at which segment casting is priority based on the master schedule.

6 Weekly Work Planning

Weekly work plan in LPS controls the production. For segment casting works, weekly meeting is conducted on Saturdays to review the progress against the planned target and plan for next week is discussed and revised if needed. The weekly work plan gives location wise segment casting planned in a week (Figs. 7 and 8).

7 Daily Meetings

Daily meeting is conducted at 5:00 PM to plan for the day's work to discuss the day-to-day issues faced and possible solution for the same. In case of deviation from the plan made during weekly meeting, the reason for variance is identified, recorded and optimal solution to it is discussed.

Fig. 8 Segment concrete curing in progress

Active participation of last planners and all key stake holders in daily meeting was mandatory. Feedback and suggestions were taken from all the participants for improvement of the sequence and productivity of segment casting works.

8 Planned Percent Complete

Planned percent complete (PPC) gives the extent to which the commitments of last planner are achieved. It does not measure productivity, it gives effectiveness of the planning. It is the ratio of number of commitments achieved to the number of commitments made. PPC for segment casting is calculated using the formula:

$$\text{PPC} = \frac{\text{Number of tasks completed}}{\text{Number of tasks planned}}$$

PPC daily and PPC weekly for the segment casting activity is calculated and plotted on a graph. In graph, work weeks are plotted on horizontal axis and per cent complete on the vertical axis (Refer Fig. 9).

Initial PPC trends are lower and it is zero on several occasions (Refer Fig. 9) due to missing of daily and weekly commitments. The commitments were missed because

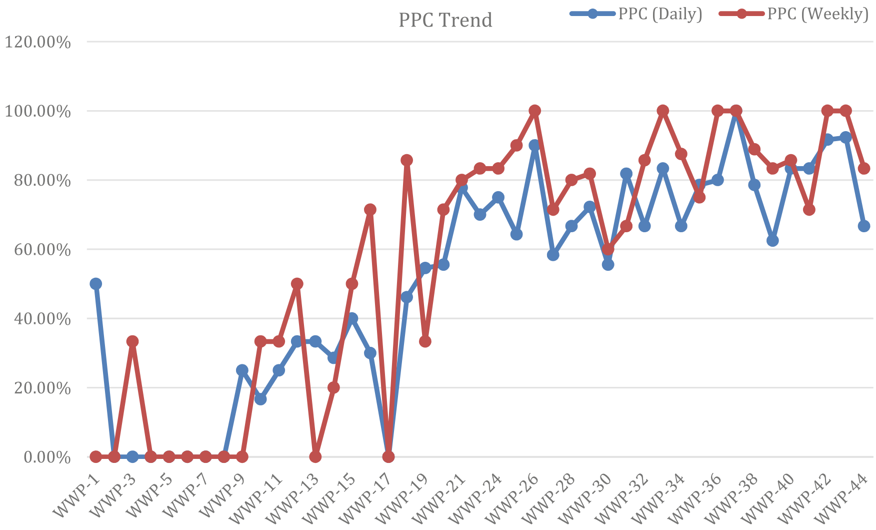

Fig. 9 PPC trends recorded for segment casting works

segment time cycle of 12 days could not be achieved. The constraints in achieving time cycle are identified by careful study of the activities involved in segment casting and discussion with last planners (Refer Table 2).

The constraints are categorized as follows,

Constraints in CFT operations

(Sr. no. 1, 2 and 3 in Table 2)

Constraints in reinforcement works

(Sr. No. 4 and 5 in Table 2)

Constraints in concreting

(Sr. No. 6, 7 and 8 in Table 2)

The constraints were identified, and solutions to improve the process were implemented. A gradual improvement in PPC trends can be observed (refer Fig. 9). First segment casting was done in 27 days' time cycle, with steady improvement, the time cycle was brought down to 9 days.

9 Conclusions

Implementation of all the elements of Last Planner System is essential for the system to be effective, part implementation will not serve the purpose. Last planners play key role to make the system effective. It is observed that the last planners tend to set

Table 2 Constraint identified in segment casting and solutions implemented

Sr. No	Constraint identified	Solution implemented
1	Rectification works due to mismatch in CFT elements	Mock-up of fabricated CFT elements is done at fabrication yard to avoid further mismatch
2	During CFT outer form lowering, outer form used to stick with concrete and it was difficult to lower leading to loss of time	It was identified that the longer the shutter stays in contact with concrete, difficulties increase in shutter lowering. To reduce the time of contact between the shutter and concrete, outer form lowering was done after 48 h of concreting (20MPa strength) before the segment stressing
3	CFT inner form which is of plywood needs to be made for every segment. Since the dimensions of local pocket area (refer Fig. 1) changes for every segment	An independent carpenter gang was deployed which makes the inner plywood shutter ready for every segment to meet the requirement
4	Due to congested reinforcement detailing in the segment blister, reinforcement tying was time consuming	Reinforcement detailing for blister was revised to ease the blister reinforcement tying and reduce the required time. Mock-up for the revised blister reinforcement was done to train the workers (refer Fig. 10)
5	There are 100 web reinforcement rings in a segment and each ring is of different height (since the depth of segment reduces). Selecting the correct web ring out of 100 during reinforcement tying was difficult	To ease the selection of web rings during reinforcement tying, numbering is done on the web rings at cutting and bending yard (refer Fig. 11)
6	Access road to viaduct is very narrow, only one vehicle can be allowed on the road, which used to create difficulties in shifting of reinforcement and concrete	Two security personnel with walkie-talkie were deployed to control the vehicle movement of the access road. Priority was given to transit mixers during concreting
7	Concrete pipe line choking. (concrete needs to travel a maximum vertical distance of 61 m and horizontal distance 45m)	After trails, a concrete mix design with workability 180mm and retention time of 3 h is prepared after trials to ensure smooth concrete flow
8	Delay in achieving the required concrete compressive strength (35MPa) to start stressing	Concrete mix design with microsilica gives the desired result. The boulders are sorted and picked for crusher to ensure good aggregate quality

Fig. 10 Segment blister reinforcement mock-up

lower targets, to avoid facing questions in case of missing a commitment. Therefore, periodic discussion of master schedule is essential. Immediate measures shall be taken to address any deviations observed from the master schedule.

Daily discussions are important, hesitation from last planner to participate in the discussions was noted during initial meetings. Efforts are necessary and all the ideas needs to be appreciated to encourage active participation from last planners.

Learning of engineers, supervisors and workers at the beginning of new activities has an effect on initial PPC trend.

Fig. 11 Numbering of segment web rings

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A Review on Embracing Lean Thinking for BIM Implementation in the Indian Construction Industry

Rhijul Sood and Boeing Laishram

Abstract Infrastructure development provides a framework that allows society to function effectively. The Government of India (GOI) has initiated various infrastructure initiatives, including Smart Cities Mission, Jal Jeevan Mission, Power for All, and others. India's infrastructure sector will need a projected sum of INR 304 trillion to continue development through 2040. However, majority of infrastructure projects experience time and cost overruns endangering continued viability of the project. According to the Ministry of Statistics and Programme Implementation, out of 1568 projects (above 150 crores), 423 reported cost overruns, and 721 were delayed. Hence, technological solutions like Building Information Modelling (BIM) that enhance project lifecycle should be implemented effectively for on-time and within-budget project completion. Adopting BIM requires changes in technology and work processes to ensure on-time project delivery. In this regard, lean principles can help to improve a process by eliminating wastes from existing process. This research reviews BIM and Lean literature to determine how BIM-Lean can help the Indian construction industry. The study employed Scopus, Web of Science, and EBSCO, peer-reviewed publications to summarize BIM & Lean independently as well when integrated. Finally, the paper's outcomes will support construction stakeholders in successfully implementing BIM by embracing lean thinking by understanding and overcoming the barriers affecting lean implementation.

Keywords BIM · GOI · Lean · NIP · O&M

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1 Introduction

The construction sector being one of the key pillars of the economic development [1] is highly unorganized but has a value similar to other business sectors in the Indian perspective. The Indian construction sector is confident about its future growth as a result of the government's plans to create large infrastructure projects and smart cities around the country [2]. The Government of India (GOI) has recently launched the National Infrastructure Pipeline (NIP) for the period FY 2020–2025 which envisions that India needs to spend about $1.4 trillion (INR 100 lakh crore) over these years on infrastructure to achieve the ambitious goal of $5 trillion GDP by 2024–25 [3]. Because of these forthcoming smart cities and other massive infrastructure projects, the Indian construction sector is hopeful about its future. It has also been estimated that approximately INR 304 trillion of investment is required in the Indian infrastructure sector till 2040 in order to sustain the country's development [4].

Various projects typically under construction encounter significant levels of uncertainty at various stages, increasing the risk of cost overruns, handover delays, and poor quality. Studies also show that most of the Indian construction projects have higher cost-overruns (63–141%) and delays (79% of initial project schedule) than the global average, including higher frequency (69% of infrastructure projects incur severe cost overruns, while 89% are delayed) [5]. According to a report of the Ministry of Statistics and Programme Implementation for May 2022, out of 1568 projects (above 150 crores), 423 reported cost overruns, and 721 were delayed. The prevalent issue of construction project delays and cost overruns has prompted a lot of studies, with much of that study focusing on the causes and potential solutions but still lacking implementation.

The Indian construction industry, which was already struggling with poor management and a lack of tracking of its labor force, entirely lost its central grip as Covid-19 spread over the nation in April 2020, halting the work of industry. Several businesses in the construction industry have tried to introduce new methods to speed up production recovery and improve their resilience in the face of the crisis. One such solution includes the use of technological solutions like Building Information Modelling (BIM) that enhance project design, construction, delivery, and Operations & Management (O&M) which helps for on-time and within-budget project completion and delivery if implemented effectively. BIM being a digital platform facilitates communication, visualization, and decision-making among project teams to enhance the success of their projects [6]. But, the implementation of BIM encounters many barriers and lean management seems to be a solution to increase the acceptance and implementation rate of BIM in the Indian construction industry.

Research into the role of lean management in hastening the adoption of BIM in the Indian construction industry is relatively scarce in comparison to the level of work done on waste reduction, productivity improvement, process efficiency enhancements, and the mitigation of negative environmental impacts [7]. Hence, this paper systematically answers about the BIM technology and the concept of lean construction (what) and embracement of lean (how) to encourage Indian construction stakeholders to implement BIM.

2 Research Methodology

A systematic literature review (SLR) is used as the research methodology for the current research as outlined by Tranfield et al. [8], presenting a comprehensive summary of the current understanding of the topic under investigation [9]. The concepts of a systematic review help get rid of bias (systematic errors), lessen the impact of chance, boost the reliability of the evidence, and provide more reliable recommendations [10]. SLR is effective for absorbing and evaluating current findings within or across areas to establish a holistic research framework [11]. Unlike traditional literature reviews, SLR uses rigorous and specific criteria to analyze and compile all of the existing studies in a certain field. Researchers can use SLRs because they provide a "unbiased and replicable mechanism to discover, analyze, and assess reported data relevant to a set of defined research objectives" [12]. The steps to conduct SLR consists of three stages as suggested by Tranfield et al. [8] which includes Stage I: Planning the review, Stage II: Conducting the review and Stage III: Analyzing and reporting.

3 Planning the Review

In this stage, suitable databases and keywords were identified as part of initial search strategy [13]. To achieve our research objectives, we used various databases as search engines to identify suitable publications. However, only publications that have been peer-reviewed were utilized in the current research, as they contain logical and consistent data with high quality level [14]. To identify and select relevant articles for the review analysis, the researchers used Scopus, Web of Science, and EBSCOhost databases as they were fully accessible from their home institute. It was decided to use these databases since they are the most comprehensive and cover the vast majority of peer-reviewed journals in project as well as construction management areas [15, 16]. Once the databases are selected, the next important thing is to compile suitable terms and keywords pertinent to aim of the study. Because of this, we used a search strategy called "building blocks," which is very prominent among literature reviewers [17]. Thus, we use Boolean operators like "AND" and "OR" to break down the research challenge into smaller and more manageable text blocks. The following terms have been discovered as relevant to the current study problem: "BIM, Building Information Modeling, Lean, Lean Management, India". Mendeley was used as the reference manager software and MS Excel was used for data extraction, analysis and data visualization. The following syntax was used as a search query in the above-mentioned databases:

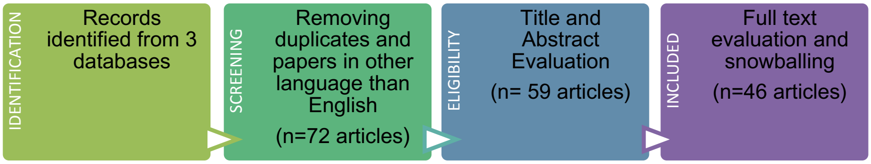


Fig. 1 Selection of studies for systematic literature review

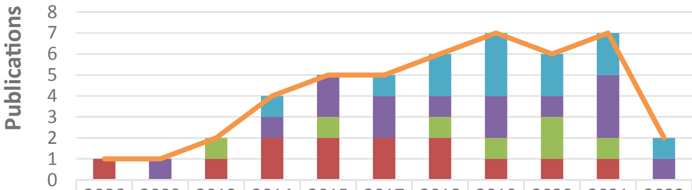
(TITLE-ABS-KEY ("BIM") OR ("Building" AND "information" AND "model*") AND ("lean") OR ("lean" AND "management") AND ("India"))

4 Conducting the Review

After the keywords were chosen in the previous section, the next stage is to search for and choose relevant articles, which is likewise a three-part procedure. In the previously mentioned three databases, a keyword search was done as the first step. To have a full list of papers, it would have been helpful to know when the research papers in the current study area came out in the Indian context. The list of articles up to June 2022 is taken care of, and in the end, 93 publications from all three databases were used to make the list. Only papers written in English were kept, and duplicate papers were also taken off the list, bringing the total number of papers to 72. The second step involved assessing publication abstracts and titles using pre-established database filters and selection criteria. This is because, despite search restrictions, many journals from unrelated fields were found (e.g., nursing, medicine, and applied economics). So, it's important to point out that this study only looked at BIM and lean studies in construction and construction management journals. After this regressive sorting and snowballing technique 59 papers were finalized for review. In the third step, a full-text manual analysis was done. This was done first by filtering by title and abstract, and then by reading the full text along with snowballing technique. A total of 46 papers were selected for the systematic review analysis that will be detailed in the next sections of this study (Fig. 1).

5 Analyzing the Review

In this stage, compiling of publication data by year and subject area for descriptive analysis of the publications was conducted. In the subsequent section, charts along with tables are used to show the results of the descriptive analysis. In inductive content analysis, the categories come from the content itself. This is done through a process of iterative coding, category development, and re-examination, with a consistent unit of



	2006	2009	2012	2014	2015	2017	2018	2019	2020	2021	2022
Surveys	0	0	0	1	0	1	2	3	2	2	1
Literature Reviews	0	1	0	1	2	2	1	2	1	3	1
Case Studies	0	0	1	0	1	0	1	1	2	1	0
Conceptual/Theoretical	1	0	1	2	2	2	2	1	1	1	0
Total	1	1	2	4	5	5	6	7	6	7	2

Fig. 2 Year-wise publications

analysis used to improve accuracy [18]. As a result, the whole text of the manuscript was chosen as the unit of analysis by the review.

6 Analysis and Results

6.1 Descriptive Analysis

The descriptive study incorporates publication patterns throughout multiple years, commencing in 2006, as shown in Fig. 2. The study spans about 16 years till June 2022, and the review analyses the adoption and implementation of BIM in India as a result of the growing use of IT technologies in the construction sector. The graph demonstrates that, up until 2015, publications were quite seldom. However, as technology has become more prevalent in the construction industry and BIM use has expanded in some of the infrastructure sectors, publications have become more frequent. The publications were also classified on their types such as surveys (12 papers), literature reviews (14 papers), case studies (7 papers), and conceptual/ theoretical (13 papers).

6.2 Content Analysis

6.2.1 What is BIM?

Building Information Modeling (BIM) can be described as "a digital representation of physical and functional attributes of a facility or infrastructure" [19]. Within the AEC industry, BIM acts as a facilitator for the interchange of information throughout all lifecycle phases [20]. BIM provides geometric features, spatial links, geographic information, amounts, and building component information.

The BIM-based design technique has the potential to make project management simpler and less challenging [21]. BIM improves the current method of communication, offers a collaborative platform, and facilitates interoperability between many fields of business [22] involved in a project such as civil, electrical, mechanical, and plumbing. It provides opportunities for stakeholders to work together throughout the building's lifecycle, whether that's to add, remove, update, or alter data as it's being generated through the BIM process [23]. Furthermore, if implemented correctly, BIM can improve performance and efficiency across the project life cycle. Additionally, BIM's data-reuse features results in fewer errors, more consistency, better communication, and designated roles of responsibility for model and task management. The other BIM benefits includes reduced cost and duration through optimization of construction schedule, increased team communication and collaboration, single platform for coordination among different construction disciplines such as architecture, civil, mechanical, electrical, plumbing etc. [24]. As a result, it is observed that the construction industry is increasingly transitioning from traditional construction methodologies to construction techniques and procedures that are based on BIM.

BIM spans across various dimensions from 3 to 7D BIM and maturity levels 0–3 correspond to the level of development the model has achieved [25]. The promotion and implementation of BIM technology provide benefits to traditional as well as industrialized (high-technology) construction [20]. BIM has been more valuable in recent years because of its potential to automate repetitive operations and reduce designers' efforts on production-oriented duties [26]. Regardless of the benefits, BIM adoption in the AEC industry remains limited and "falls short of its potential" [27]. This is the case across various developing countries including India where the maturity level of BIM is still low, therefore we need tools like lean management which can help the construction industry to improve the process of BIM adoption and implementation in the Indian AEC industry.

6.2.2 What is Lean?

Lean Production is a management philosophy based on lessons learned through analyzing the Toyota Production System (TPS). Lean Construction is a new production philosophy that was developed by adapting the principles of Lean Production to the building sector [28]. Lean is defined as a "dynamic process of change, driven by a set of principles and best practices aimed at continuous improvement" [29]. Lean focuses on the elimination of non-value-added activities/waste (or "muda") in the industry [30]. The seven wastes are motion, overproduction, over-processing, lead time, rework, inventory, and defects [31, 32]. It was found that the construction industry benefited from lean construction practices by increasing value creation and reducing environmental impact. Each sector has customized its identifications of waste within the seven basic categories.

Using a production-based approach, lean construction seeks to improve project delivery by standardizing workflow and lowering the waste [33]. It achieves so by adopting a range of strategies such as pull-based scheduling, value stream optimization, and the last planner system all of which involve rigorous collaboration between different teams of specialists. Tools from lean manufacturing can be adapted for use in the building industry. One of the most critical criteria in the adoption of these technologies is the commitment of senior management to implementation. The main prospect of the lean management principle is "Drive more value by using less of everything". Based on these principles and several case studies, Engineers Australia [34] listed the recommended practices used for the application of Lean construction methods which include (1) eliminating waste: (a) waste walks, (b) value stream mapping; (2) target value design; (3) BIM; (4) Last Planner System; (5) pull planning; (6) information center meetings; (7) five-step plan (5S) and visual management; (8) standardized work; (9) continuous improvement (CI); (10) built-in quality and error proofing; (11) Just In Time (JIT); and (12) prefabrication.

6.2.3 BIM Implementation Through Lean

The use of lean practices as mediators for obtaining increased levels of BIM use has not been extensively explored, even though the use of BIM as a mediating intervention to enable effective lean practice adoption as an outcome has been recognized. Positive attitudes towards technology, the availability of software on a trial basis, and a shared set of principles and values, contribute to the success of individual technology adoption in the Indian context [7]. Any strategy for implementing new technology must take into account both the technology and the users who will be using it [7]. As a result, it is crucial to include end users in the adoption process to promise a flawless switch to new technology within an organization. Lean encourages continual workplace improvement by fostering an atmosphere of mutual trust, respect, and harmony which boosts the process of acceptance and execution of technology. BIM and the principles of Lean construction each have a substantial impact on the construction industry's ability to build projects efficiently and effectively while adhering to budgetary constraints [35]. While research indicates that BIM can facilitate the realization of Lean principles [36, 37], evidence of lean's usefulness in facilitating BIM adoption remains limited. Embracing lean practices is a smart way to ensure the project's success in the long run and generate a positive Return on Investment (ROI).

At this point, the application of lean practices in Indian projects is still in the early stages of development [38]. Most of the studies have utilized the Last Planner System (LPS) and Value Stream Mapping (VSM) as a tool for improving construction sites in terms of productivity, coordination, and technology adoption. Mahalingam et al. [39] has attempted to demonstrate how lean practices, particularly the Last Planner System (LPS), can aid in the implementation of BIM in the Indian construction sector by examining two metro rail projects in Chennai and demonstrating how lean practices, particularly the Last Planner System (LPS), decrease coordination-related problems within the project organization along-with preparing the way for BIM adoption. Because of the emphasis placed on coordination, there may be synergies to be gained by combining BIM with lean processes and the need for establishing a connection between them [39]. It demonstrates that to secure a satisfactory return on investment in BIM tools, project managers may do well to make an initial investment in lean techniques before deploying BIM. In another study, [36] has identified 56 various possible relations between BIM functionalities and lean construction principles. After establishing the connection between BIM and lean, it was proposed that using lean on projects will improve BIM maturity levels [40]. There are multiple barriers which are responsible for slow BIM implementation and can be categorized under various Lean wastes and subsequent lean tools can help to accelerate the process of removing those barriers and adoption of technology in the Indian construction scenario. This can be achieved by developing a proper framework and subsequently analyzing and implementing the same in Indian construction sites. The issue with the construction industry is not only the barriers for adopting BIM, which has been studied and described in many works of literature but the barriers of adopting lean as well. There have been very limited studies and understanding of these barriers. In one of the study [2], the factors affecting implementation of integrated project delivery (IPD), 14 different challenges were categorized into financial, technological, cultural, legal, and others. In other similar studies by [41] and [42], cultural, financial, technological and legal based barriers were found to hamper IPD implementation in India. There are also few technical barriers such as ambiguous utilization of BIM and improper and impulsive planning of objectives before finalization of designed model. For the issues with the regulation, a new legislative framework was required to enable value-based contractor selection as compared to the lowest bidder requirement. As a result of unfamiliarity with IPD and lack of prior experience working together, creating mutual trust and respect proved to be the most difficult cultural hurdle to overcome. Until issues of the cultural shift are resolved, technological and behavioral adoption of IPD will not be successful. Other challenges were owners' lack of expertise, the involvement of stakeholders too soon, and uncertainty over how to measure quality for incentive distribution. Some of the other most common barriers listed in the literature for implementing lean tools includes: Awareness and willingness about lean among owners [2], lack of leadership [43], key timing for involvement and assigning responsibility to participants [41, 44, 45] resistance to change [43], lack of standards [44–46] lack of collaborative frameworks [45, 46], slow decision making [44, 45], lean contracts poor understanding [45], no insurance for lean failure [45, 47], multiparty agreement for entire project lifecycle [47, 48].

7 Discussion

The preceding sections essentially elucidated the necessity of accelerating the acceptance and implementation of BIM in the Indian AEC industry by embracing lean. The study also detailed the many ways in which lean tools are used through the lifecycle of an asset. It also emphasizes the need for a framework to be created to help construction owners and other stakeholders in India deal with the difficulties they have while trying to implement lean construction. With the focus still on adopting lean tools and practices, this industry faces two major challenges: cost and time overruns which can be overcome by gaining high maturity of BIM implementation. This can be achieved by implementing the lean principles and thinking among the stakeholders of construction industry. Lean rather than a technology should be seen as a cultural change which can help the stakeholders to collaborate more easily for the entire lifecycle of a project. Overall, the study provides insight into why and how the Last Planner System (LPS) and Integrated Project Delivery (IPD) might help increase the use of BIM in the Indian construction industry.

8 Future Research Scope

According to the current research, there are few research gaps that still exists in the implementation of lean for implementing BIM. Due to a lack of positive case studies, Lean is still not widely adopted in developing nations. Lack of case studies can be attributed mostly to the mindset of stakeholders and the necessity of a cultural shift. Any technology's rate of adoption within a cultural environment is affected by factors like the people, institutions, and relationships within it. Therefore, studies on the role of institutional and social scientific theories in the implementation of Lean and BIM are required. Moreover, quantitative analysis of the factors effecting lean implementation is required, and a strategy for resolving these obstacles must be developed through an effective framework. We need to look into other lean techniques besides LPS and IPD that can speed up the acceptance and implementation of other novel technology in developing countries.

9 Conclusion

The current study shows that the infrastructure industry is a dynamic one that helps drive global economic growth and promotes progress in all areas of an infrastructure asset's life cycle by making use of technology. However, the Indian AEC industry has not yet fully embraced digital technology like BIM. As with any new idea or innovation, there are many underlying problems that must be solved before the technology can be widely used. Although lean tools have been shown to be an effective driving factor in speeding up the adoption and deployment of technology in many different countries, very little research has been conducted with regard to the Indian AEC industry. In order to present an overview of the challenges involved in the effective deployment of lean technology for adopting BIM, a thorough examination of the research contribution is necessary. To that end, this study set out to perform a systematic literature review on the topic of BIM and lean implementation with the goal of better appreciating the need for a standardized Lean-BIM framework in the Indian construction industry. Scopus, the Web of Science, and EBSCO host databases were used in this literature search. The researchers used a three-pronged approach to review and narrow down 46 articles which were analyzed according to publication year and type. There have been very fewer studies understanding the engagement of BIM in India through lean technology because of fewer case studies. Overall, the paper provides a thorough and systematic analysis of BIM and lean technology, as well as the necessity of adopting Lean to speed up the BIM implementation and reap the other benefits for India's AEC sector. To do so, it is necessary to identify and eliminate the primary impediments to lean implementation and BIM acceptance. Since lean is the only solution to the problems plaguing the Indian construction industry (such as slow technology adoption, low productivity, cost and time overruns, less collaboration among stakeholders, etc.), it is essential that the obstacles to adopting lean be removed before technologies like BIM can be implemented using the methodology. The findings help further research into BIM literacy in India. Despite the review's limitations, it should serve as a useful resource for professionals and decision-makers in India's digital construction industry as they plan out the industry's path forward.

There are few limitations of this study as well such as this research focused only on two specific lean tools—IPD and LPS—to better comprehend how they may be used in BIM deployment. This study has no direct application to any single area of the infrastructure industry because of its broad scope and need to be modified based on type and scale (budget) of project. As a result, this is a theoretical article, and further empirical research is needed to confirm the findings.

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Implementation of Lean Construction to Reduce Rework in Construction Projects: A Systematic Literature Review

Nandini Sharma and Boeing Laishram

Abstract Rework is a significant contributor to cost and schedule delays in construction projects. A considerable amount of study has been conducted to address rework, yet there has been limited advancement in minimising its occurrence and negative consequences. In response, Lean construction (LC) has evolved as an effective management concept to reduce waste while also improving the safety and quality of building projects. The study aims to review and analyse literature to identify the factors affecting rework in construction industry (CI) and various lean tools mentioned in the literature that can effectively help to reduce/remove rework from various construction processes. The review is conducted by using 60 peer-reviewed articles in the field of rework retrieved from three prominent databases: EBSCO host, Scopus, and Web of science. Using the Systematic Literature Review (SLR) strategy, the articles are categorised according to the technologies used in order to assist in the findings shown by the existing literature. Thus, this study contributes to the body of knowledge by identifying the solutions to rework through LC that can help industry practitioners, policymakers, and researchers in the CI. Future research directions are offered to bridge gaps in the existing literature and improve the effectiveness of studies that aim to boost LC.

Keywords Construction industry · LC · Lean principles · Rework · Waste

1 Introduction

Construction projects are always considered to be unpredictable and volatile. This is due to the fact that construction projects are executed in different environments, requiring the collaboration of highly specialized teams to accomplish the goal of

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construction industry (CI). This volatility leads to waste due to production and process, which are often seen as inherent to building operations. One of the most significant "wastes" that must be reduced in construction projects is "rework". Rework is a common issue in infrastructure projects and may have a negative influence on the performance of Infrastructure Projects [1–4], which is described as "work that was not completed properly the first time" [5]. Not only that, rework costs have been reported to range from 5 to 20% of the contract value, with modifications to the design scope accounting for up to 50% of the rework that occurs [4, 6]. Even though "defects and errors have been recognized as part of the construction process" [7] and it is inevitable, they may be minimized by taking the right precautions at the right times. Rework has also been recognized as the primary cause of cost and schedule overruns in the CI [3]. Responding to this, lean construction (LC) is one of the most promising approaches proposed to address these issues. Among the many wastes that TPS seeks to eliminate are those of production, waiting, transportation, processing, inventory, motion, and producing the faulty product [8]. Following the introduction of the lean philosophy to the CI, there were several efforts and techniques to integrate LC across the industry in order to minimise "waste" and add "value" to projects [9]. Despite the potential benefits of LC, its implementation rate is slow owing to various hidden aspects, resulting in lack of literature review studies related to LC practical implications in depth to reduce rework. In light of this acknowledged difficulties and dearth of review studies, it is imperative to underatke a review study systematically. Thus, the suggestion of Dimitrantzou et al. [10] is followed with regard to conducting further systematic literature review (SLR) in the field of CI. Therefore, main aim of the paper is to identify the causes of rework in CI and how LC is implemented to minimise the effect of rework.

2 Methodology

The SLR methodology used in the present study follows the guidelines suggested by Tranfield et al. [11]. A review is "systematic" if it is based on explicitly articulated questions, discovers relevant research, evaluates their quality, and summarizes the data using an explicit approach [12]. Unlike the traditional review, a systematic literature review is a method that locates existing studies, selects, and analyses in such a manner that reasonably clear judgments about what is and is not known may be obtained.

According to author, three-step process must be developed to perform a systematic and well-defined research of the literature that can be replicated by other researchers [13]. Therefore, in this study, the following three-stage procedure was adopted, as highlighted in Fig. 1: Stage I: Planning the review, Stage II: Conducting the review, and Stage III: Analysing the review.

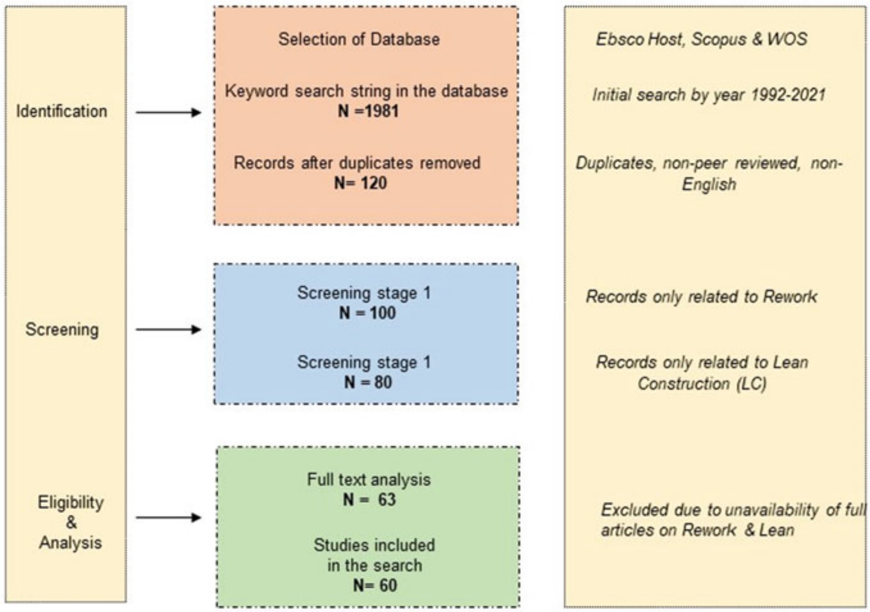


Fig. 1 Literature search and selection process

3 Planning the Review

The first step in SLR involves the research problem or defining the subject of the literature review. The review starts with identifying the relevant articles, specific keywords, and main databases to find the right set of publications. For the literature search, three databases were used: Web of Science, EBSCOhost, and Scopus. These databases were selected for their comprehensiveness since they include the majority of peer-reviewed journals in the field of project management and the construction. Therefore, the search was conducted using building blocks, which is one of the most often used search methodologies by literature reviewers [14]. Thus, the research area is broken into distinct words that are connected using Boolean operators such as AND and OR. The following keywords were used in the abstract, title, and keywords to choose articles: "Rework," "Lean Construction," "Quality Management," "Construction Industry," and "Lean". Furthermore, "LC" and "CI" are abbreviations for Lean Construction and Construction Industry, respectively, and were included in the search. These potential keywords were discovered using snowballing and trial-and-error searching, as recommended by Kuhrmann et al. [15].

4 Conducting the Review

Based on the keywords mentioned, this section comprises searching and choosing appropriate publications executed in three phases. In the first phase, a keyword search was added to the three databases. To preserve the comprehensiveness of the acquired literature, the beginning date of the publication search was not provided. All the articles until July 2021, when the search activity was undertaken, were covered and generated 1981 publications. The search results were filtered to exclude non-English, non-peer-reviewed, and duplicate results, yielding 120 publications. In the second phase, titles and abstracts of publications were examined critically based on pre-defined database filtering and selection criteria [16]. When it was uncertain from the abstract whether the article should be retained or not, the whole article was read. The publications were assessed concurrently by the authors of the present research, and any questions or discrepancies were settled by reaching a consensus [17]. The criteria included the inclusion and exclusion of papers, which included: Articles published in well-known databases: EBSCO host, Scopus, and Web of science, Articles highlighting the LC and studies concentrating on factors of rework in CI. After this regressive screening, 80 were chosen for further evaluation. In the third step, after exporting the previously filtered articles, a full-text manual analysis was conducted, and 60 publications were chosen for the systematic review analysis [15].

5 Analysing and Reporting Review

These outcomes are depicted using graphs and tables in the following section. Furthermore, an empirical content analysis was conducted to identify the origins of rework and how lean implementation mitigates these causes. Each article was read several times in order to extract, categorize, and organize data [18].

6 Analysis and Results

6.1 Descriptive Analysis

The publishing of articles on this subject commenced in 1992. This descriptive study is divided into two phases: the first phase began with infrequent publications between 1997 and 2006, and the second phase was between 2008 and 2021. Initially, publishing in the area of rework and lean was limited, but the overall number of papers published on rework and lean has risen dramatically over the past decade, with the largest numbers seen in 2004, 2008, 2009, 2019, and 2021, followed by 1998, 2010, 2013,2014, and 2017. For the years 2011, 2012, 2016, 2018, and 2020, fewer publications were reported in the second phase. Additionally, the list of articles is classified

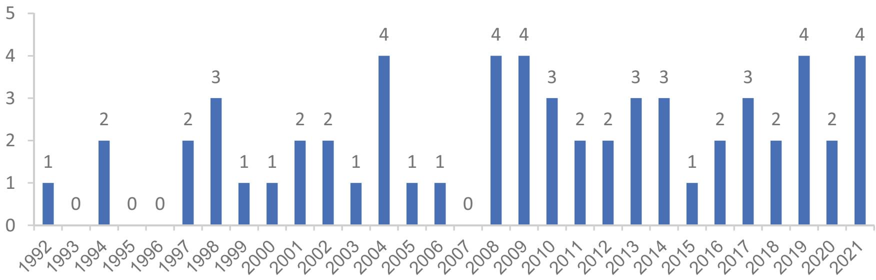
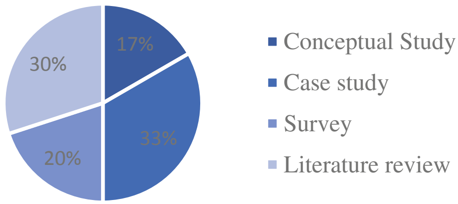


Fig. 2 Number of published articles within the selected period

Fig. 3 Overview of research methodologies conducted on lean and rework



according to the methods used to acquire the data. There were four distinct methods for data collection: conceptual research, case study, survey/questionnaire, and literature review. Major information was gathered through case studies (20 articles). Furthermore, a significant number of academics (18 articles) adopted the literature review method to gather data. The other techniques of data collecting include survey/questionnaire (12 articles) and conceptual study (10 articles) (Figs. 2 and 3).

However, country-by-country categorization is critical in determining the scope of study throughout the world. From the analysis of the review, it is evident that rework and lean practices have been studied in different continents/countries to different magnitudes, as indicated in Fig. 4. Out of 19 countries, China and Australia emerged as top countries, where the focus was on improving the reducing the rework of construction projects and implementing LC practices. Iran and UAE tied for the second position with five papers, followed by the United Kingdom four papers, and Singapore, Spain, India, Canada, and Brazil with three papers each.

6.2 Content Analysis

The content analysis results from the study of all the research articles are presented in this section. This section discusses the cost of rework in CI, root causes of the rework, and lean approaches to reduce rework in CI.

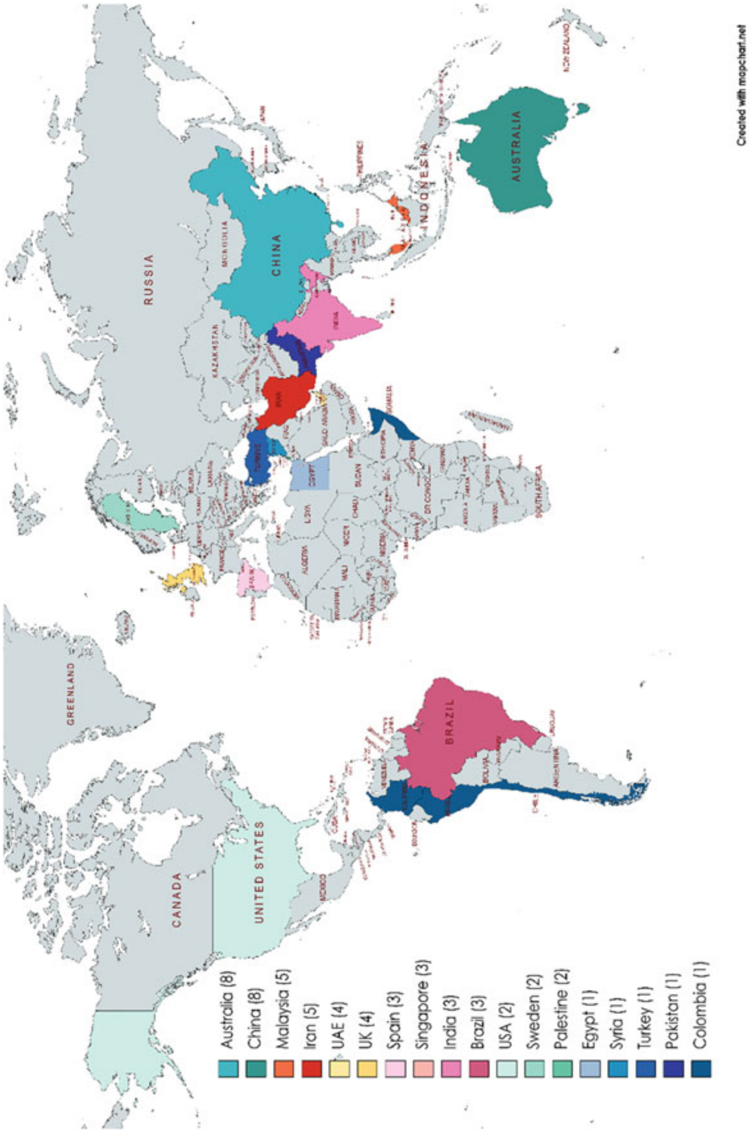


Fig. 4 Country-wise distribution of publications conducted on lean and rework

6.2.1 Cost of Rework in CI

Various definitions of "rework" have been used in the field of construction management, as described by Love [5]. "Defects" [19], "non-conformance" [20], "quality failures" [6], and "quality deviations" [21] are all examples of rework. When discussing reworks, some researchers adopt their terminology. Reworks are described as "the process through which an item is completed or corrected to correspond to the initial requirement," whereas CIDA defined rework as "doing anything at least one additional time owing to non-conformance to requirements." The majority of current rework cost estimates are stated as a percentage of the entire project cost. A recent study indicates that rework costs vary between 2–6% during construction and 3–5% during maintenance [22, 23]. It was estimated that as much as 25% of the total may be comprised of these "hidden costs" throughout the process [5]. The urgent need for effectively engaging innovative concepts like "lean" is highlighted by the fact that rework is a 'waste' of material, time, and cost that may be linked to poor quality control and/or a failure to collaborate on the design and construction of a building.

6.2.2 Root Causes of Rework

Through SLR, 12 key issues were found by coding and classification, and they were organized into seven primary groups (as shown in Table 1).

In the realm of CI, contractor-related issues are one source of reasons that have an impact on rework [26, 31, 38]. Several authors recognised that the external environment has a significant effect on rework, hence affecting sustainability [31, 38]. Moreover, external environmental elements are outside the control of the project [38].

Yet, the contract terms have not been examined under rework events in supply chain management. Because there are no contract management divisions in construction firms and clients, the lack of competent contract management specialists is primarily a result of stakeholders not taking the contract management process seriously [38]. Many building projects are indeed impeded by subcontractor errors and damage [31, 39]. Subcontractors should be hired based on their previous experience working on building projects to avoid unnecessary rework [40, 41]. Throughout the design and construction phases, however, there are frequent errors, omissions, and modifications that need to be reworked. Most essential for design management is "design modification because it conflicts with utilities." Infrastructure projects are suffering design changes or revisions due to construction-related concerns, such as the existence of subsurface utilities. The project's most important decision-maker is the client. Rework in construction is often blamed on the client, as shown by several studies. Rework may be inevitable because of the client's repeated requests for changes. It was estimated that client-specific rework would account for around 6% of total rework costs [24]. According to some sources, the most important characteristics regarding the competency of human resources that lead to redoing work include poor management and decision-making, lack of employment security, and a

Table 1 Summary of identified factors for rework

S. No	Key issues	Sub-issues	Example papers
1	Contractor management	Poor quality of construction technology and procedure	Love and Edwards, [4, 24, 25]
		Lack of use of advanced mechanical equipment	[24, 26, 27]
2	External environment	Poor site conditions	[3, 28, 29]
3	Management of contract	Low contract fees or delays in payment	[1, 2, 18, 25]
		Ambiguity in contract documentation	[22, 30]
4	Management of subcontractor	Ineffective communication between stakeholders	[31–33]
		Failure to protect the completed works	[22, 34]
5	Management of design	Poor coordination of design team members	[17, 25, 33]
		Design error	[3, 30, 35]
6	Management of client	Owner and end-user communication and coordination issues	[3, 26, 31, 34, 36]
		Delay in supplying the contractor with water and power	[30, 35]
7	Human supervisory	Lack of supervision	[22, 37]

low skill level [38, 40]. New approaches are needed to determine the relative importance of the aforementioned factors in producing rework. This can help researchers and industry to concentrate more on the category that generates the extreme rework.

6.2.3 Lean Approaches to Reduce Rework in CI

There are a number of lean tools stated in the literature that can assist decrease the quantity of rework from various construction works, but their implementation seems to be quite low. The Hu et al. (2015) categorized 32 lean approaches as design and engineering, planning and control, construction and site management, and health and safety management. The Last Planner System is the most commonly used lean tool, whereas Integrated Project Delivery is the least commonly utilized. It was also discovered that the last planner system and just-in-time were the top two most implemented lean techniques, and that the adoption of lean methods in the CI was associated with around 20 different economic, social, and environmental benefits. The various tools that can be a probable solution for construction rework are shown in the Table 2.

However, it should be mentioned that lean methods in construction projects can be implemented either as an integrated system or channel, or as stand-alone initiatives [50]. In view of rework waste and its mitigation, additional research is required

Table 2 Lean tools and approaches

Lean tools for rework	Description	Example papers
Gemba Walk	It includes examining the source of a problem to determine its cause and then correcting it	[32, 42, 43]
Total productive/ preventive maintenance (TPM)	Site personnel do preventive equipment maintenance. This ensures operators maintain equipment while using it	[42, 44, 45]
5 s Onsite management	5S is an acronym that stands for sorting, straightening, shining, standardizing, and sustaining all site operations and activities in order to produce excellent construction site management	[9, 27, 46–48]
First run study	Modelling critical building site procedures, especially when those involved don't understanding them. It requires error inquiry and prevention or mitigation techniques	[8, 42, 45, 46]
Total quality management (TQM)	TQM helps construction managers identify issues, create solutions, and evaluate results	[42, 43, 46]
Visualization tools/ management	VM instructs site employees. Sign boards or posts in designated construction sites may be utilized	[42, 44, 44, 45]
Conference management (CM)	CM is an efficient solution for scheduling project-related conferences, workshops, and trainings	[8, 43, 49]

to obtain considerable output from lean tools. There have been attempts by some clients to create opportunities for small businesses to serve as subcontractors through partnership agreements, however these often involve only the primary stakeholders. The lack of case studies in quality improvement research employing lean principles is the primary cause. To undertake LC deployment study that goes beyond some specific LC methodologies, it was advised that the complete supply chain and sector context, as well as the project governance structure, be examined [46].

7 Discussion

The above sections demonstrated how lean can be employed in the AEC industry to reduce rework in the CI. It also highlights the challenges that construction owners and other stakeholders face as a result of the rework. In addition, the study described how several lean tools are utilized during the construction phase of an asset, as well as some potential technologies that can help in decreasing rework. Several research gaps were found in order for this industry to overcome the two major obstacles of cost and schedule overruns by implementing lean in the construction phase effectively.

Overall, the study adds to a comprehensive and systematic analysis of the need to reduce rework in the CI, as well as the incorporation of lean management systems such as the Gemba Walk, Total productive/Preventive maintenance (TPM), 5 s Onsite management, First run study, Total quality management (TQM), Visualization tools/ management and Conference Management (CM).

8 Conclusion

This section presents the results of a thorough review of the existing literature on the factors of rework. This systematic study concluded that there is still a substantial gap between the theory and execution of the proposed strategies for rework minimization by contractors. Rework may be substantially reduced only if it is analysed and monitored throughout the supply chain.

However, the most influential contractor-related causes of rework have been identified as follows: ineligible construction technique, ineligible materials, insufficient check of materials and equipment, ineligible quality of construction process, non-standard construction management, misinterpretation of design intent, and lack of use of advanced mechanical equipment. There is a strong correlation between poor subcontractor selection and poor subcontractor management. In practice, subcontractors perceive the general contractor as their "client," and they indicate little regard for the project's end-user and other subcontractors with whom they must engage. As a consequence, the impact of late defect detection can be multiplied. Rework is often caused by a variety of factors, including a lack of skilled supervisors, subpar workmanship, a lack of oversight, and vague or unclear instructions given to workers, according to the findings of recent studies.

Moreover, to develop a resilient relationship and mutual understanding, stakeholders in a particular project must have the same vision. In addition, governments should enact regulations for LC construction and encourage all contracting enterprises in their respective nations to apply LC approaches by giving frequent, free training to their staff and periodically monitoring the usage of LC principles.

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Case Study on Production System Design with Discrete Event Simulation for Bangalore Metro Underground Project

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Abstract Construction processes are difficult to plan and control due to the numerous uncertainties and complex resource interactions; therefore 'launch and hope' approach is often adopted, leading to significant waste in the process. Discrete event simulation (DES) helps model the behavior of production systems to understand the combined effects of all factors influencing the process, which can lead to significant savings. Executing concrete pours for infrastructure projects in overly populated old urban areas is a very complex exercise owing to the challenges of congested roads, hours of restricted traffic movement, greater transit distances, resource constraints, uncertainties in operating conditions and stringent quality control norms. Logistics planning with optimized resource allocation is further complicated when the resources such as batching plants, transit mixers and boom placers are shared between multiple project sites managed by different stakeholders simultaneously. The case study describes the application of DES for designing the process to yield smooth flow and optimal resource allocation. The lean construction concepts such as pull planning, establishing flow and takt time have been imbibed in the process for realizing the most optimum and resilient design. Emulating the 'Last planner system', several scenarios were studied with all stakeholders virtually with the aid of ExtendSIM software before the actual execution, which led to significant savings in time and cost. Further, following the principle of Gemba and Kaizen, the field data was captured with the aid of several digital tools and analyzed. Several brainstorming sessions with critical stakeholders lead to continuous improvement and further savings in time and cost.

Keywords Discrete event simulation · Lean production planning and control · Pull planning

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1 Introduction

Production system design is the first task in any productive endeavor, which extends from organization management to design of operations, including making decisions regarding how the physical work will be structured, resources to be deployed and flow of activities leading to the accomplishment of task [3]. The performance of production systems in construction is strongly affected by variability, interdependence and uncertainty [14]. Owing to these challenges, a 'launch and hope' approach is often adopted in construction practices rather than through production system design, leading to significant waste in the process.

One of the main activities in any construction project is concreting. Executing concrete pours for large infrastructure projects is complicated due to its sheer volume, complexity and stringent quality control norms. In addition, site-related factors can further make the process more challenging. In the current case, the project was situated in an overly populated old urban area leading to additional challenges such as congested roads, hours of restricted traffic movement, greater transit distances, resource constraints and uncertainties in operating conditions. Logistics planning and optimization of resources is a significant challenge in the backdrop of such uncertainties. Most contractors try to optimize the resources such as batching plants, transit mixers (TM), boom placers by sharing them across multiple projects or project sites. This will impact factors such as the resource deployment and maximum size of each pour, further impacting the schedule and cost performance of the project.

Lean construction philosophy advocates viewing the construction processes as a production system. It emphasizes Task/Flow/Value [7] by providing a Means-Ends hierarchy for the design of project-based production systems. Further, the lean-based production system design helps reduce defective products, reduce cycle times, get more from less, deliver products that reduce variability and on time/reduced cycle times [3].

There are several methods available to design and model a production system. Discrete event simulation (DES) is a methodology for simulating the behavior of a system or process, in which events, rather than mere passing of time, causes to changes to system components and hence to the system. The DES model includes routing, queues, activities and monitoring of system components' motion, position and characteristics. It helps model the behavior of production systems to understand the combined effects of all factors influencing the process, which can lead to significant savings. This case study presents the application of DES to designing a production system for major concrete pours. The methodology adopted for the study and the organization of this case study is shown in Fig. 1.

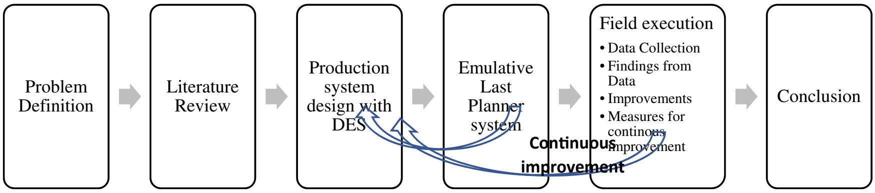

Fig. 1 Methodology and organization of case study

2 Literature Review

Previously, project planning in construction was limited to organizational structuring and work breakdown structure for carrying out the work. Production system design for organizing the work has been virtually invisible and taken for granted as mentioned by Ballard et al. [3]. Further, the researchers also proposed guidelines for production system design that will help realize the universal goals of maximizing value, minimizing waste and the third goal of linking Task, Flow and Value. However, due to the complex interaction between the various activities in a construction process, it is challenging to model such systems.

Various researchers have attempted to model the construction production system. Mario and Howell [10] applied the production design system to identify the bottlenecks in the process and arrive at a takt time for delivery of a concrete duct project. Previous studies in lean construction highlight the advantages of using virtual interactive systems. Schramm and Formoso [14] investigated the potential benefits and difficulties of applying visual interactive simulations for supporting decision-making in construction projects. It was found that the simulation animation made it easier for the manager and stakeholders to understand the impacts of local changes in a systemic way. Application of lean construction concepts such as push versus pull-driven, uncertainty, waste and flow is illustrated through case studies of adopting DES models in production system design [16]. Ming [11] has evaluated the applicability of DES for resource optimization in road projects.

A study [15] presented two case studies of applying the DES to support decision makers in production system design and operations. It also highlighted difficulties like lack of historical data and complexity involved in modeling. Several DES software packages such as Stroboscope, ARENA, WITNESS 2004, Cyclone and ExtendSIM are available [13], and these are increasingly adopted in various types of construction processes [2, 8]. DES has also been used for scenario analysis for resource decisions; Larsson et al. [9] have described case study, where four scenarios of semi-prefabricated bridge consisting of reinforcement and concreting activity were evaluated for optimizing the project requirements. Despite the several advantages of using DES in the construction industry, its use is limited to the academic community [6].

Although it has been demonstrated that the technique can shorten design cycles, lower costs and advance knowledge in the construction sector, DES's practical usefulness is constrained because the industry community does not find it to be user-friendly and perceive to have low return on investment [4]. Owing to the above reasons, the industry practitioners prefer to solve problems by making decisions intuitively and in an ad-hoc manner [5, 12]. Abdelmegid et al. [1] have summarized 14 barriers for adopting simulations by construction industry, further the authors have proposed four directions to overcome the identified barriers, out of which one of the strategies highlight on publishing the benefits realized by adopting the technique to enable wide spread industry adoption.

The intention of this case study is to demonstrate the possible applications and potential benefits of adopting discrete event simulation for production system design from a lean construction and industry implementation perspective.

3 Production System Design and Optimization

In the current work, the production system design for the major concrete pour works of the Bangalore Metro underground metro project was carried out with the aid of ExtendSIM DES software. It involved the following decisions considering several resources, operational and technical constraints.

- Size of the concrete pour
- Number of batching plants
- Number of transit mixers deployment and their optimum allocation
- Number of concrete pumps

The concrete for the Cantonment Underground Metro station could be taken only from three captive batching plant approved by the client. The locations and transit durations are shown in the map (Fig. 2).

The process chart for the concreting process with the maximum, minimum and most likely durations for each activity for concrete supply from each of the three batching plants is illustrated in Fig. 3.

As shown in Fig. 3, the probabilistic time distribution for various activity is adopted based on previous observations/site data for other activities. Figure 3 further shows the interactions between the various activities.

The optimization of the production system is carried out through what-if scenarios. The objectives and constraints of the system are given in Table 1.

Based on the data from Table 1, the DES modeling was carried out with the help of ExtendSIM software. Figure 4 shows the screenshot of the DES model.

Each cubic meter of concrete is considered as an entity/item in the model. The rate of entry of entities into the process is subject to the capacity of the respective batching plants and the availability of TM for loading concrete. Since the TMs used in the project are of six cubic meters capacity, six entities are batched onto a single resource item (empty TM) to indicate a single transit mixer truck with concrete.

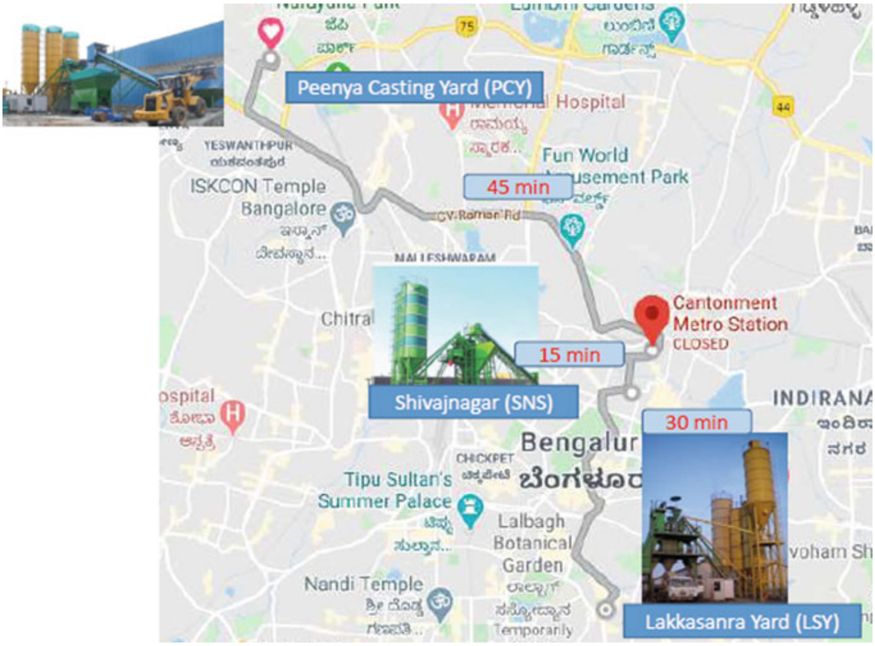

Fig. 2 Map showing the location and transit duration from batching plants to site

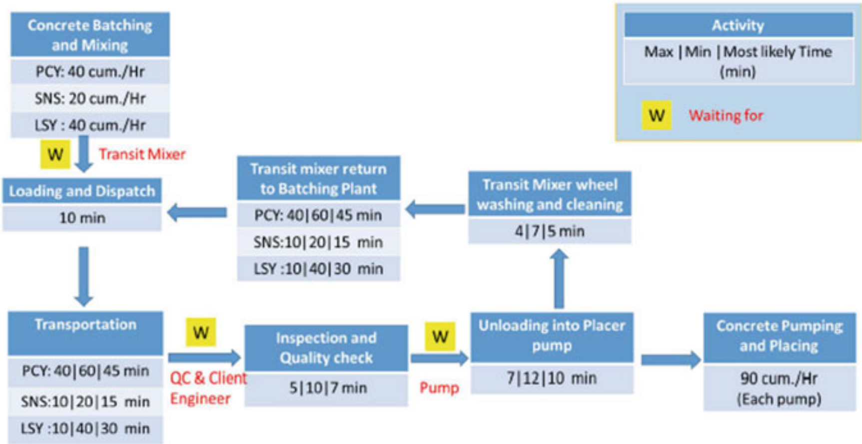

Fig. 3 Process chart for the concrete process

Table 1 Optimization parameters

Objective-maximize	Size of pour (Fewer construction joints to be treated)
	Utilization of resources (TMs, boom placers, batching plants, etc.)
	Other parallel pour–Segment casting, etc
Objective-minimize	Resources used
	Waiting time for inspection
	Waiting time for pump
	Idle time of resource
Constraints	TM movement allowed in night shift only (14 h)
	Batching plant capacity Peenya-40 cum/Hr.; Shivajinagar-20 cum/Hr.; Lakkasandra-40 cum/h
	Resource constraints on transit mixer (TM) allocation to each plant Pre-casting activity at Peenya yard should be uninterrupted Concrete supply from Shivajinagar and Lakkasandra is limited to 50% of capacity
Technical considerations	Continuity of concrete pour, which will otherwise lead to chocking of pump
	Each batch of concrete should be poured at site before the retention time (approx. 3 h)

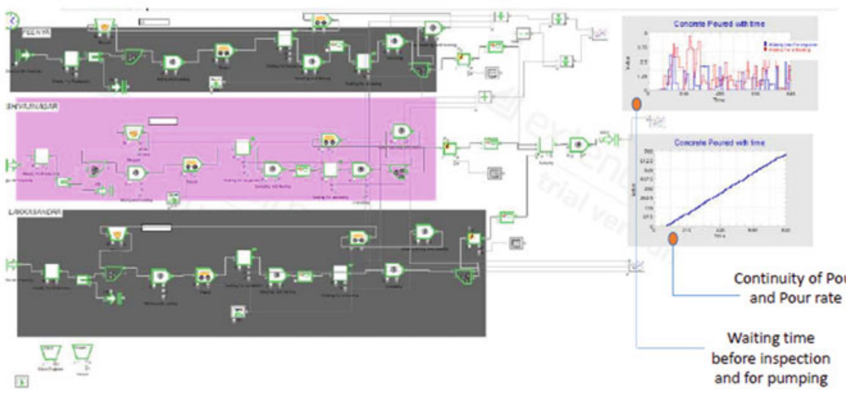

Fig. 4 Screenshot of the DES model

The loading will be completed only based on TMs' availability in the resource pool. The batching, mixing and loading take 10 min. The transit durations for concrete movement from various batching plants are modeled as triangular distribution based on the probabilistic time distribution indicated in the process chart. After the TMs reach the site, they join the queue for quality inspection and wait for unloading. The quality inspection depends on the availability of the client inspection engineer, and the unloading activity depends on the boom placer's availability. The un-batch block separates the concrete from the transit mixers. The released TM further undergoes the activity of wheel washing and transit toward batching plant.

4 Emulative Last Planner Analysis

After completing the DES model, the simulation of various scenarios of resource allocations was performed to understand the impact on the overall pour completion, utilization of resources and compliance with the technical requirements. The simulations were performed in a "big room" with the participation of project members from civil execution, quality assurance and control, plant and machinery, planning and project control and administration and accounts teams.

Various scenarios were simulated by adjusting the input resource parameters such as the number of TMs allotted at each batching plant, number of boom placers deployed for the pour and number of quality inspection workstations. The simulation outcome was collectively analyzed with the input of various stakeholders. Other sample scenarios include transit mixers breakdown, road closure, long waiting line of transit mixers at site causing a problem for local public, choking of boom placer due to intermittent pour, break time for the client quality inspection, rejection of any batch of concrete, etc. The effect of each of these input parameters and scenarios on the output parameters, such as the total concrete quantity poured at the site, the utilization of various resources such as TMs and boom placers, the continuity of the pour was evaluated. The scenario analysis and the output data help to understand the bottlenecks in the production system; thereby, the decision on resource deployment was made in such a manner to balance the process to have a smooth flow.

More than 300 scenarios were analyzed by varying the input resource parameters, and only the scenarios which yielded more than 600 cum. of concrete at the end of 14 h were chosen for further analysis. The comparison of sample scenarios of various resource allocations (TMs to each batching plant) and their respective outcome is illustrated in Fig. 5a.

The horizontal axis represents the various scenario cases obtained by varying the number of TMs deployed at the Peenya, Shivajinagar and Lakkasandra plants. The primary vertical axis indicates the total number of TMs deployed for any case, and the secondary vertical axis depicts the total concrete poured for the resource distribution. Similarly, Fig. 5b represents the vis-à-vis resource utilization efficiency which is obtained from the model output parameters. The impact of the number of boom placers deployed was also studied through the scenario analysis. It was understood that a minimum of two boom placers are required to achieve a total quantity of more than 600 cum, which would otherwise be a bottleneck. However, when the number of boom placers increased beyond two, no significant improvement in the outcome was seen; instead, the utilization efficiency reduced. Therefore, it was concluded that two boom placers would be deployed.

Due to the Last Planner-inspired simulation exercise, the various departments of the project were aware of the consequence of various scenarios on the impact pour

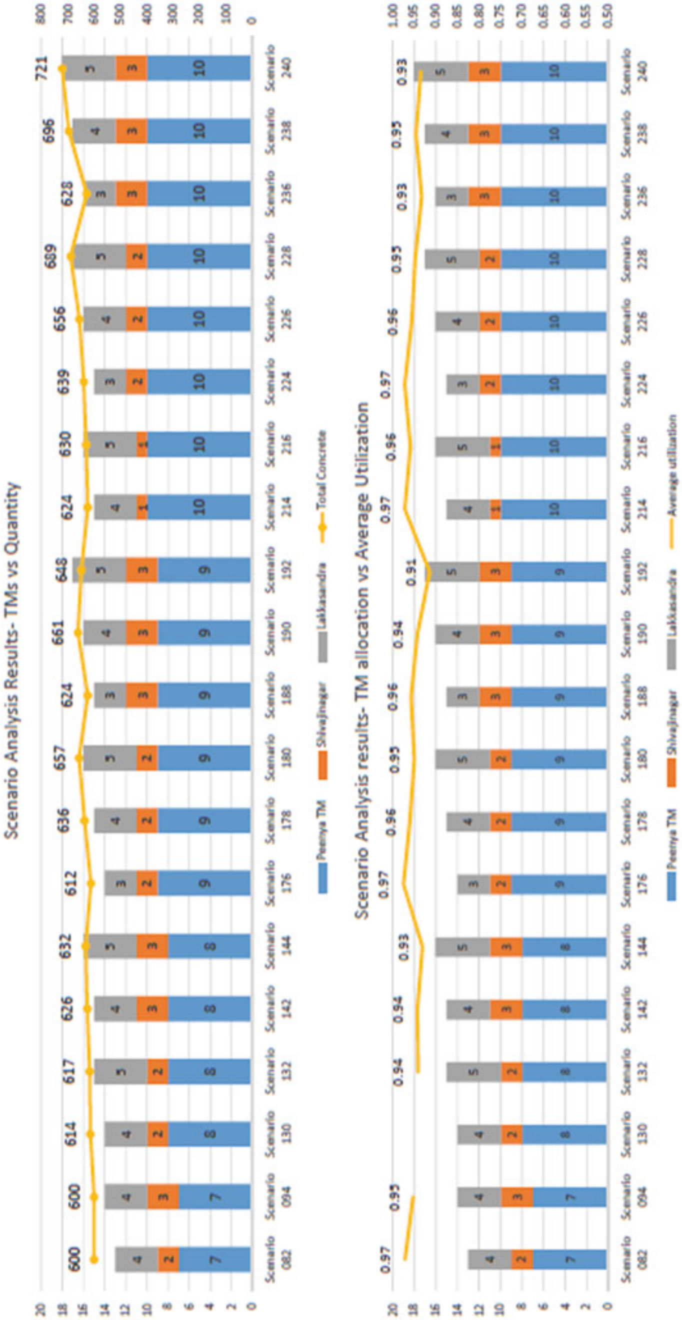

Fig. 5 **a**, **b** Sample of comparison of various scenarios of resource allocation

completion concerning the other stakeholders and their plan of action in the actual scenario. The optimum resource allocation was arrived at for executing the pour. Also, the system was made resilient by making the stakeholders aware of the impact of any failure, enabling them to prepare with their action plan.

5 Field Execution

5.1 Site Monitoring

The resource allocation was carried out based on the best outcome of the DES model, and the actual data was collected from the site for validation and monitoring of the pour. The activity durations for loading time, exit from plant, transit time, waiting time for pour, unloading time and clearance from the site were recorded for each TM. The monitoring of the concrete pour was carried out in real time by recording the TM number along with the timestamp in a Google sheet shared with the monitoring team located at various locations. CCTV cameras and IoT devices for location tracking installed on the TMs were utilized for the data collection and monitoring of the process. Turn-around time which is the time for a TM to start loading for a particular trip to its return to the batching plant was computed and monitored based on each TM for every trip. The updated sheet provided inputs to all stakeholders about the overall progress of the pour, the status of transit mixers in transit, the expected arrival time, etc., which helped to coordinate and control the process.

5.2 Findings from the Field Data

The data collected through the above exercise was analyzed for the activity time, and the various wastes/non-value-added time in the process were identified. The average time for each activity and its contribution to the total duration indicated the proportion of non-value-added duration. Apart from analyzing the average durations, the histogram for various activities was plotted to understand the variability in duration. Figure 6 shows the contribution of each activity to the total time required for the process.

Figures 7 and 8 show the histogram for loading time and the time for loading to exit from plant. The horizontal axis represents the range of time consumed and the vertical axis represents the frequency/ number of trips falling in the range.

Figure 7 shows the histogram for the loading time of TMs which shows a wide variability. It can be inferred from the Fig. 6 that a significant time of 5% is being consumed for the TMs to exit from the batching plant after the loading is completed which is a non-value-added activity. Also, from Fig. 8, it is evident that there is a high variability with respect to time lost on this non-value-added activity.

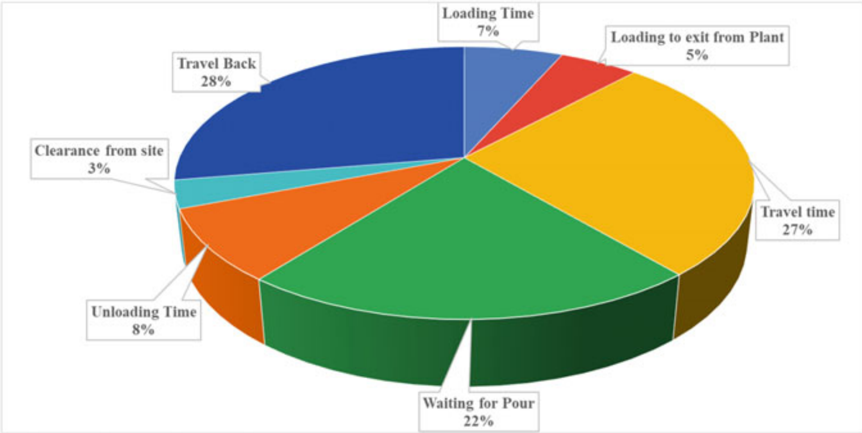

Fig. 6 Proportion of average time consumed for each activity

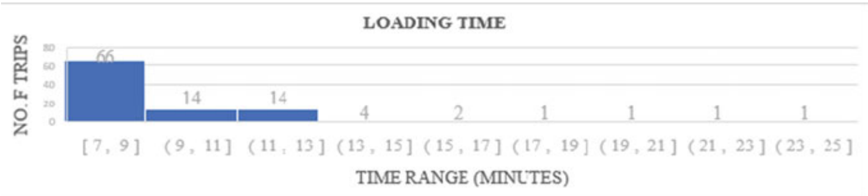

Fig. 7 Histogram for loading time of Transit mixers

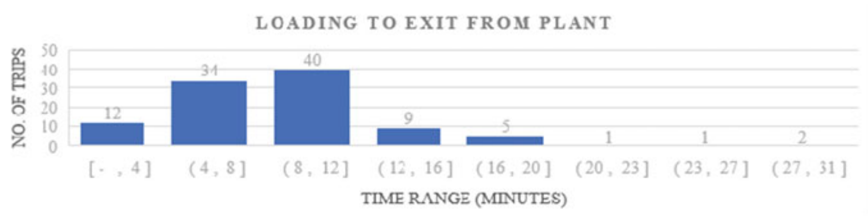

Fig. 8 Histogram for time consumed by transit mixer from loading to exit from the plant

6 Improvements

Brainstorming sessions were held with all key stakeholders to identify the root cause for higher non-value-added time and understand the reason for wide variability in the same. The activity durations and probabilistic time distribution for each activity in the DES model were modified based on the field data. With the aid of the DES model, the stakeholders were educated about the effect of the variability in upstream activities like loading time and the time for loading to exit from the plant. Table 2 indicates the areas of concern and the possible measures to mitigate the non-value-added durations and measures to mitigate the variability in the upstream activities.

Loading time of concrete which is supposed to be automated controlled process was having relatively high variability due to the issues with the raw material properties, and this variability in the upstream process impacted the overall production system negatively. Interventions were designed to control the material properties as given in Table 2. The significant time being consumed by TM from loading to exit was due to the TM drivers taking breaks after the TMs were loaded. It was observed that the drivers took a break only after loading even when there was some waiting time before loading because the TMs had to follow the queue to move forward one after other for the loading of concrete from the batching plant. To address this issue, an intervention was designed by deploying additional drivers to act as valet parking drivers, who can maneuver the TMs in the queue, allowing the TM drivers to go for a break. Similar intervention-based actions were taken to address other areas of concern.

Table 2 Area of concerns, impact areas and measures for further improvement

S. No	Areas of concern	Measures for further improvement	Impact on
1	High moisture content of M-sand leading to repeated moisture correction and slow batching	Spreading and drying with focus lamp, etc	Loading time
2	Batching only 6 cum. at a time, leading to 1–2 min excess time for each TM loading	At least 18–24 cum. per batch to be done	
3	Average of 8 min (5%) TM spending inside plant after loading	Sampling to be done quickly and break to drives to be ensured at the time of loading. (1-spare driver like valet parking)	Loading to exit from plant
4	Co-ordination between two gates and decision to divert	Proper coordination and decision making about diverting TMs required by senior. Execution team	Waiting for pour
5	Banksmen not positioned properly/not trained to pour specific requirements	Banksmen to be trained for proper guidance on reversing and positioning of TM	
6	Space constraint for positioning of TM due to material stacked	Logistics plan to be made and area for parking of TM to be soft barricaded	
7	Slow pumping rate due to quality issues like segregation—some batches were mixed only for 25 s	Slump to be maintained within limits. Mixing to be strictly 30 s	Unloading

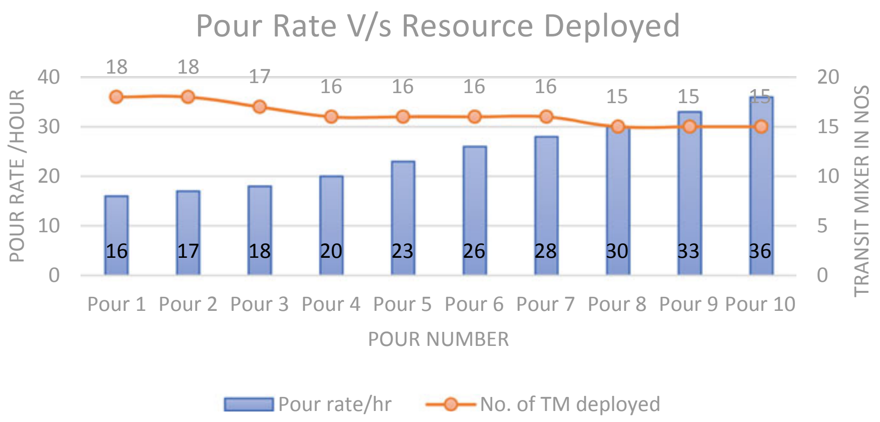

Fig. 9 Progress in pour performance

7 Measures for Continuous Improvement

The brainstorming session also focused on identifying some of the blind spots which could potentially hamper the production system and measures to control them. The DES model helped understand the impact of any such unforeseen hindrances. Following the tenet of kaizen, continuous improvement was advocated, where every concrete pour was benchmarked for its performance. The learning was translated into points in the concrete pre-pour checklist, which also set targets for the concrete pour performance. The project leadership team held frequent Gemba walks to the construction site and concrete batching plants to understand opportunities for further improvement. Adopting these lean principles coupled with DES model analysis, the performance of concreting activity has improved significantly. Figure 9 shows the pour performance with respect to the pouring rate (primary axis) and resource deployment (secondary axis) for each major concrete pour, and it is seen that the pour performance is enhanced.

8 Conclusions

This case study demonstrated the application of DES for designing a production system for industry application through a systematic approach. The DES model helped to analyze various parameters and their impacts on arriving at the optimum resource deployment plan. However, the actual execution of the task had several challenges and bottlenecks which were not anticipated in the initial DES model. Process monitoring and data collection in the execution phase helped refine the DES model to emulate the actual process better.

Adopting DES-based production system design provided the following benefits-

The process was better optimized, designed and controlled, leading to significant savings in terms of time and cost.

The DES model analysis enabled the stakeholders to make more informed decisions about resources for other parallel activities.

Through the virtual emulative Last Planner exercise, all the stakeholders were made aware of the impacts of any changes, and the production system was rendered resilient.

The impact of variability or inconsistency in process/activity durations was effectively communicated to the stakeholders.

The concrete waste generated due to the rejection was reduced significantly. This may be attributed to the production system design, which ensures lesser waiting time for transit mixers and better control in the process.

Following the lean principles of Kaizen, the production system has undergone significant refinement to yield higher resource efficiency.

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A Case Study on the Use of Simulation for Improving Equipment Utilisation and Productivity

Prashanth Kumar Sreram and Albert Thomas

Abstract Lean is all about creating value for customers and eliminating waste. The construction industry is plagued with time and cost overruns due to physical and non-physical waste. One of the non-physical wastes is the over allocation of equipment. Therefore, there is a need to assess the optimum allocation of equipment at the site as part of equipment planning. Simulation can be a valuable tool to verify various options for equipment allocation. Further, simulation helps to understand the implications before physical implementation and saves time and efforts. Moreover, simulation is beneficial to capture the various factors influencing the activity and visualise the expected output. Therefore, a methodology to use simulation for equipment allocation and productivity under different allocation scenarios is presented in this study. Further excavation is taken as a case study, by site data collection, and developed computer simulation model using Anylogic software. The proposed model can be used by practitioners for planning and estimation works, and the academicians for using it as a teaching tool for construction productivity and by researchers can do further development. Using simulation and lean is recommended to increase productivity and thus alleviate time and cost overruns in the construction industry.

Keywords Simulation · Earthwork · Productivity · Construction · Waste

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1 Introduction

The construction industry is characterised as wasteful with time and cost overruns. A few reasons cited are lack of productivity, inaccuracy in cost estimation, and under or over allocation of equipment. There are various methods for measuring productivity at a site, such as work sampling, but the implementation and analysis at the site still need to be improved in construction industry. With all other industries automating and using data analytics, the construction firms need to accelerate using latest technologies like simulation. Therefore, the study aims at demonstrating simulation as a tool for productivity and equipment allocation. The research work presented here is divided into five sections, namely Introduction, Literature Review, Methodology, Case Study, Results and Discussions and Conclusion.

2 Literature Review

Productivity is "the ratio of output of required quality to the inputs for a specific production situation." In the construction industry, it is generally accepted as "work output per man-hours worked." Productivity is regarded as a leading indicator of efficiency when comparisons are made with competitors in local and global markets. One of the construction activities whose efficiency will impact the project's successful completion is excavation [1, 2, 7].

Excavation is a critical activity irrespective of the project as all other activities commence only after excavation is completed. Further, "excavation" is measured in m^3 of soil excavated per hour. One way of improving production performance is to increase productivity by seeking ways and means to increase output and other is to optimum utilisation of resources. Literature indicates that there are various factors that influence the productivity of earthwork, as listed in Table 1. The influence of these factors on the excavation activity needs to be measured quantitatively to improve production performance [3].

Earthwork involves mass clearance of earth in the construction site. Earthwork process mainly consists of three processes cutting, hauling, and filling. Further, excavation involves the first two processes of earthwork (cutting/excavation, hauling) followed by dumping at a suitable location if the soil can be reused at the site while backfilling works begin. In the case of mechanised excavation, construction equipment's equipped with excavator bucket are used along with trucks for transportation of excavated soil. Therefore, the overall excavation process in case of a mechanised excavation can be described as excavating soil → filling the excavated soil onto the truck → transportation the soil to the location of dumping → dumping the soil, → return to the work area (refer to Fig. 1). In the excavation process, the factors like excavator bucket capacity, the fill volume of the excavator bucket during excavation, the truck filling volume, and other factors influence the overall excavation done in a given time.

Table 1 Factors affecting excavation productivity

Work-related	Equipment related
Method of excavation-Machine or manual	Proper equipment selection
Lead	Cycle time
Earthwork (presence of utilities or absent)	Bucket size
Size of excavation (trench or open)	Angle of swing
Depth of excavation	Equipment breakdown
Protection needed	Operator
Soil profile	
Excavation under or above water level	
Excavation in the vicinity of existing buildings or infrastructure	

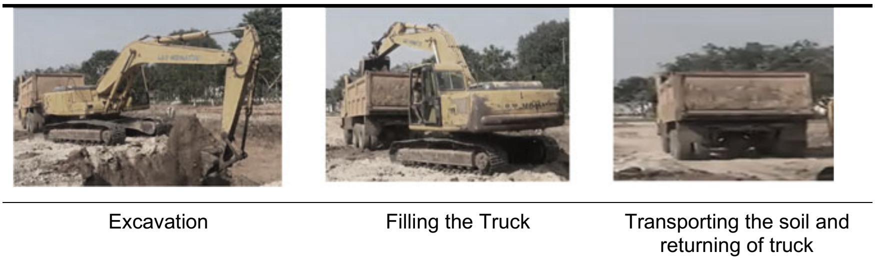

Fig. 1 Process for the mechanised method of excavation

With reference to the software for construction simulation, there are many software available Simio, ProModel, Cyclone, Stroboscope, Arena, Anylogic, Simul8, ExtendSim, SimProcess, AutoMod, JaamSim, EZStrobe, Simscript, SimPy, and NS-3 [4, 6]. However, for this study, Anylogic was used for the benefit of providing the option of integrating different types of simulation modelling as part of further research on the same study [8].

3 Methodology

The methodology adopted for using simulation in the construction productivity and equipment utilisation assessment purpose is provided in Fig. 2. The first step is to identify the activity for which the problem of productivity and resource utilisation is followed by identifying the factors influencing the activity. Later, the activity durations are to be observed or to be taken as inputs from experts in the specific activity. This will help to develop an inputs-process-outputs table for developing the computer simulation model.

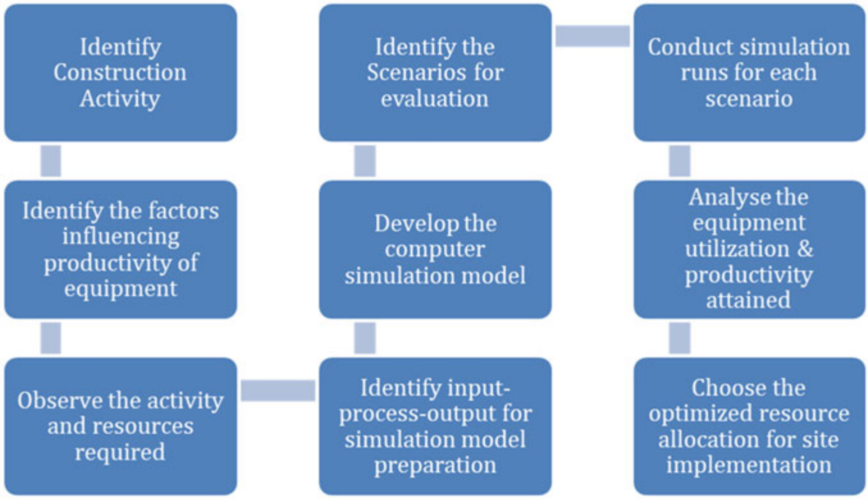

Fig. 2 Simulation model development process

Based on the site requirements and the contractor's resource constraints, scenarios can be designed for the activity. Conducting simulation runs on all the scenarios will help to decide on the best equipment allocation for the expected productivity. This method can be used for any construction activity for developing simulation models.

4 Excavation Case Study

A case study method was adopted to collect the data on excavation. For the purpose of hostel building construction, excavation activity is taken up for an institutional building. The process, as shown in Fig. 1, was observed, and the time taken for each process was measured using a stop clock on the mobile. Video recording was also done to review the entire process for validating the time measured at the site during the site visit. The site is having loose soil with no underground services present. The type of excavation was an open method to execute rafts and individual foundations for the building. The excavator used was of the make L&T Komatsu with model PC 200. As the soil condition is suitable for re-filling, the excavated soil is hauled to and then dumped at the location near the construction site. The overall data collected is presented in Table 2 in the format of inputs, process, and output framework to indicate the simulation readiness of the activity under consideration. Further, simulation model using Anylogic Person Learning Edition was prepared for simulation experiments.

A discrete event simulation model is developed for conducting simulation experiments. The model aims to determine the equipment utilisation as well as to measure

Table 2 Site data for simulation parameters

S. No	Parameter	UoM	Value
Inputs			
1	Truck capacity	MT	22
2	Excavator bucket capacity	m^3	1.22
3	Speed of truck in loaded condition	Kmph	30
4	Speed of truck in empty condition	Kmph	40
5	Soil density	T/m^3	1.4
6	Soil loose to compacted ratio	–	1.25
Process			
1	Bucket fill volume	m^3	triangular(1, 1.1, 1.2)
2	Time for filling bucket	seconds	triangular(35, 40, 45)
3	Truck fill volume	%	triangular(0.8, 0.9, 0.95);
4	Truck positioning time	seconds	triangular(0.5, 1, 1.5)
5	Truck fill time	seconds	(truckcapacity * truckfillvolume * onebuckettime)/(soilDensity * excBucketfillVolume)
Output			
1	Loads	Number	No. of trucks exited for unloading during one hour
2	Loaded Volume	m^3/hr	Total excavated soil in one hour

the productivity of excavation. Simulation is modelled for one hour of activity with simulation model units in seconds. Figure 3 presents the simulation model. A 3D model is also developed for better visualisation of the activity. The conversion of the excavation process into a simulation model is explained in Table 3. Having developed the simulation model, the base scenario of 5 trucks and two excavators has been run for 1 h of operation. The site scenario in simulation model indicated 112.85 m^3 of soil excavated with 99% excavator utilisation, as shown in Fig. 4. The same data compared with site observation of one hour showed that 115.00 m^3 of soil was excavated and the excavator was fully working with 100% utilisation. The variation between actual data and simulation output is less than 5% [5] and hence proceeded to check the need for improving the production performance by increasing or decreasing the excavators/trucks so that any value addition by eliminating waste (under-utilisation).

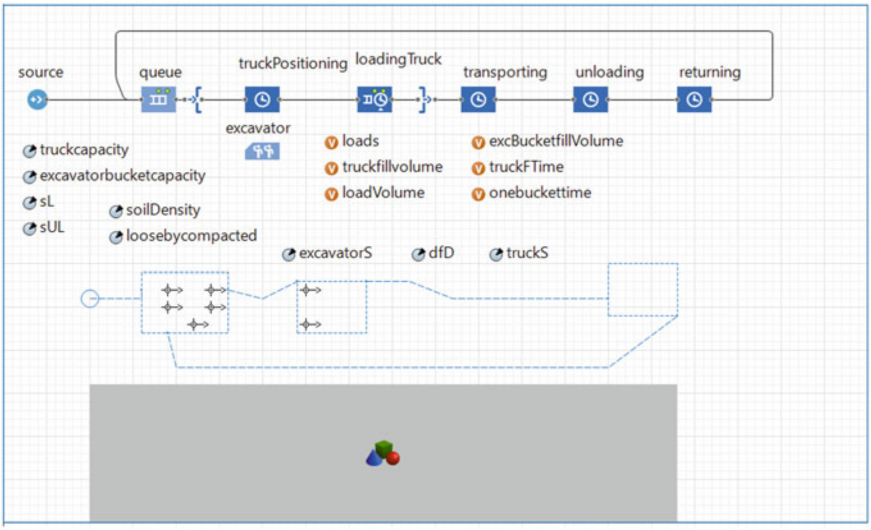

Fig. 3 Simulation model for excavation using Anylogic

Table 3 Model description

S. No	Anylogic element of the model	Activity description
1	Source	At the simulation start 5 trucks will be injected using inject function
2	Queue	The location where the five trucks are parked before proceeding to the excavation site location
3	TruckPositioning (Delay event)	This is a delay event to indicate the time taken for moving to site and positioning the truck to get loaded with excavated soil. Here, the restriction of 2 trucks can be available near the site location is modelled using *restricted area start and end*
4	Loading truck (service element)	The truck is loaded by the excavator by excavating and then dumping the soil into the truck with the help of the excavator bucket until the truck reaches it's fill volume defined in the model
5	Transporting (delay element)	The time taken for moving from site excavation area to the dumping area; the truck travels at the speed defined with Loaded condition
6	Unloading (delay)	The time taken for unloading the excavated soil at the dumping location
7	Returning	The time for returning the truck to the parking area. The truck travels at the speed defined for empty condition

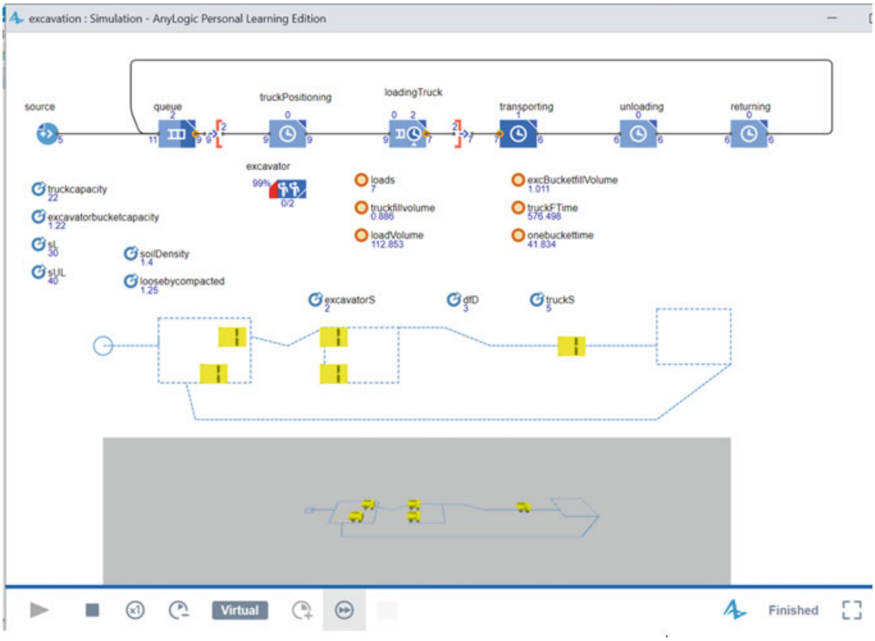

Fig. 4 Screenshot of a simulation run for site scenario

5 Scenarios for Simulation

The contractor deployed five trucks and two excavators in the case study. However, the possibility of doing the same with less needs to be evaluated. Therefore, as shown in Table 4, five scenarios were developed for the same model, and then the simulation was run. It can be inferred from the scenarios that the number of excavators has been altered from 1 to 2, and trucks have been altered from 2 to 5 keeping all other inputs unchanged. While we can also have further combinations, based on the discussions with the contractor and their resource mobilisation capacity, the following scenarios were only considered for further analysis.

Table 4 Scenarios for simulation of excavation activity

Base Scenario– 2 Excavator + 5 Trucks	Scenario 1– 1 Excavator + 5 Trucks	Scenario 2– 3 Excavator + 5 Trucks
Scenario 3– 2 Excavator + 4 Trucks	Scenario 4– 2 Excavator + 3 Trucks	Scenario 5– 2 Excavator + 2 Trucks

6 Results and Discussions

The output of all scenarios is noted as given in Table 5. Firstly, the site scenario (existing) could be better production performance as scenario 3 provides the same output with fewer trucks. Further, decreasing the excavators is affecting the output of excavation as observed in scenario 1, whereas increasing excavators leads to underutilisation of the excavator, as exhibited in scenario 3. Moreover, the site scenario, scenarios 3 and 4, provides the same output, but the utilisation of the excavator is less in scenario 4 and thus eliminates the option of having 2 excavators and 3 trucks. In between the site scenario and scenario 3, the number of trucks deployed is more in the existing scenario, and thus the existing scenario can be eliminated. Finally, scenario 4 helps in decision-making to reduce one truck from the existing site scenario so that associated costs and, thus, waste can be reduced.

The excavator efficiency of 99% is higher, possibly due to the sample observation duration. Therefore, observing for more duration would help in refining the model generated. While the model is running and providing a valuable decision, it needs to consider the cost–benefit analysis of the model itself. Therefore, cost factors are also to be developed in the model. Further, to make the model generalisable, the different soil conditions and excavation depth also need to be factored into the model. More site observations and inputs from site execution personnel are to be taken up for a more improved model for process variables. A survey is proposed to cover all these factors, as visiting all sites of excavation will be costly and time-consuming.

Apart from excavation, precast works are one area of interest due to the repetitive nature of precast operations and also the growing importance of offsite construction in India. Therefore, offsite construction-related research can be explored to identify the need for lean and simulation implementation.

Table 5 Scenario output results comparison

S. No	Scenario	Productivity (m^3/hr)	Excavator Utilisation %
1	Site Scenario–2 Excavators + 5 Trucks	112.85	99
2	Scenario 1–1 Excavator + 5 Trucks	84.13	99
3	Scenario 2–3 Excavators + 5 Trucks	112.85	66
4	Scenario 3–2 Excavators + 4 Trucks	112.85	99
5	Scenario 4–2 Excavators + 3 Trucks	112.76	77
6	Scenario 5–2 Excavators + 2 Trucks	81.01	52

7 Conclusion

The study aims to demonstrate the use of simulation as a tool for decision-making by construction professionals. Methodology to use simulation for construction activities is proposed, and excavation as a case study is demonstrated. Further models can be developed following the methodology of construction companies by using their previous project activities and experienced working professionals. The simulation model's accuracy can be further enhanced with more data samples with more data measurement duration which is the further scope of the study the authors have taken up. However, simulation is recommended to the construction industry to increase productivity and thus alleviate time and cost overruns.

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Applications of Lean Principles for Construction Safety Management: A Literature Review

Kishor Bhagwat and Venkata Santosh Kumar Delhi

Abstract The construction sector is considered one of the most hazardous sectors globally due to its risky work practices and unsafe nature. Researchers have investigated various avenues to promote safe behavior and conditions. One of the popular ways is the application of Lean principles. Research investigations have been done to investigate the applications of Lean principles to resolve safety issues in the construction industry. However, there is a lack of systematic analysis in presenting a comprehensive picture of the applications of Lean principles for Construction Safety Management (CSM). Therefore, this study aims to perform a systematic literature review to comprehend the synergies between Lean and CSM. To this end, this study considered peer-reviewed research journal articles from the Scopus and Web of Science literature databases, and an in-depth content analysis has been performed. The results highlighted the United States of America as a leading country, Tianjin University of Finance and Economics as the leading organization, and Dr. Wu Xiuyu as the foremost researcher in this domain. The current research trends investigate the implementation of Lean Construction (LC) practices, examine their impact, and identify the benefits and barriers to implementing LC for CSM. At last, the theoretical and practical contributions of the study and future research opportunities are discussed.

Keywords Lean construction · Construction industry · Safety management · Literature review

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1 Introduction

Construction projects' dynamic and complex nature often impedes managing an accident-free work environment [1]. Consequently, this sector is considered the most dangerous industrial sector globally [2]. It is responsible for an accident every nine minutes [3]. Such accidents negatively impact the industry, either in economic loss, human resource loss, or both [4]. For example, according to the International Labor Organization 2015 annual report, inefficient safety management accounts for 4% of the annual global gross domestic product [5]. Besides, construction accidents result in delays, efficiency loss, material wastage, decreased workers' morale, and an increased employee turnover rate [5]. Notwithstanding continuous efforts to enhance construction safety performance, the industry faces enormous safety issues [2]. Safety is one of the measures of a project's success, then enhancing safety performance becomes the utmost priority to achieve higher success rates in construction projects [6]. To this end, the industry is seeking novel ways to enhance construction safety performance. As a result, various frameworks, strategies, and tools have been proposed [2]. Among those, LC has captured global attention to enhance construction safety performance.

2 Lean Construction

Lean aims to enhance customer value and reduce waste while pursuing continuous improvement [1]. Lean thinking was adopted in Japan's Toyota Production System in the 1950s [7]. "Lean production is based on five fundamental principles [6]: (1) finding the value of the product from the customer perspective, (2) identifying the value stream from production to delivery to the customer, (3) enabling the product flow continuously through the value stream by eliminating waste, (4) introducing pull between all steps, and (5) looking for perfection". According to past investigations, lean implementation decreased lead time, process time, work-in-process inventory, and workforce demand while enhancing productivity [6]. Based on the obtained result, researchers emphasized that the lean philosophy is universal enough to be used, where manual operations are adopted to complete the production process [8].

In the projected direction, Finnish scholar Koskela introduced the LC concept [9]. It is a "project delivery process that uses lean methods of maximizing stakeholder value while reducing waste by emphasizing collaboration between teams on a project" [10]. The LC principle is to reduce non-value-adding actions, cycle times, and variability and enhance process transparency and output flexibility and value [11]. Past investigations highlighted the positive results in the construction sector [12]. However, applying lean principles for construction safety management is in the infancy stage. In addition, the construction industry is currently unprepared to use thoughts from the manufacturing industry [7]. Therefore, it is crucial to promote and present a comprehensive picture of the current status of lean principles for CSM.

3 Literature Gap

CSM emphasizes employing a huge inventory of safety measures for workers' safety [1]. At the same time, the lean principle is to remove waste, such as inventory, overproduction, and waiting time. Here, inefficient communication between stakeholders about lean philosophy or ill-informed workers may mislead with objectives of both the domains, i.e., CSM and LC [1]. In addition, workers may ignore their safety controls in continuously maintaining high production rates, which might result in high accident rates [1]. Even though construction accidents are considered waste from a lean perspective, very little attention has been given to examining the synergy between safety management and LC [6, 13]. In addition, the acceptance of LC is still in the evolution stage [14]. Consequently, lean philosophy has not been implemented extensively in the construction industry [14]. It is imperative to present an inclusive picture of the domain through an organized literature review to deal with the above-mentioned issues in applying lean principles for CSM. To this end, this study aims to conduct a systematic literature review of the application of lean principles for construction safety management. The study's objectives are twofold, (1) to examine the research ontologies and (2) to present the current status of the research and future research directions in the domain.

4 Research Methodology

The aim of the study is achieved in two major stages: systematic literature search and content analysis. A systematic literature review initiates with a systematic literature search. This study implemented the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) principles to recognize appropriate literature. Figure 1 shows four major steps of PRISMA guidelines: Identification, Screening, Eligibility, and Included [15]. In the first step, i.e., the relevant literature is searched using two widely used literature databases, namely Scopus and Web of Science. The keywords 'lean' and 'construction safety' are used in literature search engines. This article focused on peer-reviewed English language research journal papers with a search range of 'All Years'. A total of 110 articles have been identified from both databases. As a next step, five duplicate articles are identified using Microsoft office-Excel®. Next, 105 articles are examined against eligibility criteria (such as the keyword was considered for another purpose, lack of thorough examination, or focus was on structural safety assessment). A total of 23 articles passed the eligibility criteria and appeared in the included step for further data analysis.

The relevant literature is further considered for the content analysis. Content analysis is "a research method for determining major facets of and valid inferences from written, verbal, or visual communication messages, either qualitatively or quantitatively, depending on the nature of the project and the issues to be addressed in the research" [16]. This study adopted both quantitative and qualitative content analysis

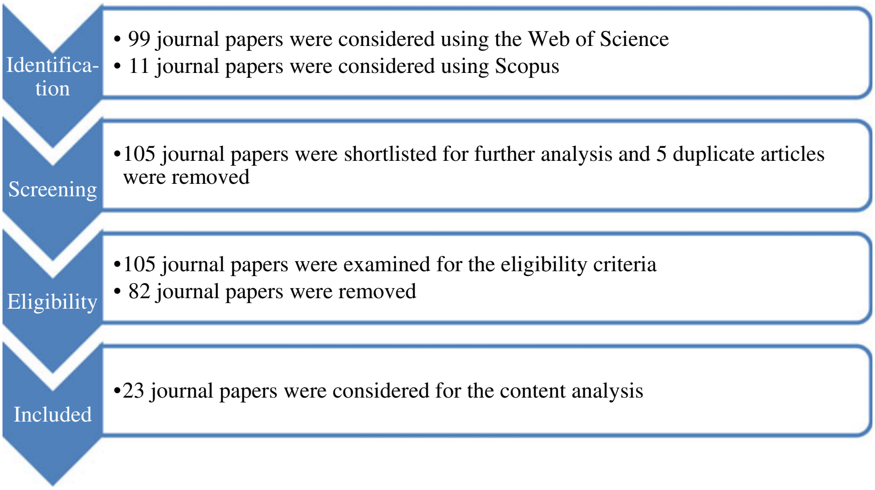

Fig. 1 PRISMA guidelines for literature search

approaches. More specifically, the quantitative content analysis focuses on investigating research ontologies, and qualitative content analysis focuses on determining recent research inclinations and future research avenues. The results of the content analysis have been presented in the next section.

5 Quantitative Content Analysis Results and Discussion

"The quantitative content analysis investigates the numerical values of categorized data, such as frequencies, rankings, and ratings, by counting the number of times a topic is mentioned [16]". In this study, the quantitative content analysis focused on research ontologies such as yearly, worldwide, organization-based, and author-based investigations to comprehend the trends and contributions from different parts of the world. This study used VOSviewer as a data analysis tool to investigate research ontologies due to its superior text-mining feature and open access [17].

6 Yearly Publications

The annual research article publication trend is shown in Fig. 2. Results highlighted that the research was initiated in 2008, and there has been a sudden contribution growth since 2019.

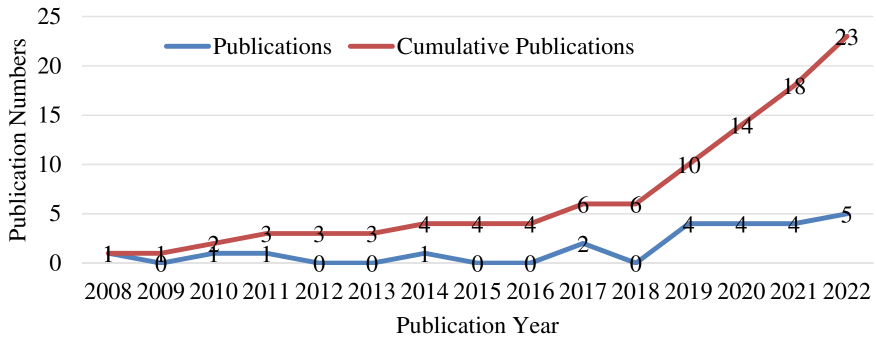

Fig. 2 Yearly research publication trend

7 Worldwide Publications

A total of 18 countries are involved in this research domain. The leading ten countries based on research publications are given in Table 1a. The leading three countries are the United States of America (6 articles and 114 citations), China (5 articles and 60 citations), and Australia (3 articles and 42 citations). According to Bhagwat and Delhi [18], these countries are not only leading in lean construction for safety management but are overall leaders in global CSM research.

8 Organization Publications

A total of 37 organizations contributed to this research domain. The leading ten organizations based on research publications are given in Table 1b. The leading three organizations are Tianjin University of Finance and Economics (4 articles and 44 citations), Islamic University of Gaza (3 articles and 40 citations), and Louisiana State University (2 articles and 67 citations).

9 Author Publications

A total of 58 researchers are involved in this research domain. The top ten researchers based on research publications are given in Table 1c. The leading four researchers are Wu Xiuyu (4 articles and 44 citations), Ikuma, Laura h. (2 articles and 67 citations), James, Joel (2 articles and 67 citations), and Nahmens I. (2 articles and 67 citations).

Table 1 Leading ten countries, organizations, and authors based on article numbers (AN)

(a) Country-based investigation			(b) Organization-based investigation			(c) Author-based investigation		
Country	AN	Citation	Organization	AN	Citations	Author	AN	Citation
United States of America	6	114	Tianjin University of Finance and Economics	4	44	Wu Xiuyu	4	44
China	5	60	Islamic University of Gaza	3	40	Ikuma, Laura h	2	67
Australia	3	42	Louisiana State University	2	67	James, Joel	2	67
Palestine	3	40	University of Washington	2	44	Nahmens I	2	67
Poland	2	37	Leantrix SP	2	37	Li, Shuquan	2	44
Turkey	2	13	Gebze Technical University	2	13	Misiurek, Bartosz	2	37
Hungary	1	184	Plaza CTR N.V	1	184	Misiurek, Katarzyna	2	37
Israel	1	184	Technion - Israel Institute of Technology	1	184	Tayeh, Bassam A	2	27
Brazil	1	92	Federal University of Rio Grande do Sul	1	92	Fang, Yanqing	2	24
Nigeria	1	75	Covenant University	1	75	Demirkesen S	2	13

10 Research Level

The lean for CSM literature emphasized three research levels Industry, Organization, and Project level, as given in Table 2a. According to the results, most past investigations have been conducted at the Industry level (20 articles) using questionnaire surveys, interview techniques, or other research instruments. In comparison, research at the Project (3 articles) and Organization (1 article) level has rarely been conducted.

Table 2 LC for CSM research characteristics

(a) Research level		(b) Project phase		(c) Project type		(d) Research instrument		(e) Research data source	
Level	AN	Phase	AN	Type	AN	Instrument	AN	Data source	AN
Industry	20	Execution	15	Residential building	7	Questionnaire survey	14	Management personnel	14
Project	3	Design	2	Industrial building	6	Interview	11	Supervisory personnel	11
Organization	1	Planning	1	Commercial building	4	Literature review	6	Researcher	9
		Alt. and rehabilitation	1	Infrastructure	2	Case Study	4	Safety journal article	6
		Not mentioned	8	Highway	1			Worker	5
				Underground work	1			Safety personnel	4
				Not mentioned	13			Contractor	4
								Architect	4
								Professor	3
								Student	3
								Owner	2
								Lean leader	1
								Accident report	1
								Others	3

11 Project Phase

The lean for CSM literature focused on four project phases Planning, Design, Execution, and Alteration and Rehabilitation, as given in Table 2b. Articles not mentioning the project phase are considered under the 'Not Mentioned' category. According to the results, most past investigations have been focused on the project's execution phase (15 articles). In comparison, the research in other phases, such as planning (1 article) and alteration and rehabilitation phase (1 article) have been rarely conducted.

12 Project Type

The lean for CSM literature focused on six project types Residential Building, Commercial Building, Industrial Building, Infrastructure, Highway, and Underground Work, as given in Table 2c. According to the results, most of the past investigations have been conducted in Residential Buildings (7 articles), Industrial Buildings (6 articles), and Commercial Buildings (4 articles). The research on other project types such as Highway (1 article) and Underground Work (1 article) has been rarely conducted.

13 Research Instrument

The lean for CSM literature focused on four research instruments Questionnaire Survey, Interview, Literature Review, and Case Study, as given in Table 2d. According to the results, most past investigations have been conducted using a Questionnaire Survey (14 articles) and Interview (11 articles) research instruments. In contrast, research instrument such as Case Study (4 articles) has received comparatively little attention from the researchers.

14 Research Data Source

The domain literature focused on fourteen research data sources as Management Personnel, Supervisory Personnel, Researcher, Safety Journal Article, Worker, Safety Personnel, Contractor, Architect, Professor, Student, Owner, Lean Leader, Accident Report, and Others, as given in Table 2e. According to the results, most of the investigations have considered Management Personnel (14 articles), Supervisory Personnel (11 articles), and Researchers (9 articles) as a source of input to conduct the study. Research considering Lean Leader (1 article) and Accident Report (1 article) has rarely been performed.

15 Qualitative Content Analysis Results and Discussion

"Qualitative Content Analysis categorizes data into suitable categories or themes [16]". In this study, the Qualitative Content Analysis focused on investigating the current status of research in the domain and presenting future research directions.

16 Current Research Trends

Based on the qualitative content analysis, this study identified majorly five research trends such as (1) investigation of the implementation of LC for safety management, (2) examining the impact and relationships between LC practices and safety compliance and performance, (3) development of novel framework such as 6S (Five S Process + Safety), (4) identifying benefits of LC for safety management, and (5) identifying barriers to implement lean in the construction industry. More specifically, past studies implemented Kaizen and noticed an increment in productivity and safety by mitigating safety risks on the project [12, 19]. Few studies focused on examining the relationship between LC practices and safety performance and reported that LC practices provide opportunities to employees for safe work behavior [20, 21]. Also, LC has a strong [6], positive [7, 11], and statistically remarkable [5] impact and relationship with safety management. Some studies added safety to existing LC practices, such as the Five S Process, and proposed a 6S framework [8]. The developed 6S framework resulted in an improved safety climate in the construction project [22]. Some studies highlighted that LC could assist project managers in motivating employees for better safety performance [23] and play a significant role in enhancing psychological safety and overall safety on construction projects [2]. At the same time, LC implementation can be hindered by management, financial, educational, governmental, technical, and human attitudinal factors. The Gaza strip is experiencing the educational factor as a major hurdle [14]. In addition, Enshassi et al. [14] also identified 39 detailed barriers to implementing lean philosophy in the Gaza strip.

This study identified 44 LC practices from past studies [7, 20, 24], as given in Table 3. Out of which, Babalola et al. [24] highlighted 'Fail-Safe for Quality and Safety', 'Plan of Conditions and Work Environment or Environmental Management System', and 'Health and Safety Improvement Management' practices as Health and Safety Management Practices. Further, Abu Aisheh et al. [11] reported LC techniques for safety management, as given in Table 4. This study also noticed several research directions and presented them in the next section for upcoming examinations.

Table 3 LC tools/practices [7, 20, 24]

Andon	Kitting
Benchmarking	Last planner system
Concurrent engineering	Lean project delivery system
Conference management	Location-based management system
Cross-functional teams	Pareto analysis
Daily clustering/huddle meeting	Plan of conditions and work environment or environmental management system
Deferring decisions to the last responsible moment	Poka-Yoke
Design structure matrix	Prefabrication and modularization
Design workshop or big room	Pull scheduling
Detailed briefing	Set-based design
Early involvement of specialty contractors	Simultaneous product and process design
Fail-safe for quality and safety	Six sigma
First-run study	Standardization
Five S process	Target value design
Five why	Teamwork and partnering
Frequent team communications	Total productive maintenance
Gemba walk	Total quality management
Health and safety improvement management	Value stream mapping
Integrated project delivery	Virtual design construction
Just-in-time	Visualization tools/management
Kaizen	Waste reduction
Kanban	Work structuring and scheduling

17 Future Research Directions

Future investigations can explore integrating lean tools and safety practices and understand the effect of continual process improvement [25]. A comparative analysis of the construction project safety performance with and without lean implementation can influence the industry exponentially [12]. The relationship between LC and the project's safety performance other than the execution phase, i.e., the design phase and maintenance phase, can be examined [5].

Past inquiries in the manufacturing industry highlighted that lean increases activity pace and physical demands, possibly resulting in musculoskeletal injuries [12, 25]. A similar inquiry is imperative in the construction domain. There is a need to research novel ways to remove LC implementation barriers [6], promote LC philosophy [21], and develop LC capability maturity model [9] to extend the lean philosophy beyond existing boundaries.

Table 4 LC practices for safety management [11]

Schedule tasks for employees daily
Perform a risk analysis before the commencement of a job
Assign work to employees based on their competencies
Work weekly work assignments
Continual discussions among project management and site employees
Work every day with employees
Coordinate and allocate concurrent and interconnected works at the same time
Proper planning of key and interconnected activities
Planning within a team
Explain the process and manner in which the job is to be executed by the employees
Prepare safety protocols and strategies
Enhance visibility at the workplace by eliminating obstacles that block vision
Setting up of fire alarm systems
Carrying out housekeeping at the workplace almost daily
Organize and arrange materials and equipment on the site
Continual material supply to the workplace as needed to prevent their accumulation and congestion
Follow safety and safety standards at work

18 Theoretical and Practical Contributions

The theoretical contributions are (1) this study is a step toward the promotion of lean philosophy for CSM, (2) it determined and presented a comprehensive picture of LC practices, benefits, implementation barriers, and relationship with safety management, and (3) also, presented current trends along with future research directions for upcoming studies. The practical contributions are (1) construction professionals can explore the comprehensive list of LC tools/practices and adapt them to their projects, (2) they can research barriers and promotional activities with the help of real-life case studies, and (3) they can follow the highlighted LC techniques for safety management.

19 Conclusions

This study noticed construction industry is struggling with poor safety performance due to unsafe behavior and conditions. This extensive literature review revealed that LC has the potential to enhance safety performance through improved safety behavior and conditions on the construction project. This study noticed contributions in this domain from different parts of the world. Out of which, the United States of

America is the leading country, Tianjin University of Finance and Economics is the leading organization, and Dr. Wu Xiuyu is the leading researcher in this domain. Based on the qualitative content analysis, this study noticed that the primary focus of the past research investigations was at Industry level research, focusing on building construction projects' execution phase using Management and Supervisory personnel inputs through Questionnaire Surveys and Interview techniques.

Further, the literature analysis highlighted research trends, such as the investigation of the level of implementation, relationship, benefits, and barriers in applying LC for CSM. Future studies can conduct quantitative research investigations focusing on the impact of LC practices on CSM at an organizational level and project level focusing on diverse construction projects. Construction professionals can implement the identified LC practices to enhance the existing safety performance of the projects. As a limitation, this study only referred to online available English language research journal articles from Scopus and Web of Science databases. Other types of literature (conference articles, books, etc.), databases (Google Scholar, etc.), and offline literature may add new contributions to the presented findings of the study.

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Improving Formwork Productivity by Using Aluminium Formwork for Sub-structure Works

Sumanth Kashyap, N. Surya, and Ashish Kumar Saxena

Abstract Formwork system accounts for approximately 15–20% of the construction cost in a typical residential project and is a major driver to ensure the anticipated project margin. While analysing the Formwork performance of residential projects, especially in sub-structures, it was evident that lower labour output, moderate material utilization, and lower efficiency levels and inferior concrete surface finish were the major problems affecting the overall performance. Major factors for the low productivity being the weight of shutters, having too many Formwork systems (Conventional, Alufo, Aluminium) within a site, low plywood durability, etc. Given the light weight, better load bearing capacity, excellent reusable properties and the ability to produce a good concrete finish, Aluminium Formwork system was believed to be a promising alternative for the existing Conventional system. Traditionally, the standard Aluminium panels were scrapped-off after completing the planned cycle of typical floors. But as per the intended strategy of utilizing the used Aluminium panels, the panels were systematically refurbished with multiple scheme drawings to ascertain the feasibility of using standard Aluminium panels for elements of varying sizes. The implementation has shown improvement in labour productivity, material reusability and faster execution by a factor of around 20%.

Keywords Productivity improvement · Lean thinking · Resource management

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1 Introduction

Studies and experiences of the practitioners have revealed that the presence of heavier shutter panels, having too many Formwork systems within site, dependence on too many accessories items forming a set, low plywood durability, etc., were some of the major contributing factors, which adversely affected the performance. There has been a long chain of discussions on the alternatives for material which will optimize the system and reduce the effort and cost for executing residential projects. Properties such as light weight, better load bearing capacity, excellent reusable properties as well as ability to produce good concrete finish of Aluminium Formwork system have always attracted the industry [1]. Considering the material requirement for limited duration for sub-structures, exploring the possibilities of using used Aluminium Formwork materials was expected to be a financially viable and operationally feasible alternative. Furthermore, it maintains the quality of work with a standard methodology that enhances labour productivity and fulfils the demand for speedy construction [2].

2 Challenges Faced with Conventional Formwork System for Substructure

Following are the major challenges faced while using the Conventional Formwork in sub-structures:

- Handling of more number of accessories.
- Required skilled workforce.
- Limited number of repetitions.
- Degradation of material quality over time with repetitive usage.
- Heavy shutters require more effort in assembling.
- Higher possibility of shutters getting damaged due to mishandling.

3 Lean Intervention

Contemplating the limited usability of Conventional system for a limited period and then scrapping off the material is a general practice. Foreseeing the anticipated value that will be added by using the Aluminium shutters for the sub-structure works gave confidence to the teams. Multiple Formwork schemes were developed to ascertain the feasibility of using standard Aluminium panels, for varying sizes of footings, shear walls, retaining walls, slabs, etc., Prior strategy with standard Aluminium panel had been to scrap-off the panels, once they complete the intended typical floors scope. However, with the strategy of further usage in sub-structure, Aluminium (AL) standard panels had to be systematically refurbished, before they are put to use.

Following sections provide a detailed report on the results achieved at a residential project for using AL FW in Wall, Column and Slab.

4 Design and Implementation of Aluminium Formwork

Though the material usage is made highly sophisticated for the Towers, the huge requirements in the Non-Tower Areas (or Common Areas) demanded for even more rigorous material planning. Construction of Non-Tower Area generally spans for up to 25% of the project duration and needs to be re-allocated to other scopes for further usage.

Typically, the Non-Tower Area (NTA) consists of following three components:

- Retaining Wall
- Slabs
- Columns

The intervention was targeted to optimize the material quantity and cost parameters with better utilization strategies.

5 Retaining Wall

Given the significant scope of 4.5 km (multiple levels) of retaining wall, decision was taken to adopt a Formwork system that would not only provide more than repetitions with quality finish, but also be light weight in nature as well as being labour productive. For this, Formwork scheme was designed with Aluminium wall standard panels, supported by pipe walers, tie-rods and other alignment props. Major factor in savings can be attributed to 35–40% reduction in water-disc barriers (consumables) as system is designed with significantly less tie-rods and eliminating use of plywood. This Formwork system being light weight and few in accessories has resulted in about 15–20% improvement in labour productivity over conventional methods. Figure 1 shows the pictures of use of Aluminium Formwork for retaining walls.

Table 1 shows the comparison of material and labour component between the use of Conventional Formwork and Aluminium Formwork for retaining walls.

6 Slabs

Given the flat slab structure of the Non-Tower Area (NTA) section, coupled with the availability of old Aluminium slab Formwork panels, decision was taken to improvise by developing a scheme for NTA section, predominantly using standard Aluminium slab panels. Scheme design covered the laying pattern of slab panels, followed by

Fig. 1 Retaining wall with aluminium formwork

Table 1 Savings with use of aluminium formwork over conventional formwork for retaining walls

Total scope	42,840 m^2				
Mobilization qty	1176 m^2 (140 m of 4.2 m height)				
Completed scope	38,214 m^2				
Description	As per the original estimate	Qty with AL system	Savings	Approx. savings (Rs.)	Remarks
Formwork steel (tripod and CT prop, clamps, tie-rods)	635 ton-months	508 ton-months	127 ton-months	2 lacs	20% reduction in consumption (from 30 to 24 kg/m^2)
Plywood	6426 m^2	–	6426 m^2	26 lacs	Plywood not required with AL system
Water-disc barrier	42,646 nos	24,834 nos	17,812 nos	25 lacs	Reduction of more than 42% owing to increased tie-rod spacing in
Labour requirement	11,892 man-days	9746 man-days	2146 man-days	8 lacs	Productivity improvement from 2.6 to 3.1 m^2/man-day

Fig. 2 NTA slabs with aluminium formwork

decking arrangement, where slab panels rested on mid-beam/end-beams, which were eventually supported by CT (collapsible tube) props, for load transfer. Figure 2 shows the arrangement for Non-Tower slabs with Aluminium Formwork.

Some of the obvious advantages over Conventional Flex/HDT system are as follows.

Reduction in Formwork steel consumption from 30–35 kg/m^2 (Flex) to 20–22 kg/m^2 (Min 30% less).

Allows 4th day slab deshuttering (owing to left-in prop system), in comparison minimum 7-day retention requirement of Flex system. This allowed a comfortable 15-day slab cycle time versus 18–20 days for Flex system.

Higher repetitions (100+) in comparison to plywood (about 8–10 repetitions).

No or minimum rework is required after concreting and deshuttering.

Ease in handling (light weight) and fewer components, enable high labour output.

Eliminating plywood and H-beams makes the system more environment friendly.

Table 2 shows the comparison of material and labour component between the use of Conventional Formwork and Aluminium Formwork for slabs.

7 Circular Columns

The project's NTA consists of 2400 Nos of 600 mm Dia columns. In order to execute this vast scope, custom-made circular Aluminium Formwork system was selected over steel or plywood-based Formwork methods, as high durability and ease in material handling being the driving factors [3]. This system basically consists of circular Aluminium panels that are connected by pins/wedges, backed by circular Walers and alignment props. During the implementation over the course of time, in addition to constantly delivering quality finish during its repeated usage, circular Aluminium Formwork system has enabled site in savings of over Rs. 5 Lacs in materials and 25% in labour productivity over the initial estimate as high durability, ease in

Table 2 Savings with use of aluminium formwork over conventional formwork for slabs

Scope with AL slab FW	98,200 m^2				
Mobilized qty	9300 m^2				
Completed scope	22,868 m^2				
In use for	6 months				
Savings calculated for the completed scope					
Description	Original estimate	Qty with AL system	Savings	Savings (Rs.)	Remarks
Formwork steel (tripod and CT prop, clamps, tie-rods)	1953 ton-months	1228 ton-months	725 ton-months	11 lacs	35–40% reduction in consumption (35–22 kg/m^2)
Plywood	9300 m^2	–	9300 m^2	37 lacs	Plywood is not needed with AL system
H-beams	3.35 L.Rmt-months	–	3.35 L.Rmt-months	54 lacs	H-beams are completely avoided
Labour requirement	9147 man-days	6930 man-days	2217 man-days	9 lacs	About 24% Productivity: 2.5–3.3 m^2/man-day
AL slab FW	–	9300 m^2	(–) 9300 m^2	(–) 57 lacs	

material assembling/dissembling, and need for only few accessories being the influencing factors. Furthermore, this also eliminated the use of Tower Crane for handling the shutters. The panels being lighter than the Conventional Formwork system can be manually handled. Figure 3 shows the arrangement for circular columns with Aluminium Formwork.

8 Results and Inferences

Amongst the other obvious benefits with AL Formwork usage for sub-structures, the fact that this system allows us to work with at least 20% less labour force, at a time when there is huge scarcity in availability of Skilled labour force, would definitely encourage sites to further expand usage of Aluminium Formwork in most structural elements [4]. With further expansion in adoption of Aluminium Formwork for sub-structures across other projects.

Fig. 3 Circular columns with aluminium formwork

The performance summary for the various scenarios are given in Tables 3 and 4 stating the comparison of the system modifications for retaining wall and NTA slabs, respectively.

Based on positive results received from Project 1, the same approach was implemented in three more projects and the results are summarized in Tables 5 and 6.

Table 3 Performance summary for retaining wall

Performance summary			
Performance parameter	Conv. system	Aluminium system	Remarks
Material consumption (steel)	30 kg/m^2	24 kg/m^2	20% reduction in steel requirement due to scheme improvisation
Labour productivity	2.6 m^2/Mday	3.1 m^2/Mday	15% improvement owing to light wt. panels, enabling quicker assembling as well as dissembling of shutter panels
QMS index	8.1–8.5	8.5–8.8	AL panels provide superior finish to plywood, despite having gone through many repetitions
Cost savings (refer Table 1)	Savings of about Rs. 61 lacs (43% savings)		

Table 4 Performance summary for NTA slabs

Performance summary			
Performance parameter	Conventional system	Aluminium system	Remarks
Material consumption (steel)	35 kg/m^2	22 kg/m^2	Around 35–40% steel reduction due to scheme improvisation
Cycle time in days	18–20 days	15 days	Around 25% improvement in cycle time
Labour productivity	2.5 m^2/man-day	3.3 m^2/ man-day	Around 30% improvement, due to lighter panels and fewer components, enabling quicker fixing/removing of shutters
QMS index	8.1–8.5	8.5–8.8	Aluminium panels provide superior finish than plywood
Cost savings (refer Table 2)	Savings of about Rs. 54 lacs (34% savings)		

Table 5 Overall summary of savings for four projects

Summary		
Performance parameter	Target unit savings	Remarks
Material: steel	15,270 ton-months	31% reduction in steel consumption
Material: H-beam	6.3 lakh Rmts	24% reduction in H-beam consumption
Labour in Mdays	21,077 man-days	With avg 25% increase in labour output
Cost savings	Rs. 4.57 cr	(refer Table 6)

Table 6 Project-wise savings

Item	UOM	Savings							
		Proj-1		Proj-2		Proj-3		Proj-4	
		Qty	Value (Rs. lacs)	Qty	Value (Rs. lacs)	Qty	Value (Rs. lacs)	Qty	Value (Rs. lacs)
Conv. FW-material									
L&T steel	T-Mnths	3516	53	8298	124	657	10	2799	42
H-beam	Rmt-Mnths	178,425	29	162,675	26	18,054	3	279,207	45
Plywood	Sqm	9305	37	648	3	508	3	2278	11
AL Slab Formwork	Sqm-Mnths	–55,800	–52						
Consumables			32		2		1		3
Conv. FW-workmen									
Labour	Man-days	7362	29	4100	16	6285	25	3330	13
Savings in Rs. lacs		**128**		**172**		**41**		**114**	

Bold indicates the savings

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Improving Handing Over of Residential Units Using Lean Tools

V. Ramani, A. Subramanian, Praveen Reddy, and Ashish Kumar Saxena

Abstract Construction projects are known to be customer-centric. Traditionally, there is a process of intermittent handing over of the dwelling units in any residential project across various stakeholders. This alternating cycle of handing over and taking over (HO-TO) leads to time wastage and creation of contractual issues such as DLP duration and cost claims and affects the adjacent ongoing activities due to resource re-allocation. This cycle can be optimized with bringing all the stakeholders working according to a comprehensive work schedule, thus streamlining the interdependence. The project under study is a residential project with more than 3600 dwelling units to be constructed and handed over to the end-customer over a period of 4 years. The project team devised an efficient way of collaborative planning system for handing over of flat units. The collaboration and the dynamic project planning facilitated the teams to hand over the residential units to the customers at an exceptional monthly rate of 211 units with an approximate improvement of about 40%. Implementation of Lean tools such as Big Rooms, PPC, constraint analysis, root-cause analysis and other site-based micro-level monitoring techniques have resulted in a significant improvement in the monthly rate of handing over.

Keywords Big rooms · Collaborative planning system · Micro monitoring · Bottlenecks

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1 Introduction

Residential projects (especially in Elite Housing) involves a large number of stakeholders. Handing over of flats to the customer is a tedious task that requires rigorous and seamless coordination among the participants. One of the major factors for any delay in handing over has been the interdependency of activities from different stakeholders [1]. The main reason for this mis-coordination can be attributed to the traditional style of working in silos.

The Big Room helps to hold the collaborative planning meetings; contributes to understanding of constraints and reducing waste and rework. As a result, it enables continuous flow and hence improves productivity. The collaborative planning [2] in the Big Room further contributes to sustain a common understanding of values, objectives and status of the project and improve relationships among the project teams having different roles having related goals.

The quality of interactions gets improved when people from different disciplines plan together in the same room at the same time. The shared responsibility and exchange of information with the right team at the right time facilitate early identification of the problem and faster resolution in a more effective manner [3].

The appropriate decision-makers are generally a part of all the collaborative planning meetings performed in the Big Room. One of the major significance is that the collaboration, communication and interactions reduce the time of decision-making and contribute to obtain better decisions and increase.

2 Need for the Study

The work till customer handing over involves L&T as well as non-L&T vendors with different work scopes. The cross-organizational dependencies had a varying impact on each of the activities. Even after completion of L&T's scope of work, there was a visible delay in final handing over of the dwelling units to the customer. As the final handing over to customer was under L&T's scope, there was a need to closely monitor the process, identify and arrest the bottleneck. Figure 1 shows the typical process followed in the handing over of residential units across various organizations.

The processes flow helped to find the bottleneck in a more systematic manner and facilitated arresting the same with collaborative planning.

3 Methodology

The detailed process chart as shown in Fig. 1 clearly shows to identify L&T's dependency on other agencies' scope of work. This process chart enabled the team to adopt the DMAIC strategy to improve the process by identifying the bottlenecks

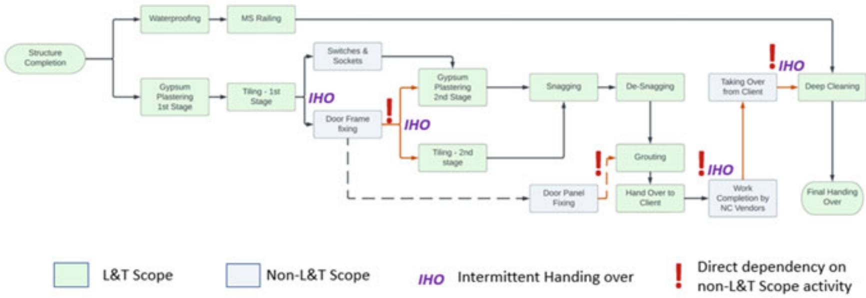


Fig. 1 Process of handing over of residential units

and arresting the same by virtue of discussions in the Big Room (progress review) Meetings.

D: Define—Slow handing over of residential units to customer in Phase-1.
M: Measure—Rate of handing over and taking over was measured for every subsequent activity with reference to the previous one for Phase-1.
A: Analyse—The analysis was done with the process chart (Fig. 1) in the internal progress reviews. The same was then extended to project-level Big Room Meetings. The Big Room included various stakeholders, the status was shared to all at the same time, and inputs were shared. The bottlenecks were identified, and action plans were prepared and circulated.
I: Improve—A more rigorous tracking of cross-organizational scopes facilitated for a faster project delivery. All the design-related and intermittent HO-TO processes were sped-up which in-turn escalated the overall cycle. Learnings from the past were incorporated into the monitoring mechanism for Phase-2, and the gap kept reducing with every review passing by.
C: Control—The refined system of project monitoring was implemented and used for faster customer handing over.

Figure 2 shows a sample of the simplified tracing sheet which was projected in the Big Rooms.

4 Study

The study takes into account the intermittent handing over and taking over as a part of the life cycle of the flat units or project at large. The duration of the study is kept one year considering it as the most crucial period for any project as per the discussions with the industry practitioners. To keep the effect of external factors such as mass mobilization of vendors or workmen and bulk material supply negligible, the period

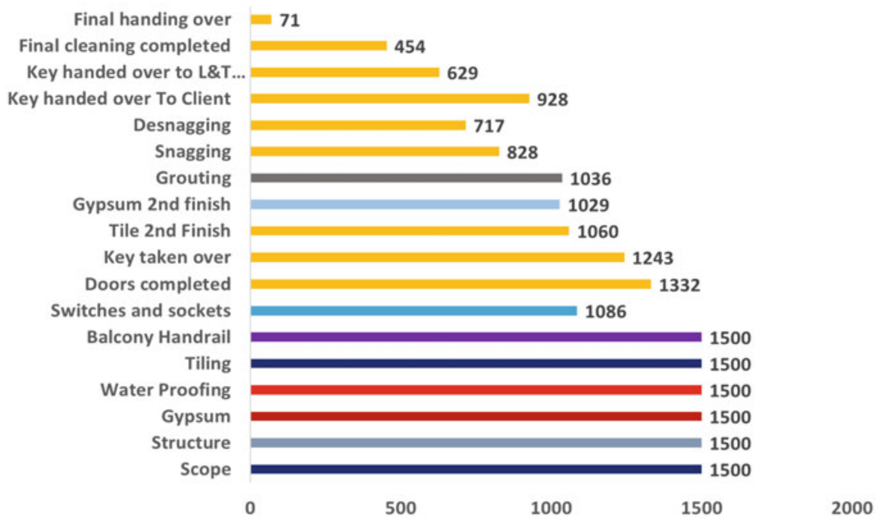


Fig. 2 Comprehensive progress tracking sheet

is not kept common for both the phases but is based on the progress of the respective phases. It starts from the time when 2/3rd of the flat units (in that phase) are concreted.

Phase-1 did not follow any comprehensive tracking mechanism, while Phase-2 did. Table 1 shows the status of flat units for that one year on a half-yearly basis.

Table 1 Status of flat units for Phase-1 and 2 at different intervals

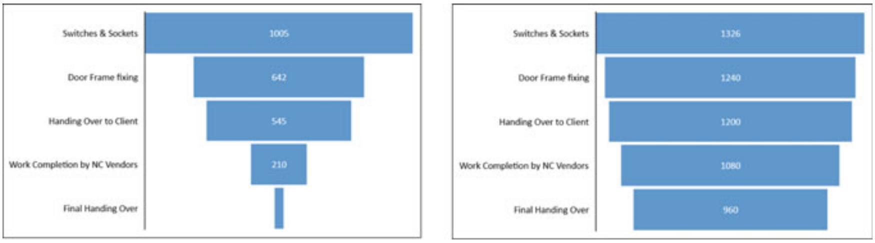
Description	Phase-1			Phase-2		
	2/3rd str. Comp	0–6 months	6–12 months	2/3rd str. Comp	0–6 months	6–12 months
Scope	**2100**	**2100**	**2100**	**1500**	**1500**	**1500**
L&T-1st HO	1390	1716	2100	890	1350	1500
Switches and sockets	345	920	1350	19	540	1345
Door frame fixing	158	350	800	–	470	1240
Handing over to client	5	100	550	–	390	1200
Work completion by NC vendors	–	10	210	–	350	1080
Final handing over	–	–	35	–	280	960

Bold indicates the numbers importance

Figure 3 clearly shows the number of flat units that have cleared the particular stage for the period under consideration, i.e. one year. On comparing the status for Phase-1 and 2, it is visibly evident that the difference between the continuous activities has reduced. This has facilitated timely (rather before time) handing over to the customers.

Furthermore, considering a common period of 1 year for the project as a whole (Sep’21–Sep’22), there has been an improvement in the HO-To cycle. Table 2 clearly depicts that due to the rigorous follow-ups and monitoring, the rate of handing over of flats to the customer has increased in H2 (Mar’22–Sep’22) as compared to the H1 (Sep’21–Mar’22).

Exceptional improvement in switches and sockets works facilitated a smoother and faster customer handing over. Since the strategy involved collaborative planning, this acknowledges the fact that there can be competing interests and similar to mediation, and the negotiation seeks mutually accepted outcomes.



Phase – 1 (b) Phase – 2

Fig. 3 Comparison of progress made during the period for Phase-1 and 2

Table 2 HO-TO-HO progress details for the period Sep’21–Sep’22

Description	Cum. till Sep-21	Cum. till Mar-22	Cum. till Sep-22	H1	H2
L&T scope work completion	1900 flats	2800 flats	3600 flats	900 flats	800 flats
Switches and sockets	**72%**	**75%**	**91%**	**3%**	**17%**
Door frame fixing	32%	75%	98%	43%	23%
Handing over to client	18%	65%	87%	47%	21%
Work completion by NC vendors	3%	60%	78%	57%	18%
Final handing over	**1%**	**33%**	**62%**	**32% (897 flats)**	**30% (1270 flats)**

Bold indicates the numbers importance

5 Conclusion

Collaborative planning ensured that all the stakeholders are at the same page at any given time. There was a visible increase in the progress of the subsequent activities that facilitated faster HO-TO-HO cycle and timely handing over to the customers.

Major conclusions are summarized as mentioned below:

Rate of customer handing over improved from 3 to 80 flats per month from Phase-1 to Phase-2 after the implementation of the comprehensive progress tracking.

Mobilization of manpower and material for switches and sockets improved drastically from Phase-1 to Phase-2. The year progress for Phase-1 was 48%, while it increased to 89% for the said period.

The rate of handing over increased from 150 to 211 flats per month for the project (Sep'21–Sep'22).

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Revolutionizing Work Process at Turner Construction Through Lean Construction

Sruthi Dongari and Bhargav Munagala

Abstract Turner Construction's Lean design and construction process—With the intent to continuously improve the efficiency of the existing systems, Turner Construction has adopted the last planner system as their main means to implement the Lean design and construction principles within the organization. Last planner system is one of the predominant tools used to enhance planning and management of the construction projects. Though the system was initially conceived to be used for planning and production control, it grew to become a holistic system to support Lean planning and execution of the projects. In this paper, we will discuss the implementation of the last planner system at Turner Construction, the changes made to existing systems, and the need to integrate feedback from the construction sites and the personnel from the jobsites to develop effective Lean management strategies.

Keywords Lean construction · Management strategies · Lean principles · Last planner system · Push and pull methodology

1 Introduction

As every organization looks to improve their processes and methodologies to meet the ever-changing demands of the public. The concept of Lean construction is becoming popular within the construction industry, though principles of Lean have been applied across various sectors since the concept is popularized by Toyota as Toyota Production System, its adaptation to the construction industry has been slow.

The organization in focus for this paper is Turner Construction who adopted Lean design and construction methodologies in their work processes to create a culture of continuous improvement. Turner Construction uses last planner system as their

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main means of software system to implement Lean design and construction at their organization.

In addition to the last planner system, they have just started using various principles and methodologies like target value design, visual management, robust 5s programs, 3D and 4D building information modeling and off-site construction [1] to meet the current day standards. Implementation of all these processes and methodologies vary on the parameters like location, client, budget, type of resources like workers, building materials, etc., of each construction project.

2 Turner Construction's Lean Design and Construction Process

With the intent to continuously improve the efficiency of the existing systems, Turner Construction has adopted the Last Planner System as their main means to implement the Lean design and construction principles within the organization. Last Planner System is one of the predominant tools used to enhance planning and management of the construction projects. It is also one of the key tools used in the scheduling of the projects as it helps in improving project's reliability, productivity, and performance [2]. Though the system was initially conceived to be used for planning and production control, it grew to become a holistic system to support Lean planning and execution of the projects [3].

The generic concept of this system is to bring people who are responsible to assign final work segments to the work executors and ensure they have required resources to execute the project without any issues. In the design part, this system would be used by Architects, Engineers, etc. and during construction superintendents or construction supervisors would use the system. It helps in integrating various phases of the project into a single system.

This system consists of five major parts, i.e., master planning, phase planning, make-ready planning, Weekly work planning and daily learning. The first part of the system deals with identifying the overall planning with emphasis on key milestones that guide the progress of the project.

The second part of the system is phase planning where a particular phase of the project is planned to final details like who would be doing what task, which task precedes and succeeds, management of the required resources to execute the task, etc. Here, the pull planning approach is used to sequence the tasks using Lean practices, and hence, this second part is the most important part among all the parts of the system. The second part is usually planned about 2–3 months ahead of the phase.

The third part of the system is make-ready planning which focuses on getting the tasks done where the team looks ahead to understand, evaluate, and identify potential constraints. This part is usually done about 6 weeks before the task where the focus is moved on to the look ahead plan. In this step, the crucial step is to log all the constraints with a deep level of detail and resource allocation, so that the team removes all the constraints ahead of the schedule.

The fourth part of the system is the project weekly plan, where the team tries to fulfill the promises made in the earlier stages of the project. Here, the key is to focus on the tasks at hand with effective communication and coordination among the teams. This could be seen in the images below, where the image shows the weekly plan implemented by the Turner Construction at 222 Second St. Project [4] (Figs. 1 and 2).

The fifth and final part is to learn from the project. This is usually achieved through the daily meetings where all the team members are assembled to discuss the progress of the previous and the current tasks to plan the future tasks. This daily huddling process of the construction crew could be compared to the daily stand-up meetings in the Information Technology field. Another advantage of the learning process is it allows the project managers to manage the resources by looking at the key metrics of the various teams to determine the progress and coordinate the other trades accordingly.

3 Key Challenges of the Current Turner construction's Last Planner System

The prominent users of the last planner system are the end users like the construction crew on the field, and sometimes the communication does not reach the management systems. The management needs to be initiative-taking and be involved in the processes and day to day activities of the construction crew. The management team cannot be seated in the offices and lead the crew on the jobsites. Hence, the management practices must align with the culture, and the management should look at the key facilitators of planning and resources to the construction crew to execute the tasks correctly.

The other key issue of utilizing the last planner system is the technical aspects of the systems, where the construction crew must be trained to use these programs and this system needs to be practiced and used daily to make the best use of the system. All the additional documentation of the steps and the processes by the site superintendent increases the additional steps in managing and supervising the construction crew, resulting in more mistakes or wastage of the resources. Hence while utilizing this system, it demands a more experienced crew at the jobsite to avoid these mistakes and wastage of resources.

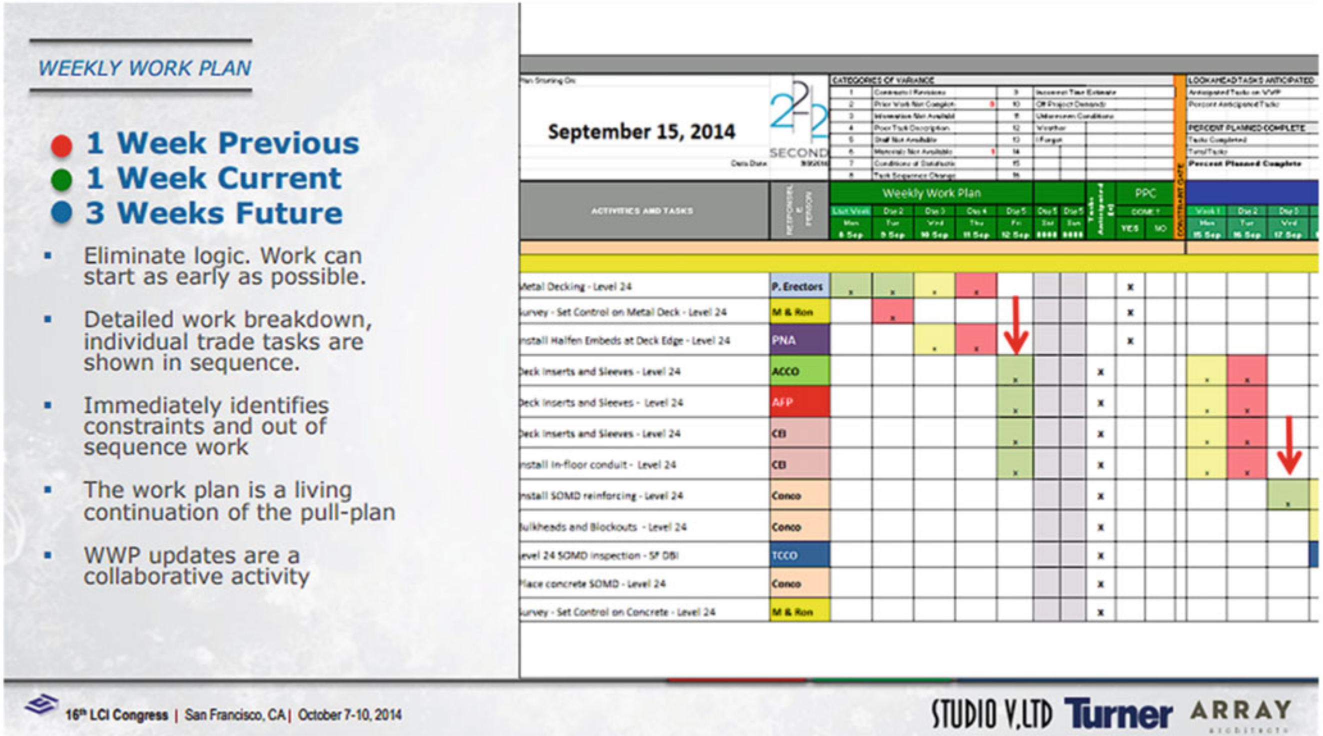

Fig. 1 Weekly work plan system implemented by Turner Construction. *Source* Turner Construction [4]

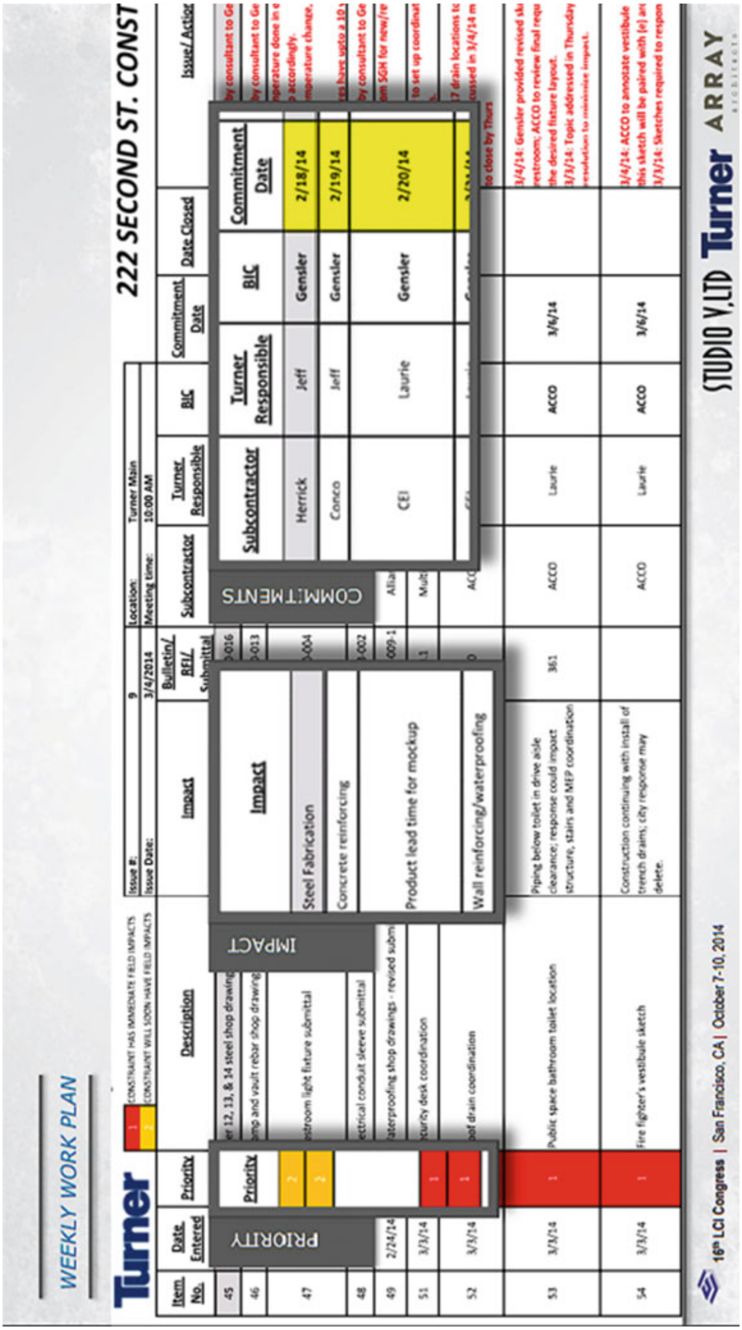

Fig. 2 Daily details of weekly work plan system implemented by Turner Construction. This image highlights the tasks according to priority, how those tasks would impact other tasks, and the people that are committed to the tasks to execute them. *Source* Turner Construction [4]

4 Improving Turner Construction's Last Planner System with Lean Design Principles

There are numerous ways to improve the Turner Construction methodology with latest technological advances that could be simultaneously deployed with the last planner system to create a better system. This process could be said as optimizing the value stream process by eliminating waste and excess processing. Eliminating waste could be achieved by reducing the waiting time for doing the tasks, while the superintendent is filing and documenting the processes for the day in the last planner system. This could also be achieved by utilizing the right talent where the construction crew does not have to be spoon-fed with the daily tasks and the processes to accomplish them.

Tying up the material resources along with the weekly work planning system could be achieved by using "just in time" approach rather than "just in case" where the materials for the job would be delivered only before the beginning of the task which would allow the construction crew to utilize the space efficiently to execute the tasks in hand. Additionally, dividing the project into separate production zones will help the crew to execute the project in time. For example, if we are building a multistory building, when the concrete team is pouring on the higher level, the wall framing team could start framing the bottom portion of the building instead of waiting for the concrete team to finish all the floors of the building.

The Turner Construction could also integrate the building information modeling into their comprehensive system that would help the construction crew to visualize the processes and understand the demands of the client along with the intent of the architect. This 3D modeling process would also help the construction crew to integrate the different trades and detect the potential conflicts that might arise during the construction process. If the management team could integrate this methodology to their existing Make-Ready Planning phase, then it would help the respective teams to solve the issues before they spiral down to hold or stop the construction process.

5 Conclusion

The overdependence of Turner Construction on the last planner system as a single solution to all the problems needs to change, and they could develop a comprehensive system which uses best strategies from across the field to address the waste problems. Once the last planner system combined with the "just in time" approach, reducing the redundant paperwork and finally utilizing the computer-aided design software would benefit the Turner Construction to be a modern age organization to solve modern construction problems.

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Choosing by Advantage for a Commercial Project with a BIM Implementation

Shanil Shah, Keval Modi, Jyoti Trivedi, and Ganesh A. Devkar

Abstract Each construction project is designed and uniquely planned, making it distinctive at least in terms of location. During the planning stage, when decisions influence building performance, the architecture, engineering, and construction (AEC) industry requires more efficient decision-making practices to obtain maximum value for the client within the targeted cost. A lack of coordination between stakeholders can result in poor planning and frequent design changes that lead to project failure. In this work, we use the choosing by advantage (CBA) approach to maintain acceptance and clarity in the decision-making process in a real-life construction project. This study investigates the use of CBA to choose a design for steel reinforcement in a beam–column junction. This study shows that the efficiency of the CBA approach to choose the best from alternate designs through a visualization decision-making process. The design methodology adopted is collaborative as well as dynamic and technology-driven which has a significant impact on design development. The outcome of more numbers of parameters in BIM along with the CBA decision-making process.

Keywords Choosing by advantage (CBA) · Lean design · Decision-making · Reinforced concrete design · BIM implementation

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1 Introduction

A country's socioeconomic progress is significantly influenced by the construction industry [1]. In general, commercial projects feature a set of construction operations like reinforcement and shuttering that are repetitive and typical across projects and provide scope for improvements and time savings in repetitive processes has necessitated a fundamental rethink of the planning management process, and execution of such projects. The increasingly popular Lean construction approach can enable a better model for productive interaction among all stakeholders of the construction project and use a strong performance management system to manage execution.

Choosing by advantages (CBA) is a decision-making approach that aims to ensure that a decision yields the most value and best outcome for all stakeholders. Traditionally CBA is preferentially used during the design development phase as a Lean tool to reduce waste and add value. In this work, we posit that CBA can be used in the construction phase and use it in a live project to establish the idea.

Adopting the Lean mindset, when constructing RCC, column–beam intersections need extra attention since they commonly get clogged. Rebar selection for beams and columns that join at a point may be challenging as a result. The reinforcement for a beam is frequently planned separately from that for a column, and structural engineers then verify their compatibility [2]. The minimum rebar diameter, the area ratio of the rebar to concrete in the joint, and the development length for the beam reinforcement are all required by Indian standards for compatibility evaluations. However, as Indian standards do not impose any constructability rules, it could be difficult to build joints that adhere to the code. Reinforcement contractors may not be satisfied with code-compliant designs.

The core strength of CBA is the inclusion of various stakeholders in deciding on alternate designs to overcome some of the above limitations. Fewer contradictory questions are generated on adopting CBA, which also enables stakeholders to talk about their values in greater depth [3].

2 Delivery Methodology

CBA was used as the tool for making decisions while choosing the best rebar joint. The choice of the rebar is influenced by several factors and involves numerous stakeholders with a variety of interests and points of view. This case study was carried out as a part of the studio "Integrated Construction Practices" by a group of students in CEPT University. A live commercial project located at Ahmedabad was chosen for the collaborative implementation of Lean and BIM. Structure engineers and contractors were considered in this study. The methodology followed in a study is shown in Fig. 1.

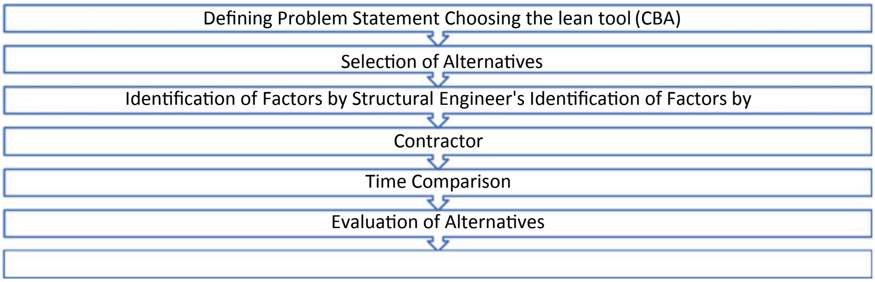


Fig. 1 Methodology adopted

3 Problem Statement

The problem was at the basement area of a commercial project. Since the reinforcement was excessively crowded at the connection, the contractor was having trouble building the reinforcement and pouring concrete in the basement ramp beam. Since there were three basements, the developer was worried about this issue when he built the third basement. As a result, the contractor and structure consultant brainstormed and used CBA to the ramp beam–column connection while constructing the second and first basement ramps. The graphic illustrates the reinforcement area need for column and beam that link at the junction in an RCC frame (Fig. 2).

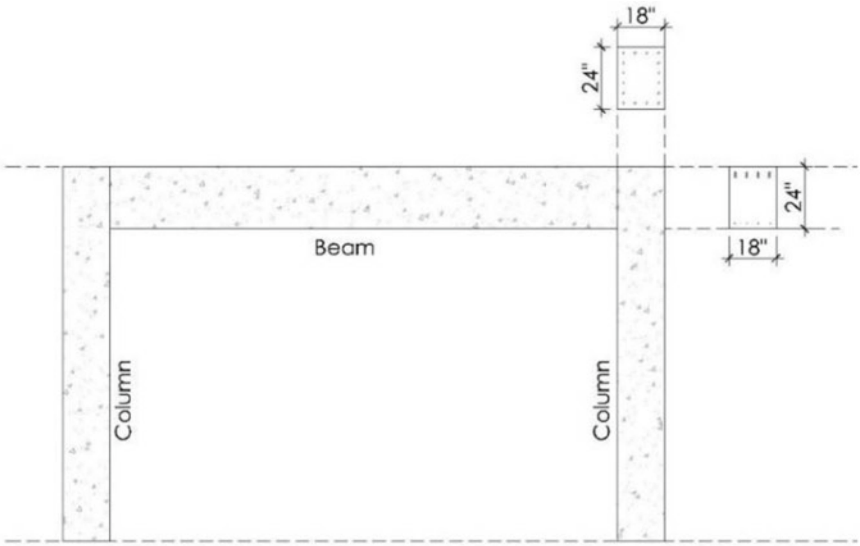


Fig. 2 Reinforced concrete frame with beam and column

The structural engineer then collaborated with the contractor team to establish sets of design possibilities for column and beam after calculating the necessary rebar areas. Given that several reinforcement configurations could potentially satisfy the rebar area criteria, the range of potential designs was broad. Not all reinforcement options are represented in this example.

4 Selection of Alternatives

The sample sets were taken for different configuration of reinforcement alternatives which were suggested by the structure engineer. Figure 3 shows the design alternatives for beams and columns, made of different reinforcement sizes. Other alternatives included reinforcing the beam or column with smaller rebar. At beam–column junction, considerable stress is generated above the neutral axis of the beam (upper side in beam). Therefore, different configurations were given for the reinforcement above the neutral axis. The stirrups and tension reinforcement configurations were taken to be the same in all alternatives [2].

Legends:

Bar Diameter	Colour	
10 mm	Black	
12 mm	Green	
16 mm	Yellow	
20 mm	Red	
25 mm	Blue	
32 mm	Grey	

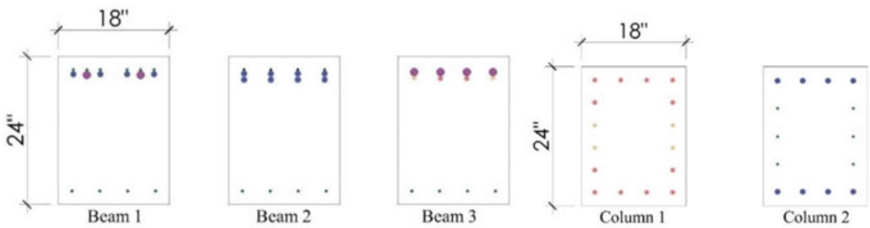


Fig. 3 Sample set for design alternatives of beam and column

5 Identification of Factors and Criteria

Using the tabular technique of the CBA and importance scale, decision-makers can compare choices once they have been created. In this case study, we considered six beam–column junctions. The factors that were considered depended on the decision-makers capacity to identify the distinctive advantages of choices within a given aspect [4].

6 Structural Engineer's Factors

6.1 Rebar's Total Cross-Sectional Area in a Column

The determining criteria for the column's rebar area were chosen from the standard outlined in IS 456:2000, which states that the minimum longitudinal steel reinforcement for the column is 0.8% of the gross column area (IS 456, 2000). The engineer calculated the required amount of rebar based on the desired tensile strength of the column. This criterion reflected the preference for reducing the overall reinforcement area in order to reduce reinforcement ratio and the material costs.

6.2 Rebar's Total Cross-Sectional Area in the Beam's Top

The determining factor was the compliance of the rebar area in the top of the beam with the IS 456:2000's is must criteria.

6.3 Linear Mass of Rebar

The weight per meter of length in the joint of rebar is known as its linear weight in joint. Rebar costs are often calculated per tonne, and therefore, doing so in this calculation minimized material costs. The sole requirement in this component is to reduce weight, which represented the engineer's intention to cut material costs and the weight of the material to be installed [2].

6.4 Column Bars at Their Widest Point

An element with several little bars was considered by the engineer to be more homogeneous than an element with a single large bar, and the material becomes less homogeneous as the largest separation increases. The uniformity of the material could be more important to an engineer than the number of bars being used [2].

7 Contractor's Factors

7.1 Reinforcement at the Junction of the Beam and the Column

The junction of column and beam reinforcement refers to whether the reinforcements joint is placed as directed or not. If the plans called for intersecting beam and column rebar, it had to be bent or otherwise altered on site before being installed. If both beam reinforcement and the column reinforcement were on the joint's center line, rebar placers would adjust the beam or column bar to place the joint. Bars did not physically cross one other, although designs can show crossings. The bars entering the joint could not overlap [4].

7.2 The Required Number of Bends to Prevent the Intersection of the Beam and Column Bars

For the option as stated, there needed to be a certain number of bends to ensure that the bars of the beam and the columns did not cross. The designers made the premise that a bar must be bent once to eliminate a junction that were depicted on the drawings when describing. In reality, however, instead of being bent in the field, bars could just be shifted. Thus, fewer bends were desirable since straight bars were easier to produce.

7.3 Bar Accessibility

Bar availability refers to the availability and accessibility of bars of a particular size in the project site. This component considers the reinforcement stock as well as the wait time before receiving bars from the steel mill. This criterion required that bars be readily available for use whenever they were needed in construction timetable.

7.4 The Quantity of Bars

The quantity of bars refers to the overall number of bars required on construction site. The requirement was that mandates that the entire steel area meet IS standards. This meant that fewer bars were preferred since they could be erected rapidly.

7.5 Number of Reinforcing Layers in the Beam's Top

The number of reinforcement layers present at the top of each option is indicated by the number of layers of reinforcement at top of beam. This requirement established the bare minimum required for reinforcing layers. This need reflected the contractor's preference for fewer layers of reinforcing bars in order to reduce requirement for space to maintain a certain minimum gap between layers of rebar so that concrete may fill the space in between.

7.6 Productivity

Labor productivity is considered one of the most important parameters for constructability. Factors like reinforcement diameter size, column sizes, total quantity of reinforcement, and column geometry can affect labor productivity. Constructability time mainly depends on column sizes, column geometry, rebar diameter size, and reinforcement quantity. For easy calculation and time constraint, the column size and column geometry are taken as constant.

The rebar diameter size and reinforcement quantities are varying factors. As per the literature survey [5] (Table 1),

$$\text{Productivity (kg/man-day)} = (51.72 + 7.43 * \text{Dia} + 0.000492 * \text{TQ} - 2078 * \text{Geom} \\ + 0.000761 * (\text{Geom} * \text{TQ}))/\text{working hour}$$

TQ	Total quantity in kg
Geom	0 for rectangular beam and column
Dia	Diameter in mm.

The highest productivity was seen in for Column 2–Beam 3, and therefore, from constructability perspective, Column 2–Beam 3 required least time for rebar work. Comparing this productivity with least productivity for Column 2–beam 2, laborers could potentially achieve 25% more productivity if Column 2–Beam 3 is selected.

Table 1 Productivity for alternatives

Alternatives	Dia (mm)	Total quantity (kg)	Total steel on beam + column (kg)	Productivity kg/man-day
Column 1, Beam 1	32	56	367	194
	12	24		
	25	45		
	10	21		
	16	56		
	20	165		
Column 1, Beam 3	20	218	367	200
	32	24		
	16	101		
	12	24		
Column 1, Beam 2	25	89	366	175
	10	32		
	12	24		
	16	56		
	20	165		
Column 2, Beam 1	32	56	372	199
	12	75		
	25	220		
	10	21		
Column 2, Beam 3	20	53	372	**208**
	32	24		
	16	45		
	25	175		
	12	75		
Column 2, Beam 2	25	264	371	168
	10	32		
	12	75		

8 Evaluation of Alternatives

The requirements and features of all the factors were combined, and the advantages compared and contrasted. Each of the benefits has since been assigned a score. The choice of beam and column would be aided by the benefits' overall score given in Table 2. Further the importance scale was prepared as shown in Fig. 4.

Table 2 CBA comparison table

Sr No	Design alternatives factor and criterion	Column 1, Beam 1	Imp	Column 1, Beam 2	Imp	Column 1, Beam 3	Imp	Column 2, Beam 1	Imp	Column 2, Beam 2	Imp	Column 2, Beam 3	Imp
S1	Total cross-sectional area of rebar in column	Att: 4572 mm^2		Att: 4572 mm^2		Att: 4572 mm^2		Att: 4603 mm^2		Att: 4603 mm^2		Att: 4603 mm^2	
	Criterion: The **least** amount of rebar to fulfill must criterion is best	Adv: 31 mm^2 fewer	10	Adv: 31 mm^2 fewer	10	Adv: 31 mm^2 fewer	10	Adv:	0	Adv:	0	Adv:	0
S2	Total cross-sectional area of rebar in top of beam	Att: 4248 mm^2		Att: 4239 mm^2		Att: 4245 mm^2		Att: 4248 mm^2		Att: 4239 mm^2		Att: 4245 mm^2	
	Criterion: The **least** amount of rebar to fulfill must criterion is best	Adv:	0	Adv: 9 mm^2 fewer	20	Adv: 3 mm^2 fewer	0	Adv:	0	Adv: 9 mm^2 fewer	0	Adv: 3 mm^2 fewer	0
S3	Lineal mass of rebar	Att: 33.9 kg		Att: 33.33 kg		Att: 34.38 kg		Att: 33.4 kg		Att: 33.33 kg		Att: 33.38 kg	
	Criterion: The **lighter** the better	Adv: 0.48 kg less	0	Adv: 1.05 kg less	20	Adv:	0	Adv: 0.48 kg less	0	Adv: 1.05 kg less	20	Adv:	0
S4	Maximum spacing between column bars	Att: 114 mm		Att: 114 mm		Att: 114 mm		Att: 121 mm		Att: 121 mm		Att: 121 mm	
	Criterion: The **more homogeneous**, the better (lower maximum spacing is best)	Adv: 7 mm less space	10	Adv: 7 mm less space	10	Adv: 7 mm less space	10	Adv:	0	Adv:	0	Adv:	0

(continued)

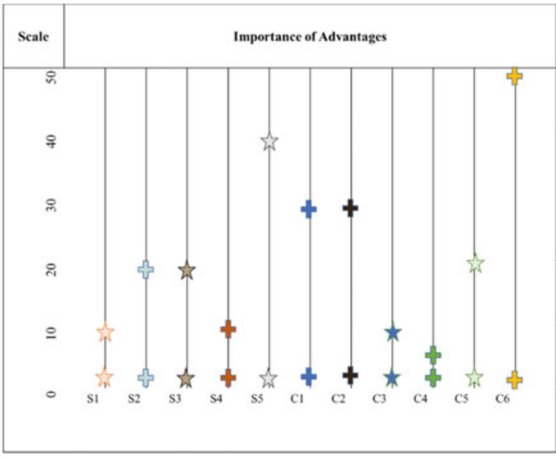
Table 2 (continued)

Sr No	Design alternatives factor and criterion	Column 1, Beam 1	Imp	Column 1, Beam 2	Imp	Column 1, Beam 3	Imp	Column 2, Beam 1	Imp	Column 2, Beam 2	Imp	Column 2, Beam 3	Imp
S5	Intersection of beam and column reinforcement	Att: 60 mm between beam and column reinf		Att: Intersection		Att: Intersection		Att: 60 mm between beam and column reinf		Att: Intersection		Att: 63 mm between beam and column reinf	
	Criterion: The beam bars and column bars will touch, but not intersect	Adv: 60 mm less intersection	40	Adv:	0	Adv:	0	Adv: 60 mm less intersection	40	Adv:	0	Adv: 63 mm less intersection	40
C1	Number of bends necessary for beam and column bars not to intersect	Att: 4 bends		Att: 4 bends		Att: 2 bends		Att: 4 bends		Att: 4 bends		Att: 2 bends	
	Criterion: **Fewer** bends are better	Adv:	0	Adv:	0	Adv: 2 bends fewer	30	Adv:	0	Adv:	0	Adv: 2 bends fewer	30
C2	Bar availability	Att: #32 bar are not readily available		Att: No #32 bar are used		Att: #32 bar are not readily available		Att: #32 bar are not readily available		Att: No #32 bar are used		Att: #32 bar are not readily available	
	Criterion: Prefer to use bars with the **shortest** lead time	Adv:	0	Adv: Material is most available	30	Adv:	0	Adv:	0	Adv: Material is most available	30	Adv:	0
C3	Number of bars used	Att: 28 bars		Att: 28 bars		Att: 24 bars		Att: 26 bars		Att: 26 bars		Att: 22 bars	
	Criterion: The **less** bars, the better	Adv:	0	Adv:	0	Adv: 4 bars are less	5	Adv: 2 bars are less	5	Adv: 2 bars are less	5	Adv: 6 bars are less	10
C4	Number of layers of rebar in top of beam	Att: 2 layers		Att: 3 layers		Att: 2 layers		Att: 2 layers		Att: 3 layers		Att: 2 layers	

(continued)

Table 2 (continued)

Sr No	Design alternatives factor and criterion	Column 1, Beam 1	Imp	Column 1, Beam 2	Imp	Column 1, Beam 3	Imp	Column 2, Beam 1	Imp	Column 2, Beam 2	Imp	Column 2, Beam 3	Imp
	Criterion: **Fewer** layers of reinforcement are preferred	Adv: 1 less layer	5	Adv:	0	Adv: 1 less layer	5	Adv: 1 less layer	5	Adv:	0	Adv: 1 less layer	5
C5	Number of different bar sizes used	Att: 5 types		Att: 4 types		Att: 4 types		Att: 3 types		Att: 3 types		Att: 5 types	
	Criterion: **Fewer** layers of reinforcement are preferred	Adv:	0	Adv: 1 type less	16	Adv: 1 type less	16	Adv: 2 types less	8	Adv: 2 types less	20	Adv:	0
C6	Productivity	Att: 194 kg/man-day		Att: 175 kg/man-day		Att: 200 kg/man-day		Att: 199 kg/man-day		Att: 168 kg/man-day		Att: 208 kg/man-day	
	Criterion: **Higher** productivity is better	Adv: 14 kg/man-day is more	32	Adv: 33 kg/man-day is more	9	Adv: 8 kg/man-day is more	40	Adv: 9 kg/man-day is more	38	Adv:	0	Adv: 40 kg/man-day is more	50
	Total score		97		115		116		96		75		**135**



Value	Factor	Advantages
50	C6	40 kg/man-day is more
40	S5	No clash/interaction between Column and beam reinforcement
30	C1, C2	2 bends fewer, Material are available on site easily
20	S2, S3, C5	9 sq.mm fewer, 1.05 kg less, 2 type less
10	S1, S4, C3	31 sq.mm fewer, 7 mm less space, 6 bars are less
05	C4	1 less layer

Fig. 4 Importance scale for CBA analysis

9 BIM as Aid Tool in CBA

BIM and Lean are slightly different initiatives, but both have impact on the industry. The glossary of the BIM handbook [6] defines BIM as "a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation." Lean construction, on the other hand, refers to the application and adaptation of the underlying concepts and principles of the Toyota Production System (TPS) to construction. As in the TPS, the focus in Lean construction is on reduction in waste, increase in value to the customer, and continuous improvement [7] (Fig. 5).

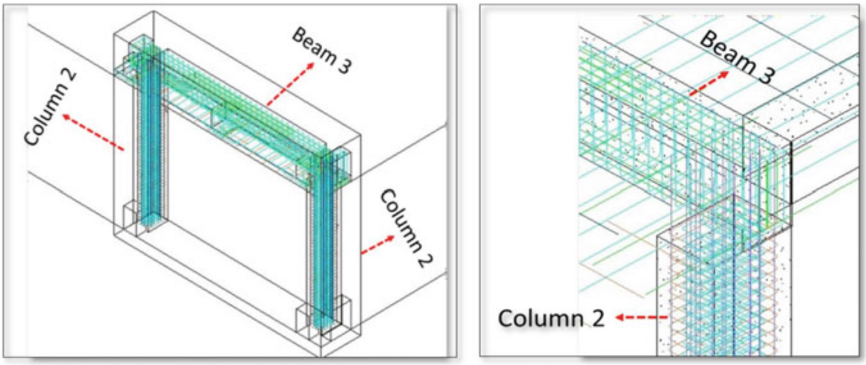


Fig. 5 Outputs from LOD-400 structural Revit model

Advantages of BIM in the current study

- BIM model will give better visualization of reinforcement joint
- Rapid generation of design alternatives
- Reuse of model and data prediction
- Collaboration in design construction
- Pouring of concreting visualization in complicated junctions.

Advantages of Lean Principles in current study

- Reduce cycle time by increasing productivity
- Increase flexibility from constructability aspects
- Use visual management.

10 Decision Making

In this case study, total six alternatives of a different combinations of beam and column were considered, and factors of compression were taken from contractor and structural engineer. The quantity takes-off for comparing the alternatives was taken from the Revit structural LOD 400 model. Using the LOD 400 model, the quantity take-off could be assessed easily and quickly. By just one click, the bar diameter could be changed, whereas in manual calculations, same interaction had to be repeated for all models. For each alternative, IOFA was calculated, and the maximum IOFA was for column 2 and beam 3, with a value of 135.

Cost is also important parameter in the decision making. It is directly dependent on the material, labors, and machinery. The material used in all options was almost same, and therefore, material cost did not vary. However, labor cost and machinery cost have direct relationship with the productivity. Here, from a literature survey, the difference in productivity is shown above in Table 1. Higher productivity shows that workers are completing work ahead of their due date, and therefore, there is a reduction in labor costs. In this case study option 6, column 2–beam 3 had the least cost among all the options that were considered.

11 Conclusion

The CBA method outperformed value-based methods in selecting sustainable alternatives in the AEC industry. It added value by minimizing the conflict among the stakeholders involved in the project. The factors chosen collaboratively were based on the experience and perspective of the value.

Six alternatives designs were compared for the study, and sixth alternative (Column 2–Beam 3) was found to have it has highest productivity, least column–beam intersection for reinforcement and fewer number of bars used leading to highest IoFA value.

This study investigates the use of CBA to choose a design for steel reinforcement, in a beam–column joint. It also indicates that BIM helps deciding on this alternative that has the best outcomes. Lean-BIM integration is an emerging branch in construction industry which can add value in the project by providing better visualization, rapidly generated data, reusable the models, and collaborative construction design. To simulate the construction processes, it offers the best visual environment for projects during the design and construction phases. Rapid turnaround to prepare cost estimates and other performance evaluations at the conceptual design stage allows for the evaluation of numerous design options, including the use of multi-objective optimization techniques.

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Comparative Analysis of FDS in Real Estate Projects

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Abstract The construction sector is riddled with project delays due to a variety of reasons. Both researchers and industrialists are working towards finding solutions and approaches to reduce such delays. The Lean construction approach is being increasingly considered a promising approach to prevent materials, effort, and time waste in the construction sector. Action-based Foreman Delay Survey is a holistic approach to finding the root cause of delays in construction and proposing solutions to overcome them. This paper reports the results of an action-based Foreman Delay Survey that was conducted on four real estate projects in the state of Gujarat in India. The survey showed the causes of two types of delays—supportive and recoverable delays. In this paper, these causes are analysed and solutions are proposed to help eliminate or minimize such delays in large construction projects.

Keywords Lean construction · Foreman delay survey · Action-based · Recoverable delay · Supportive delay

1 Introduction

Project delays are serious problems in the construction industry. One of the markers for successful project completion is its completion within the stipulated time frame. Given the risks and losses associated with delays in construction, researchers all over the world have been developing efficiency-enhancing approaches such as Lean construction, integrated project delivery, virtual design construction, prefab construction, and others, in order to prevent delays and associated problems.

The concept of Lean construction, derived from Lean manufacturing, emphasizes the generation of value in construction projects. 'Lean' is a way to design

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production systems to minimize the waste of materials, time, and effort to generate the maximum possible amount of value [1]. The core principles of Lean require that all employees be participants in the methods of continuous improvement. Such participation can enhance job satisfaction and make the job simpler than non-Lean-based approaches. Lean construction concepts can provide clients with better goods and services, through lower costs, enhanced safety, improved quality, and shortened delivery times.

Despite the promise and established benefits, Lean manufacturing continues to have two obstacles: the first is the tendency to continue with the status quo, which prevents asking employees to participate in solving underlying problems. The second obstacle is the extraordinary aversion to change, sometimes known as the "not invented here syndrome" [2].

Lean construction focuses on the reduction of waste, not just of materials but also of effort. Work sampling is an effective Lean tool that can be used to manage site resources, time, and labour. In work sampling, productivity is measured through a series of instantaneous observations or random snapshots of work in progress over the work period. Such observations provide comprehensive information on the amount of time spent by workers on productive, supportive, and non-productive work. Work sampling offers timely data that can help the management identify problems for remedial action or devise strategies to increase efficiency. Work sampling is particularly useful for analysing non-repetitive or irregularly recurring operations for which comprehensive techniques and frequency descriptions are difficult to define. Work sampling offers a preliminary analysis to determine whether more research on issue solutions is necessary [3].

The Foreman Delay Survey (FDS) is a tool that adheres to the same objectives, but it has not been widely applied in India to foster Lean culture awareness. Foreman Delay Surveys are a tool for assessing performance and boosting efficiency. Performance is evaluated by quantifying the occurrence of delays in the workforce's daily schedule. FDS are designed to gather accurate information on delays, prevent conflict with the workforce, and foster a culture of positivity and motivation through rapid detection and effective resolution of issues. Through the utilization of resources already existent on building sites, the FDS seek to minimize the expenditure of their management with no need for new investment [4].

While a survey of literature provides information on various causes and means of delays in construction projects, project planning teams seldom obtain and consider inputs from the actual last planners and the site workers which results in a push-based programme. Since there is an evident gap witnessed between the actual last planner and the site planning team, this study seeks to obtain information on site labour productivity for selected projects, by considering inputs from site workers. It is posited that while designing the construction programme the construction managers or site planners must take into account, the requirements and concerns of the site workers.

The purpose of this article is to employ the Foreman Delay Survey to recognize the common causes of delays in real estate projects and provide probable interventions to increase worker productivity on the job site through the application of Lean tools.

2 Research Setting

The research was carried out on four ongoing real estate projects within the Ahmedabad and Gandhinagar region in the state of Gujarat in India. Three of these were residential projects and one was commercial. The study adopted the FDS method to measure their project performances and improve productivity. The Lean tool was applied to the project sites, and the data and information were collected by work sampling. The work sample analysis of one construction activity was carried out in all four real estate projects is performed and the work was evaluated. Following this, interviews were conducted to determine how the crew and workplace conditions had changed over time.

3 The Projects

Project one was a commercial office building of twelve storeys. The project commenced on January 2021 and had been running for one and a half years at the time this study was carried out. The work conducted by two fitters, and two helpers on the third storey of the 12-storey building was observed. Their block work activities were observed to understand the working conditions under harsh weather conditions.

Project two was a residential cum commercial project, located in one of the most congested areas of the city connected by two major roads. The building comprises six separate blocks of fourteen floors each. The project construction period was planned to be three years from 2021. However, considerable time was spent on handling the construction materials and equipment on site due to space limitations.

Project three was a typical residential project located on the outskirts of a big city. The project site is adjacent to another construction site, and benefits from common resource sharing such as site office, material stacking yard, RMC Plant, and water services. The site offered ample open space for vehicular mobility and allowed for the freedom to plan site logistics. However, the site is located in a remote location with poor connectivity to the core city.

Project four was a 33-storey residential building made of two towers. The site lies in the planned business district, and hence, the work speed and quality requirements were high. The schedule was tight with workers often running up and down the stairs instead of waiting for the elevator. Considerable amounts of time were also spent on handling construction materials and equipment on site due to height constraints.

Further information about the projects is given in Table 1.

Table 1 Projects information

Project	Type of project	Project cost (INR)	Built up (m^2)	Contractor	Storey
1	Commercial	110 crores	13,306	Contractor A	G + 11
2	Residential + commercial	130 crores	61,062	Contractor B	G + 13
3	Residential	103 crores	11,000	Contractor A	G + 13
4	Residential	160 crores	48,702	Contractor C	G + 32

4 Research Methodology

An action-based case study technique was used as the research methodology. To optimize solutions, this research looked for waste at the microlevel utilizing Lean methods appropriate to construction projects. The FDS was used to implement the Lean concept at the construction site.

This technique differed from classic FDS methods in that it not only identified the problem, but also analysed the situation, and proposed improvements while evaluating the impact of those changes.

Action-based research is a five-phase cyclical process that entails diagnosing, action planning, action taking, evaluating, and specifying learning. The diagnosing step involves analysing the primary source of the problem during any activity. During this case study, the problem was identified by each team at their project sites. Action planning involves finding a solution to the primary problems through planned action. The action-taking phase involves the practical application of the planned approach towards overcoming the problem. In this method, the practitioners take the action for the problems. During the fourth stage, the implemented procedures are evaluated. The last stage involves the learning that practitioners gain through the success of the applied solution.

All the data used in the research were collected for the four construction project sites through an eight-hour monitoring of various activities during the peak summer time of April 2022. These projects will hitherto be referred to as projects one, two, three, and four in this paper. In project one, the activity observed was the laying of bricks. In project two the activity observed was the laying of reinforcement. In project three, the laying of bricks was monitored, and in project four, formwork installation was observed. The time spent on each activity was noted in terms of man-hours worked and man-hours lost. The man-hours lost were further classified into recoverable delays and non-recoverable delays. The analysis is explained in further sections.

5 Data Collection

Table 2 Summary sheet for FDS.

Table 2 Summary sheet for FDS real estate project

	Project name	Project 1 (%)	Project 2 (%)	Project 3 (%)	Project 4 (%)	Total avg delay (%)
Type of delay	**Supportive delay**					
	Material/tool mobilization	2.21	4.66	5.31	5.41	4.40
	Receiving/ giving instructions	3.22	2.37	7.22	3.21	4.01
	Inspection	5.25	3.22	5.14	1.47	3.77
	Cleaning	4.21	1.77	3.71	4.21	3.48
	Waiting time for materials	3.17	4.21	2.64	2.89	3.23
	Total supportive delay (A)	18.06	16.23	24.02	17.19	18.88
	Recoverable delay					
	Late start	3.25	7.44	4.57	5.33	5.15
	Discussion	2.36	4.99	2.69	2.31	3.09
	Idle time	29.32	19.56	15.33	20.45	21.17
	Waiting for co-workers	6.23	4.21	5.11	6.64	5.55
	Personal break	14.32	14.36	12.47	18.42	14.89
	Waiting for tools	4.98	1.98	2.68	2.65	3.07
	Repetitive works	3.11	2.54	2.47	2.14	2.57
	Total recoverable delay (B)	63.57	55.08	45.32	57.94	55.48
	Man-hours lost (A + B)	81.63	71.31	69.34	75.13	74.35
	Man-hours worked (C)	18.37	28.69	30.66	24.87	25.65
	Total observed time (A + B + C)	100	100	100	100	100

6 Data Analysis

In the work sampling study, the values of man-hours lost are displayed for each category in percentage value. The FDS summary data indicate a high percentage of man-hours lost with an average of 72.69%. Project 1 and project 3 had lost man-hours of nearly 69.64% to 81.63%, respectively. The man-hours performed for all four projects were very small, with an average of 27.31% of the total man-hours spent on the respective projects.

The number of man-hours lost for the supportive delay and recoverable delay corresponded to an average of 18.88% and 55.48%, respectively. The supportive delays such as receiving/giving instructions and material and tool mobilization contributed significantly with an average of 4%. However, idle time and personal breaks contributed 21.17% and 14.89%, respectively, to recoverable delays.

The data can be summed up in Table 2: Summary sheet for FDS (Table 1). The details of supportive delay and recoverable delay analysis are described below.

6.1 Supportive Delay Analysis

A radar graph is plotted on the four projects to compare and analyse the various supportive delays incurred. This information is closely related to man-hours work and man-hours loss for individual labour to track productivity. The cumulative results for supportive delay are shown in Fig. 1: Comparative analysis of supportive delays and supported by data shown in Table 2: Summary sheet for FDS (Table 1).

Figure 1 shows cumulative data of supporting delay for projects 1, 2, 3, and 4 in percentage value. It is observed that the project 3 polyline has the highest delay for receiving and giving information at 7.22%. The polylines of project 2, project 3, and

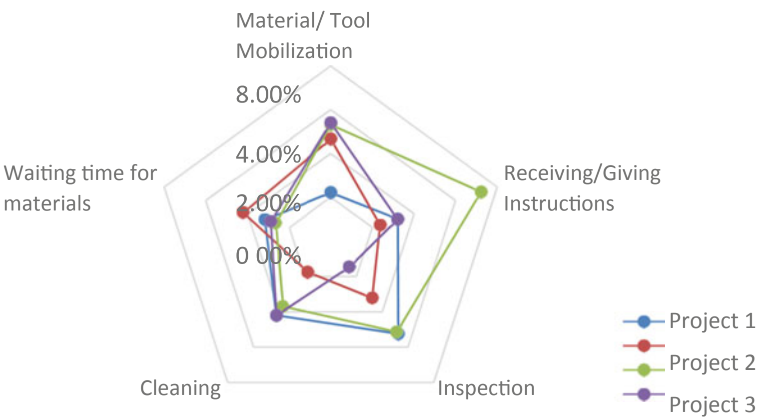

Fig. 1 Comparative analysis of supportive delays

project 4 shows nearly similar percentage of delays for material/tool mobilization, at 4.66%, 5.31%, and 5.41%, respectively. The distributions of the polylines for inspection delay, cleaning delay and waiting for material delay have similar range values of 3.77%, 3.48% and 3.23%, respectively. This analysis of supportive delays for all four projects accounts for an average of 18.88% varying from 16.23% as the lowest for project 2 and the highest of 24.02% for project 3. The graphs also show that receiving and giving material and material tool mobilization are the major delays for all four projects. Delays due to cleaning, delays due to material waiting time, and delays due to inspection are similar across all projects.

6.2 Recoverable Delay Analysis

A similar radar graph is plotted to compare and analyse the various recoverable delays for the four projects. Figure 2: Comparative analysis of recoverable delays summaries the significant recoverable delays for various categories across the four projects and the results contribute to understating the major causes for the delays.

Figure 2 shows the amount of recoverable delay incurred for projects 1, 2, 3, and 4 based on the percentage delays. It indicates idle time delay has the highest value across the four projects polylines with an average of 21.17% of the total recoverable delay varying between 15.33% for project 3 and 29.32% for project 1. The second major delay observed was personal breaks taken during working hours with the highest score of 18.42% for project 4 and the lowest of 12.47% for project 3, while project 1 and project 2 had a similar value of 14.3%. On the hand, recoverable delays such as waiting for co-workers and a late start was 5% which could be eliminated by applying suitable Lean techniques. The value of delays caused by discussions, waiting for tools, and repetitive labour were nearly similar for the four project polylines but were insignificant compared to the major two recoverable delays. Hence, these two

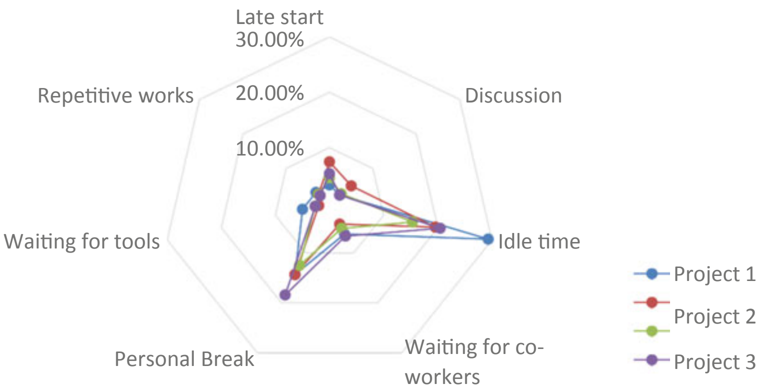

Fig. 2 Comparative analysis of recoverable delays

primary delays must be eliminated by the application of suitable Lean practices on the site.

7 Research Findings

Two types of delay categories, such as supportive and recoverable, were discussed in the above data analysis with their respective delay subtypes. This section discusses the top two subtypes in both delay categories, and the plausible solutions to mitigate these most frequently occurring delay types.

The delay subtype material/tool mobilization at 23.30% and receiving/giving with Instructions at 21.22% were found to have a significant impact in the supportive delay's categories. The supportive delay percentage across four projects can be seen in the graphs below.

Material/tool mobilization can be improved upon by planning the tasks such that all the constraints are resolved before the commencement of the task. Planning techniques such as location-based planning and collaborating planning systems like the Last Planner System (LPS) that involve the actual site workers' inputs and commitments in the planning can help resolve issues at the onset, unlike push-based planning systems. Technologies like virtual design and construction, building information modelling, and 4D visualization can enhance plans with informative models and such model simulations can make the task flow visible. Such tools can help in virtual rehearsal of the task along with sequencing before actual site commencement, which would facilitate proactive/advanced material/tool mobilization (Fig. 3).

The delay caused by the receiving/giving instructions represents the hours lost through interruptions during the tasks for information dissemination. Daily huddles with the work crew could be included as part of the project team meetings and would ensure their participation and prompt communication. The work crew can address issues during daily huddles and avoid missing targets. Huddles also provide the team with a chance to assess their successes from the day before and establish goals for the next. The instructions must be clearly stated and described in the standard operating procedures (SOP) to restrain unnecessary repetitive communication. The SOP serves as a reference for the future and can thus enhance sustainability.

Similarly, the two most prominent delay subtypes identified in the recoverable delay category are idle time at 39.33% and personal breaks at 27.67%. The recoverable delay percentage across the four projects can be seen in the graphs below.

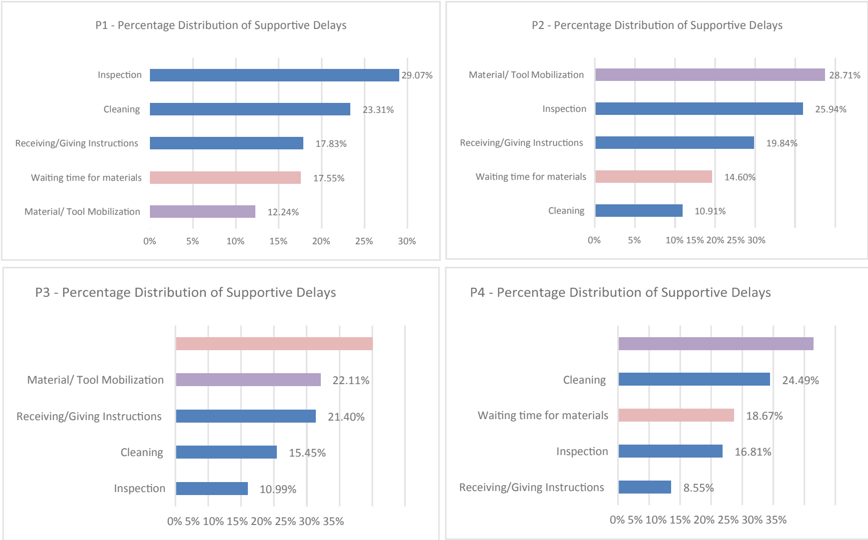

Fig. 3 Percentage distribution across supportive delays

The data collected poses the question of "Why" and "How" are these delays caused? Inefficient management of construction resources like materials, manpower, and equipment can result in low productivity. Therefore, contractors and construction managers need to evaluate the performance for the efficient utilization of resources [5] (Fig. 4).

The performance of the labour has a direct correlation with four environmental factors associated with hot weather—temperature, humidity, radiant heat, and wind speed. It was shown that excessive heat exposure during the peak summer season causes weariness and leads to more frequent personal breaks to fight heat stress [6].

The challenge identified in this paper points to the urgent need to understand how the project manager can address these challenges for creating tolerable working conditions that would eventually increase the worker's productivity in any workplace. One policy to address this issue is to adjust work hours to early morning or late-night shifts to avoid working during peak midday hours.

The integration of modern technology at the construction site is one of the latest trends to for monitoring labour performance levels during site operation. The issue is how real-time tracking not only improves production control but also enables measuring the performance level of site operations on daily basis [7].

"The worker progress can be monitored and site problems can be tacked on time by the adoption of remote monitoring technology. Wireless tracking systems such as Bluetooth low energy (BLE), sensor-based technology such as radio frequency identification (RFID), and other forms of long-distance communication such as ZigBee can help in live monitoring of the workspace. Such technology can help integrate sensor data collected from multiple sources into operational, tactical, and strategic

Fig. 4 Percentage distribution across recoverable delays

decision-making, thereby assisting the project manager to make real-time changes that improve worker performance. The GPS technology is suitable and efficient for outdoor spaces while BLE technology is an appropriate solution for resource tracking in indoor construction.

The observations highlight the fact that there is a need for the adoption of a system that enables monitoring production performance daily to tackle the problem of the major two delays caused on a construction site [7].

8 Conclusion

The objectives of this paper were to analyse the faults and communication gaps in existing real estate projects that influence last-person output and how the use of Lean technologies could help minimize them. Surveys were conducted at four construction sites in Ahmedabad and the results were analysed. Each construction site had specific attributes that affected activity and man-hours.

We concluded the following from a cumulative analysis of various delays.

The maximum delays were caused by supporting activities like receiving and giving instructions and materials/tools mobilization. According to the analysis, in all four projects, receiving/giving instructions (21.22%) and material/tool mobilization

(23.30%) had a significant influence on supporting delays. Such delays can be avoided by involving the last persons in planning, implementing technologies, and using effective communication.

Similarly, the major delay identified in the recoverable delay category were idle time at 39.33% and personal breaks at 27.67%.

The recoverable delays can be reduced on the construction site by effectively allocating resources and assessing performance, both of which can be done by construction managers and contractors. There is an urgent need to understand the working conditions for labours and try to create tolerable working conditions by integrating modern technology on the construction site resulting in reduced workflow variability, analysis, and performance improvement. By the adoption of systems that enable daily monitoring of production performance, the two major delays in the construction sector can be significantly reduced.

In summary, our study presents an efficient method for understanding the factors that cause delays in the Indian construction sector, to stimulate discussions on current working situations and how they can be improved by integrating technology with Lean principles.

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Navigate Complexity Through Implication of the Last Planner System

M. Pandiaraja, Rahul Ruikar, Swapnil Tribhan, and Ramesh Bhandarkar

Abstract The success of every construction project depends on both effective project planning and execution. Production control is essential for making sure that everyone completes tasks according to the predetermined timeframe, regardless of the size or scope of the project. There are many task dependencies in construction projects, and alternate paths must frequently be followed to fulfil tasks and reach objectives. The last planner is regarded as a managerial strategy for effectively managing a construction project. The fundamental tenet of the method is to hold each contractor and subcontractor on a construction site accountable for the job they committed to doing while ensuring that they can manage their workload. This article will demonstrate how the Last Planner System and the Tasks Made Ready improve the accuracy of the weekly work planning for the road construction work carried out as part of our project. TMR is a reliable indicator of project length. This paper explains how pull sessions can be used by planners to remove limitations from the top-down level management approach process, how this affects the accuracy of construction planning, and how this affects project length.

Keywords Stakeholder commitments · Design · Engineering · Collaborative planning · Meetings

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1 Introduction

The organisation had planned to develop an industrial township in Khalapur, Raigad district area of the state of Maharashtra in order to suit the organisation's Business expansion needs. In order to receive the statutory approval needed by the state government body MSRDC, the completion of the road work inside of plot was extremely crucial and time sensitive. Additionally, a road's completion was necessary for access to transport materials needed for the construction of an industrial shed. The topography of the chosen plot was quite mountainous and required varied degrees of cutting and filling. Additionally, because that area is industrial, heavy vehicle traffic has an impact on the flow of supplies needed for road development. Variations in material delivery would have caused material to accumulate and be handled twice, which would have hampered timely completion of the work. Despite the fact that the Last Planner System is involved in all of the activities on the site, we have chosen the road construction works to highlight in this article for a better understanding of process flows.

2 Top-Down Flow of Last Planner System

As the moment for their involvement draws near, the Last Planner System incorporates the relevant stakeholders according to their drive roles as assigned by the organisation from each stage of a project into the planning process [1]. These people, known as the "last planners," may assist define more precisely how long each step of a building project will take, spot any possible problems, and ensure that work is finished on schedule. The Last Planner System's success is largely attributable to its emphasis on teamwork and defining goals. The range of meeting and project participants who attend meetings and provide every bit of effort to work at each level is shown in Fig. 1.

2.1 Master Planning

During the Annual Strategic Planning (ABP) process, which includes the master planning of works, Apex management of the business determines its strategic objectives. One of the main initiatives in the ABP process is the creation of the North Campus. As a result, as it falls under master planning, road construction work is included.

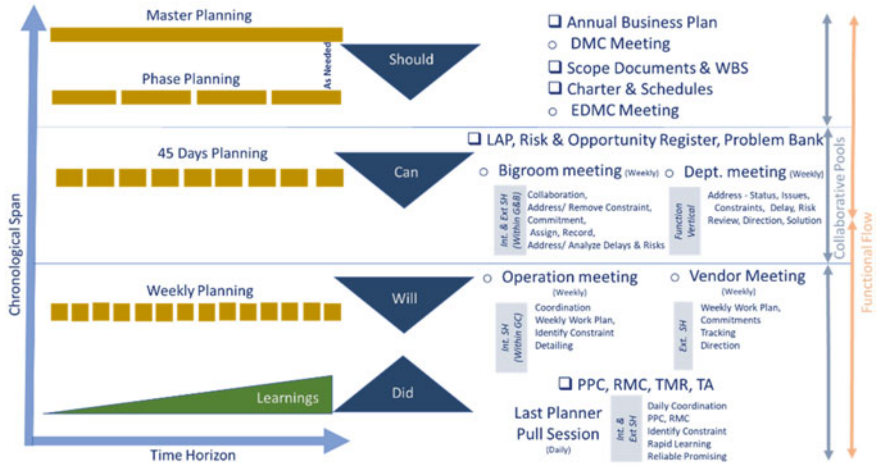


Fig. 1 Last planner system

2.2 *Phase Planning*

In this phase of planning, the specific scope, timetable, and work breakdown structures are created. Based on this information, a detailed Base Line Schedule is created and uploaded to the Project Monitoring System known as NPulse.

The activities are specifically listed throughout the schedule preparation process and categorised using the value stream mapping methodology. The following types of activities make up the microlevel planning and categorisation of the activities.

- Non-value-adding operations (NVA)
- Necessary but non-value adding (NNVA)
- Value adding (VA)

The WBS for the North Campus development project includes the road development work as a value-adding activity.

2.2.1 45 Days Planning/Look Ahead Planning

A connecting step between the master or phase schedule and the weekly work plan is called look ahead planning [2]. The 45-day look ahead plan is extracted from the NPulse monitoring tool. Big room meetings are crucial in this phase. The Big Room Meeting discusses the LAP as well as the status, delays, constraints, risks, and possibilities of each and every task. Using the Big Room helps the team communicate important information more effectively, gives everyone on the team access to the most recent versions of plans or designs, and encourages openness amongst the stakeholders of the organisation. This helps to cut down on time wastage and a lot of reworks.

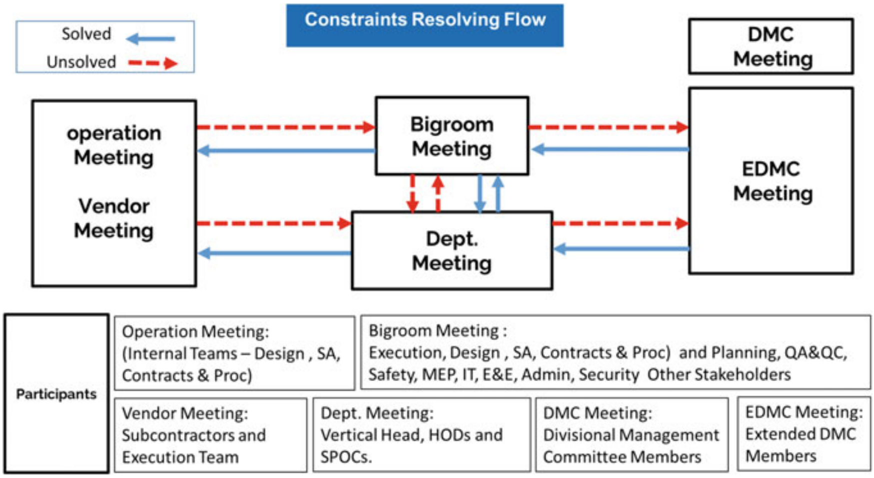


Fig. 2 Constraints resolving flow. *DMC—Divisional Management Committee consisting of Business/Section Heads, EDMC—extended DMC consisting of senior level managers of sections

The observation and any issues that need to be escalated are documented and brought up at the department meeting. Vertical Head is incharge of Dept meeting. The points for solutions, directions, modifications, and future issue escalation are considered in this meeting. Some of the tools for discussion from a progress monitoring standpoint include the NPulse Dashboard, Key Issues Tracker, and Kanban Board.

Figure 2 illustrates how different levels of involvement and collaboration between stakeholders occur. Meetings are set up technically and communicatively to help participants express their positions and commitments, escalate problems for resolution, and resolve problems in a bottom-up and top-down manner.

Tasks Made Ready (TMR) are identified and recorded in the NPulse (as Fig. 3). Here, the status of the project, its challenges, and its delivery are mentioned, along with the project's assignee and completion deadlines. The automated email system informs users of impending job responsibilities they must accomplish. This is accomplished through a cooperative exercise in which the project's stakeholders identify the tasks they will carry out and choose which project activity must be finished before the next one can start. Pull Planning, a technique borrowed from just-in-time delivery, is the advancement of workflows based on the timing and readiness of the next stage.

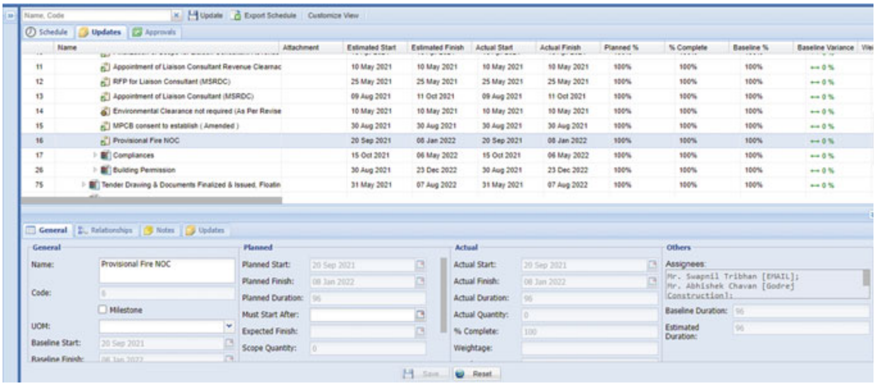


Fig. 3 Tasks made ready (TMR) are identified and recorded in the NPulse

2.3 Weekly Planning

The site-level operation of the Last Planner System starts during this weekly planning phase. LPS for project planning enables more precise planning as the execution date approaches, the identification of constraints during look ahead planning, and the removal of constraints in time to prepare work for execution; increasing the predictability of workflow.

Weekly schedules are created based on the LAP and current work commitments. The following measures are used to jointly evaluate the commitment plan.

Percent Plan Complete (PPC)—This analysis determines what percentage of the weekly tasks were accomplished.

Reasons for Missed Commitments (RMC)—This tracks the variance of the missed commitments and identifies categories of improvement to eliminate reoccurrence of a constraint.

Tasks Anticipated (TA)—This analysis simply measures how many tasks were identified for the upcoming week.

Last Planner System is implicated at following two levels in GC.

Operation Level.

Site Execution Level.

2.4 Operation Level

In operation meeting, the PPC of Execution, Design, Statutory approval, and Procurement and Contracts departments are discussed and mapped as in Fig. 4. Then teams have the weekly work plan, where they collaborate to plan each day's work. The point of maximum progressive elaboration is carried out to create reliable work plans. Also, vendor meeting is conducted for Progress review. For improved comprehension and greater clarity on workflow to prevent any rework, the execution engineers are given a detailed explanation of the problems involved in integrating electrical and MEP lines during the road laying process.

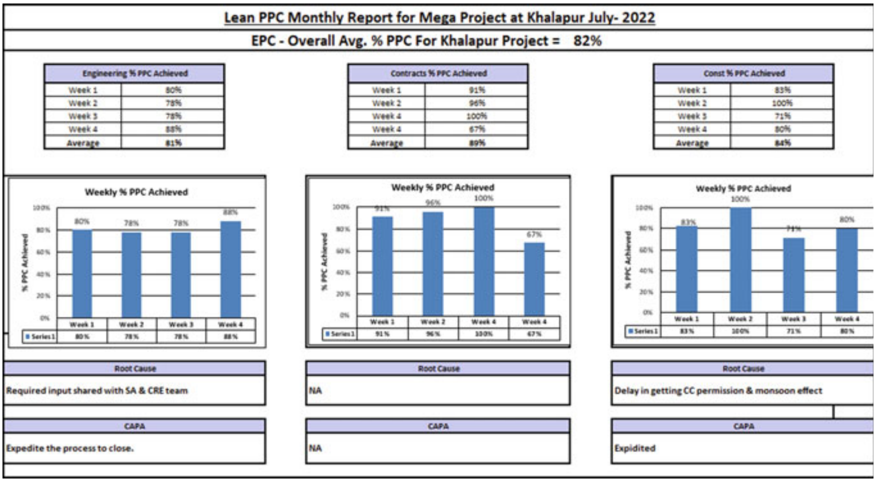


Fig. 4 PPC of execution, design, statutory approval, and procurement and contracts departments

2.5 Site Execution Level

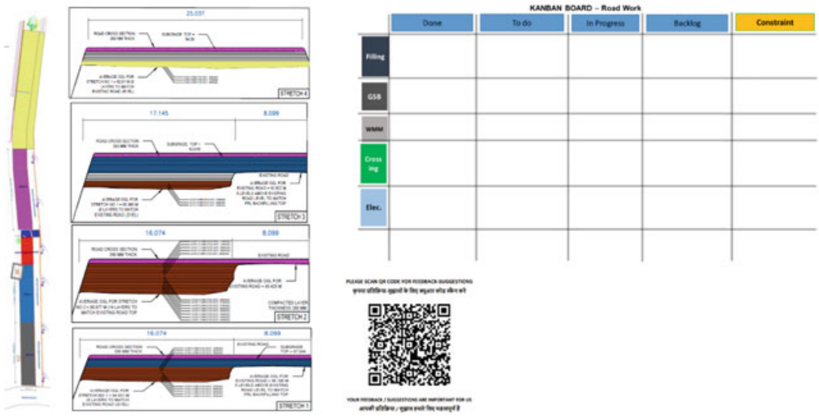
Understanding limits and minimising waste and rework are two benefits of **Tasks Made Ready (TMR)**. It so permits continuous flow and boosts productivity.

At the site, daily huddle sessions are held. In the meeting, daily work commitments and deliverables are addressed. Also present are execution engineers, MEP engineers, contractor's engineers, safety engineers, QA&QC engineers, supervisors, truck drivers, and excavator operators. The daily needs for the trucks, Murum, GSB, and WMM, have been meticulously prepared. The linear work flow was produced as a result of this prediction technique, despite the variable throughput requirements. The throughput needs were used to map the variance in road filling material delivery (i.e. Murum), GSB (granular sub-base), and WMM (Wet Mix Macadam), and effective traffic management was carried out through daily huddle meetings. With regard to the flow of heavy vehicles, peak hour, inward and outward procedures, and lead time, distinct traffic management plans are created and discussed daily.

At the site level, **visual management** is essential for helping participants understand their work areas, commitment dates, and committed quantities as well as for resolving concerns, restrictions, non-conformances, and risk [3]. For the benefit of all attendees to the meeting, road sections and drawings are displayed on the board together with information on the status of the current work and the proposed site for the next work.

Individual work tasks are mapped to sticky notes that are arranged in columns on a big board to create a **Kanban Board**. The columns on the board indicate the value stream, which is the orderly process that tasks or products must follow from conception to completion. Work items are listed on cards and put in the appropriate columns after being typed down.

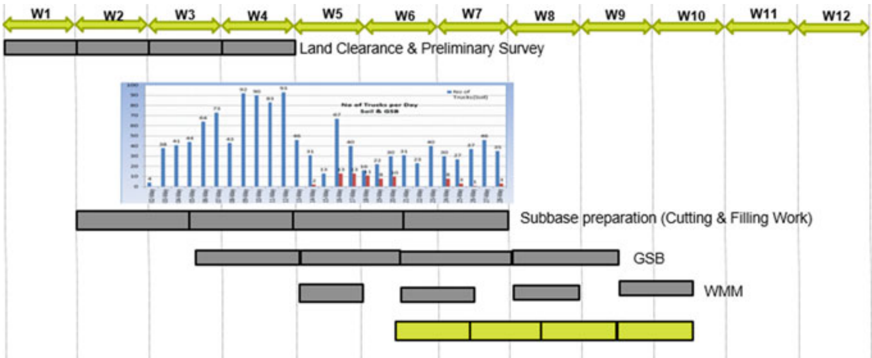
To arrange teams working on the same board, horizontal rows, also known as swimlanes, are employed. Different card colours are used for various work item kinds. As work advances, team members select cards and slide them through columns from left to right. Some columns have capacity restrictions to maintain efficient work flow.



Any feedbacks or improvements relating to the site can be escalated to the site incharge and the safety incharge since feedback and suggestions on the site are collected using the digital platform of Google Forms and a QR Code of Google form is pasted at board. I-Report, a mobile app, is used to report non-conformances and to close them.

3 Conclusion

A collaborative planning method called the Last Planner System enables better control and lowers unpredictability at the construction site [4]. The fundamental tenet of the method is to hold each contractor and subcontractor on a building site accountable for the job they committed to doing while ensuring that they can manage their workload. The Last Planner System and other Lean techniques were used, and they were very successful in hastening the work completion of road laying and delighting the stakeholders. The Last Planner System efficiently handled local administrative concerns, 22,000 cum of soil filling in a 1-km section of road levelling, culvert building, street light pole installation, chamber and trench line construction, tree replanting, and truck traffic (80 trips on average each day).



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Improving Productivity with Site-Based Training Setup at a Mega Construction Project

Ashish Kumar Saxena, E. N. Nihala, and V. Anand

Abstract Construction industry is one of the very few labor-intensive industries. Workmen is the most vital resource for any construction project. Unlike manufacturing industry, construction is end-to-end depended on the human resources. This makes the performance of the workmen even more critical for the success of any project. A good performing workforce can stand out from the crowd with visible results and motivation. This paper captures a short case study on the improvement in workforce productivity after establishing a site-based training (SBT) set up. The project under consideration has stringent timelines, and huge volume of work has to be executed. Considering the scope of work and the milestone deadlines, there is hardly any room for rework. Workmen productivity and skill play a very important role in this scenario. In the initial phase, the project faced a lot of problems pertaining to the productivity. Based on the trends in reducing productivity, workforce skill, and other miscellaneous factors, such as type of construction and location, the senior management anticipates a severe scarcity of the skilled workforce in the coming years. This paper covers the process implementation for root cause analysis, work sampling, etc., and further taking a preventive measure of establishing a site-based training setup that filters out the workforce based on the skill and not on mere mouth of word.

Keywords Site-based training · Skill development · Lean thinking · Productivity improvement

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1 Introduction

To achieve good customer service, more advanced productivity and quality management techniques adopted by management will provide means of improving productivity and quality and hence the overall organizational competitiveness. This directs the researchers and practitioners to appreciate productivity and quality improvement issues form needs and opportunities point of view. In modern times, the manager is responsible for not only the progress but the corresponding productivity and quality management functions and improvements. Various project level enablers have a range of impact of the workforce involvement. Factors such as appreciation, curiosity, and relationships play a vital role in project collaborations [1].

It has been witnessed and accepted by the practitioners that project-based environment has a very huge impact on the workforce productivity. As there is workmen movement across the state borders, there are many challenges faced which have negative impact on the performance. Common challenges faced by the construction workers as told by the construction workforce are as follows [2]:

- Technological and demographical changes;
- Change in people' values and beliefs;
- Change in team composition;
- Stringent project timelines;
- Changing proficiency, skill and competency requirements;
- Client pressure.

After taking into account the workmen skill as one of the major causes of poor performance (based on the site interviews and results of work sampling), the site management proposed to establish a site-based training (SBT) setup. The SBT is intended to facilitate the more rigorous skill-based screening of workmen and training of potentially skilled or semi-skilled workmen. The SBT induction was made a mandatory part of the workmen induction system.

2 Literature Review

Construction is one of the most labor-intensive industries in the world. It is regarded as the major contributor to the process of development. India, in particular, is experiencing the increase in infrastructure projects with an anticipated upsurge in employment in the construction sector. This accounts for the diversified roles of workmen in executing the works. Skill and knowledge are the main factors contributing the sustaining employment in the sector. This has consideration to the technological advancements growing at a rapid pace. People with better skills and knowledge effectively grab the opportunities. Furthermore, it takes extra effort for the engineer to make the workers understand about the working methodology and also and about the construction safety standards. Lack of basic knowledge poses a great barrier in such scenarios [3].

Training and development is the best method to improve the working and personal condition for the worker, industry, and nation at large. The project National Initiative for Promoting Upskilling of Nirman Workers (NIPUN), which is an initiative of Ministry of Housing and Urban Affairs (MoHUA), is running under the flagship program of Deendayal Antyodaya Yojana-National Urban Livelihoods Mission (DAY-NULM) with an objective of training over 1 lakh construction worker highlights the importance of skill development through training for the deprived classes (NIPUN scheme, MoHUA, GOI).

Many centers for skill development have been setup in India with collaboration of state and central governments along with the industry practitioners under various schemes such as Skill India, PMKY, ASEEM, etc. With one such vision, National Academy of Construction (NAC) was set up in Andhra to train the unemployed and unskilled workforce to make them suitable for the industry requirements [4–6].

3 Objectives

This paper encompasses the exercises carried out by the project site team in identifying the causes of poor performance and devising a systematic procedure to resolve the same. Broadly, the study covers the following objectives:

Identifying the root cause of below-par performance;
Establishing a site-based training setup as a part of the workmen induction system;
Evaluating the impact of SBT on productivity improvement.

4 Waste Identification

Contemplating the sudden necessity to execute huge volume of work, there was an immediate requirement for large number of workmen. Efforts were put in to mobilize the large workforce in the limited time. In such stringent timelines and because of the high work-pressure for execution, the workmen were inadequately screened and put in the work location immediately after a short questionnaire. This had impact on the workmanship due to inadequate skill of the workforce deployed. There was in fact the inverse correlation between the number of workmen and the activity productivity. This led to various brainstorming sessions with site team and management and the supervisors.

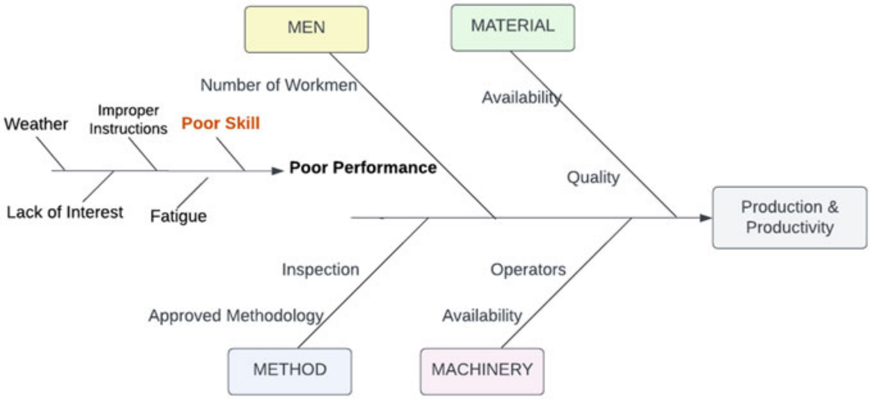

Fig. 1 Cause-and-effect diagram for low performance of RCC works

5 Lean Tools for Identifying Wastes

Lean tools such as work sampling, root cause analysis and multiple brainstorming sessions were deployed to the work locations and made a part of the BIG Room meetings. After multiple sessions and monitoring, it was deduced that since the major cause of the reduction in the productivity is the skill, and there has to be a site-based training (SBT) setup established for adequate screening and further training if required.

Based on the major causes of poor performance as implicated by the cause-and-effect diagram (Fig. 1), work sampling was done at various locations to deduce the major cause. Figure 2 shows the results of compiled work sampling results. The results show that major factor for the poor performance was the workmen itself. Around 38% of the cases, the non-value addition were attributed to "Men." When the work sampling results were drilled down to understand the major contributors (pertaining to the workforce), it was observed that in most of the cases, either the workmen were not able to understand the instructions or they lacked the required skill.

Based on the studies conducted and the BIG Room meetings, considering the huge volume of quantities to be executed, a site-based training setup was established and was made a part of the workmen induction system to filter out the skilled or semi-skilled workmen from the workforce.

6 Introduction of "SBT" in Workmen Induction System

After carrying out waste identification exercises through lean tools such as RCA and work sampling.

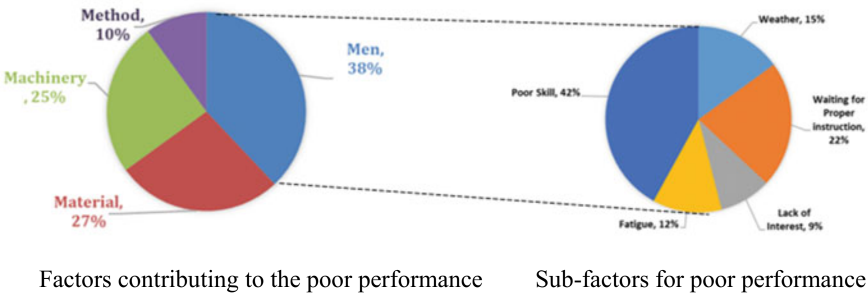

Fig. 2 Work sampling results capturing the factors and sub-factors of poor productivity

Figure 3 shows the comparison of the traditional and modified system of workmen induction after incorporating the SBT.

SBT is well-equipped with the classroom facilities, demonstrations, and facilities for practical sessions. Traditionally, the sub-contractor brings the workmen under two categories, i.e., skilled and unskilled or semi-skilled in a few cases. After the implementation of SBT, the workforce can be filtered as skilled, semi-skilled and the unskilled wherein, the semi-skilled workmen are given the on-job training (OJT) and monitored closely for their skill development.

This filtering allowed the following benefits:

1. The skilled workforce was filtered and can be engaged in the work accordingly.
2. Semi-skilled category enabled close monitoring of the workmen and thus leading to their skill development which is beneficial for the site as well as the workmen individually.
3. Built confidence in client that the quality of workmen is ensured during the mass mobilization.

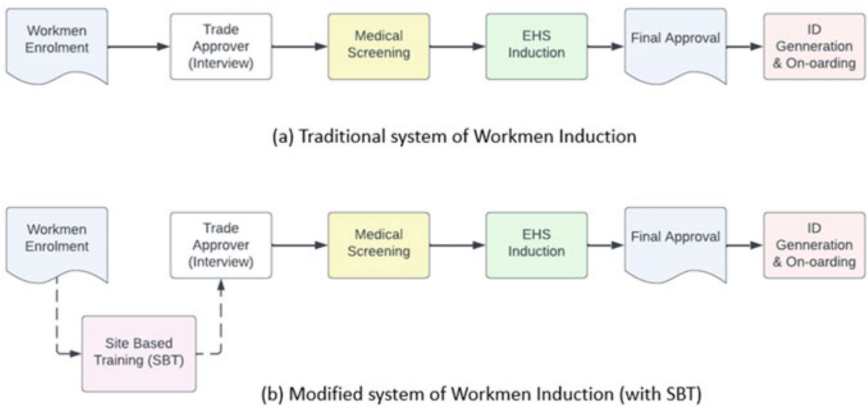

Fig. 3 Comparison of traditional and modified workmen induction system

Practical Interviews

Fig. 4 Workmen screening during the workmen induction program

Classroom Sessions Practical Sessions On-site Pep-talks

Fig. 5 Trainings during and after workmen induction program

4. Quality of work is ensured to a great extent.

Figures 4 and 5 show some of the site-level screenings conducted during the induction and for the workmen during the induction and progressively.

By adopting the screening system through SBT, the site was able to filter out the semi-skilled and unskilled workforce form the so-called skilled workforce. The bifurcation of the skilled workforce after the SBT screening is shown in Fig. 6. The percentages in the figure shows the percentage of skilled, semi-skilled, and unskilled workmen categorized from the workmen initially enrolled as skilled. For illustration, in the third month, out of the workmen enrolled as "skilled," only 38% of the workmen were identified as the "skilled workmen" and 31% as the semi-skilled. Remaining 31% were classified as the unskilled after the screening through SBT. The induction through SBT enabled the filtering of workmen based on the skill. SBT served as a preventive measure for correctly categorizing the workmen and thus inhibiting the anticipated productivity losses at the site.

Over a span of 10 months, the site was able to re-categorize the workmen based on the actual skill. This re-categorization facilitated to have a saving of an approx. 2% on the payment and also enabled a better allocation and distribution of workmen to the designated areas which improved the productivity. The PPC in Fig. 7 clearly shows the improvement over a span of past 10 months.

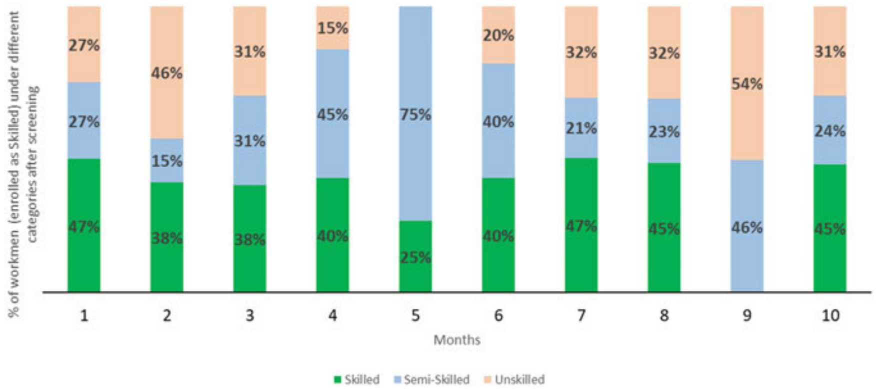

Fig. 6 Re-sorting of workmen as per the SBT screening procedure

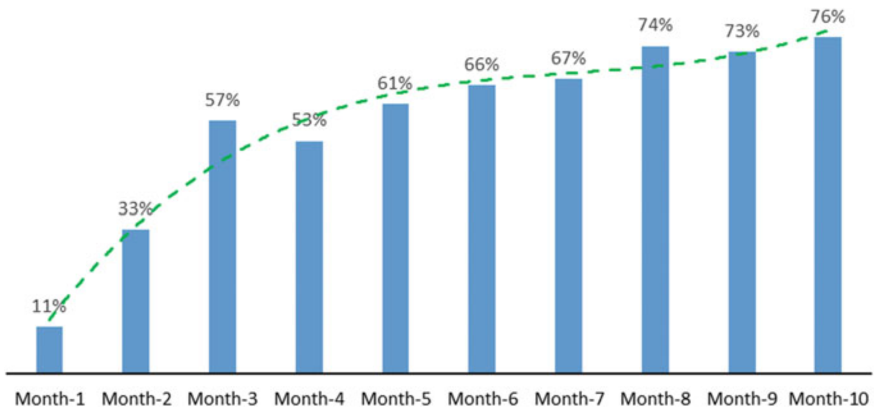

Fig. 7 PPC trend for 10 months

7 Results and Conclusions

Traditionally, monthly and weekly plans were prepared based on the workmen mobilization plans that had skill-wise number as conveyed by the sub-contractor and not on the actual skill. This was found to be the major reason of lower PPC in the initial months. After the workforce was started to be screened through SBT, it added more reliability to the skill.

The PPC (Fig. 7) also shows that the appropriate screening and allocation based on skill has a direct impact on the performance. The monthly plans were more reliable as it was based on the availability of skilled workforce and not merely on the number.

The introduction of site-based training setup has benefitted the site in the following manner.

Approximately 4000 workmen were screened through the SBT over a span of 10 months. This ensured the availability of skilled workforce at work locations.

Skill-based screening facilitated appropriate allocation of workmen.

Re-categorization enabled to have an approximate direct savings of 2% and further value addition based on the appropriate allocation of workforce.

Built confidence and reliability in the minds of client that further smoothen the project coordination.

8 Future Direction for Implementation

The site-based training setup has successfully resulted in filtering out the workforce based on the skill. Moreover, the categorization has also resulted in clear identification of the potential skilled workmen. These workmen are closely monitored and given the due training for their skill development. In future, such SBT setup at a mega construction project can act as a central screening center for the region. The setup can serve as a center for social upliftment through skill upgradation. This will contribute to the nation and society for excellence and sustaining the skilled workforce amid the anticipated shortage of workmen in the construction industry.

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Cycle-Time Improvement Through Collaborative Planning System

Ashish Kumar Saxena, V. Ramani, Praveen Reddy, and K. Ravichandran

Abstract Construction projects especially the residential projects suffer a huge delay due to miscoordination. As a construction project involves a large number of stakeholders, it demands a closed-loop collaboration and seamless coordination for a successful project completion. With more and more regulations such as RERA coming in, completing the project within the stringent timelines is inevitable. Collaborative planning system (CPS) is one of the most easy to understand yet most difficult to implement lean management concept for any construction project. CPS is a comprehensive lean management concept that encompasses the benefits of lean tools such as last planner system, big rooms, PPC, and root cause analysis. The site under study has shown a considerable savings in time in the overall phase through cycle-time tracking against the day-wise plan for typical floors. A combined result of utilizing the major lean tools enabled the project team to continuously achieve 6–7 days of cycle time. Further extending the micro-monitoring to above terrace works facilitated the completion in average 39 days against the pre-planned duration of 60 days. The implementation has resulted in a saving of approximate 50 days (12% time) for the phase which facilitated over-and-above cost benefits due to early demobilization of resources. This paper captures the comprehensive lean thinking and construction site-based implementations incorporating the lean tools.

Keywords Comprehensive cycle-time improvement · Productivity improvement · Collaborative planning system

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1 Introduction

Any construction project is a network of numerous small and big activities. The interdependency of these activities is of such a scale that any effect on a small activity may have a tremendous impact on a large activity. The project suffers a cascading effect due to change in even a small activity. It is evident from the visuals from a construction project that most of the time is wasted in non-value added (NVA) or non-value-added but necessary (NVAN) activities due to process inefficiencies. These network of inefficiencies have a cascading impacts on the project as a whole.

It is a general practice at construction project sites to revise the schedule frequently. A few of the major causes for the revisions are uncertainty on availability of resources, lack of clarity of instructions, incomplete information, etc. Many a times, this leads to delays or rework in other scenarios. The amount of follow-ups and coordination required in such projects is huge which leads to low productivity and cost overruns. These inefficiencies often lead to underutilization of resources.

2 Literature Review

Lean project management or lean project delivery system is a phased system of reducing wastes in processes and workings. In manufacturing, these phases are project definition, design, supply and assembly [1]. Contemplating the analogy in construction industry, these phases can be broadly divided as—project definition, design, planning (on-site), execution, and hand over. All these phases share a to-and-fro relationship during the project life cycle. As the project progresses, the feedback loop starts to accommodate more stakeholders that increase the chances of creation of more wastes (considering the delay in decision making). Lean principles thus aim for the continuous elimination of all types of wastes. One of the major causes as understood from the industry practitioners is that a lot of waste is generated in process due to lack of coordination and miscommunications at the dynamic construction sites. After reviewing the studies conducted on the fundamental lean principles and how they create wastes in manufacturing industry, similar wastes were observed in the construction industry as well. Simple and specified pathways, supplier–customer relationship, and coordination through rich communication are a few of the major lean principles which need special focus to have a smooth project life cycle [2].

3 Challenges to the Flow of Work

People are the main project drivers. Apart from being the biggest supporters, people are also the biggest resistance to any workflow. Thus, it becomes quite important to involve the people in decision making. It is evident from the current scenarios at any construction site that faces a huge challenge of lagging in inter-dependent activities. This is mainly due to the fact that most of the departments work in silos. Every function is considered as an independent activity and is planned individually. The feedback at a later stage hampers the flow of work that results in delays, cost overruns, penalties, and negative brand value.

Construction projects have witnessed tremendous changes in terms of complexity and size of projects over a span of few decades. Every construction project is unique in nature and involves large number of interrelated activities. This close-knit network of interdependency involves a large number of stakeholders such as owners, designers, contractors, sub-contractors, and suppliers. Thus, collaboration plays a vital role in success of any project. This involves dealing with large amount of information, and the correct information is made available to the correct stakeholder at the correct time [3].

Collaborative planning system or CPS is one of such tool that breaks the walls of the silos and facilitates a seamless flow of information and ideas across the functional and departmental boundaries.

4 Objective

The major focus of the study can be summarized in the below mentioned points:

1. To identify the bottlenecks in the process through brainstorming sessions and root cause analysis.
2. To establish a system of collaborative planning system that facilitates seamless exchange of information and ideas across the departmental boundaries.
3. To appreciate the benefits realized in improving the cycle time in a residential project due to implementation of comprehensive lean management principles.

5 Collaborative Planning System (CPS)

Collaborative planning system (CPS) is one the interesting and advanced collaboration system which has started finding its utilization in the Indian construction industry [4, 5]. Collaborative planning approach refers to establishing a practical framework incorporating the best practices from various management concepts such as project management and lean construction to have an improved communication, better coordination, and effective collaboration among project professionals from across the departments and organizations. CPS is basically application of practices followed in systematic and structured way which can significantly improve the project performance and workmen productivity. CPS has four levels of planning which includes reducing the monthly plan from the master plan, look-ahead plan from the monthly plan, and daily plan from the weekly plan. There are chances of weekly and monthly plan to get revised more frequently than the master plan.

In a construction project, the interdependency of people is much higher than any other industry. Project has to face a multiple issues like unavailability of workforce, delay in finalizing vendor, error in drawings, waiting for approvals, etc., which will lead to crisis and require firefighting unless these problems are identified at early stage, channelized to the right people and resolved jointly.

6 Implementation

A comprehensive planning system's implementation demands a thorough study of the processes and clarity on the activities and their correlations with the subsequent activities. CPS works on the feedback mechanism where the weekly plan is revised based on the percent plan complete (PPC). Figure 1 clearly depicts the schematic diagram of collaborative planning system implemented at a construction project.

In CPS, the main schedule is broken down into phased schedules with sub-milestones. The week in which the work is planned also addresses the backlogs of the previous weeks which is reviewed along with the look-ahead window of say typically 2 to 3 months.

Master construction plan is used to prepare the look-ahead plan which is actually the plan for next 60 or 90 days. Based on this look-ahead, a weekly (or monthly) plan is prepared that is tracked and updated on a regular intervals. With all the major stakeholders, micro or daily plan is prepared in consultation with the last planner [6]. Along with the plan, constraints are discussed, and the root causes for the past failures are deduced and discussed. Due responsibility is allocated for all the root causes and constraints. The progress is regularly updated on a kanban board. At the end of the week (or any pre-defined interval), the percent plan complete (PPC) is calculated which serves as the input for the weekly plan for future. PPC is used for checking the efficiency of the system and is kept improving all the time. It also enables the major factors for the failure through use of lean tools such as cause and effect

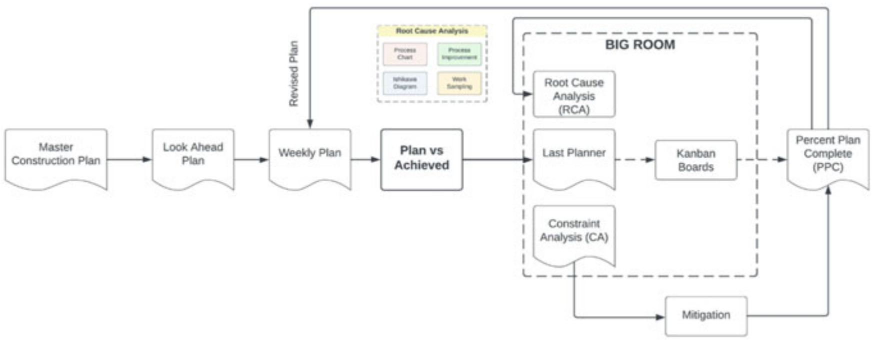


Fig. 1 Schematic diagram of collaborative system

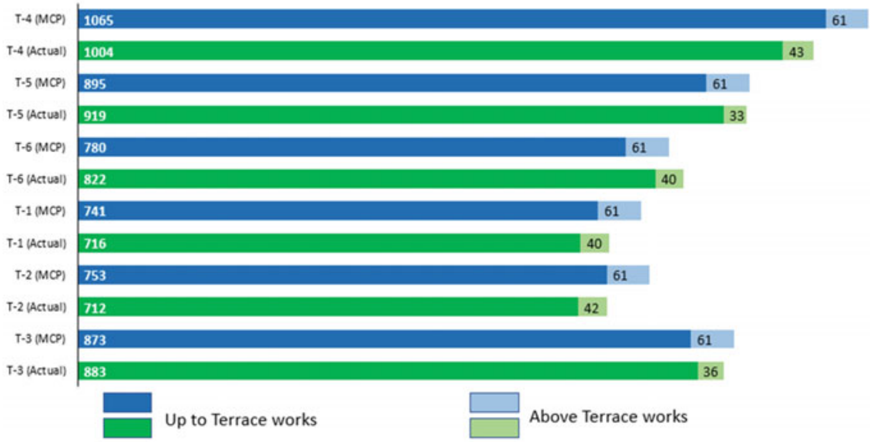


Fig. 2 Tower-wise tracking against the MCP

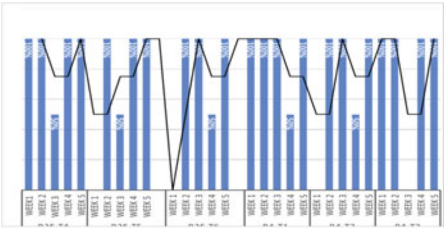
diagram, process charts, and work sampling. Finally, the big room meetings bring all the stakeholders in the same space along with the front-line supervisors. The essential planning involves the supervisors based on the inputs from other stakeholders such as resource managers, design team, project managers, and project controller. Furthermore, the progress is also tracked against the 10-days standard cycle-time template which is updated every day, the backlog is discussed in the morning (daily) huddles, and the issues are resolved.

The same tracking mechanism is followed throughout the project life. The impact of the micro-level monitoring can be deduced from the saving of 53 days for the phase. Figure 2 shows the actual duration taken to complete the various towers against the duration considered in the master construction program (MCP).

Various lean tools such as big rooms, last planner system, constraint analysis, and variation analysis were deployed, and the synergic impact of the tools were compared against the performance in similar projects and against the master construction plan. Figure 3 shows the various lean tools implemented at the project site for better management.

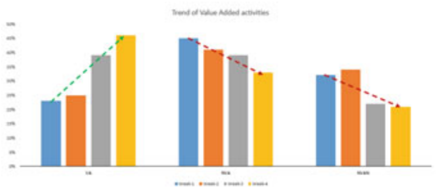
7 Results and Conclusions

Lean tools such as root cause analysis, constraint analysis, big room meetings, and last planner system enabled the project team to narrow down the major factors for the in-efficient process system. One of the major factors in the seamless flow of work is the lack of an efficient system communication and coordination. This also captures the fact that most of the information lies in silos that hinders the holistic decision making at the project level.

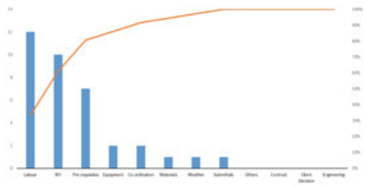


Percent Plan Complete (PPC)

Last Planner



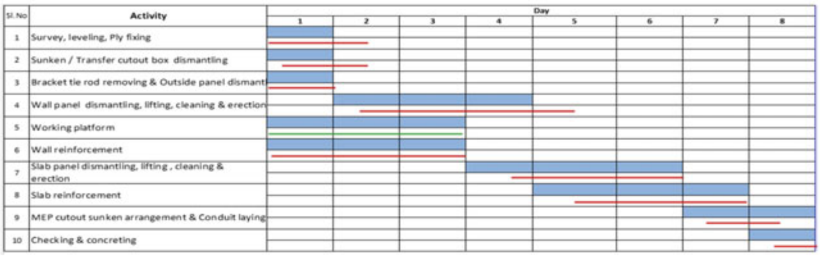
Work Sampling results for 4 weeks



Variance Analysis – Pareto Chart

S. No.	Activity	Constraints / Points	Constraints	Remedial action	Responsibility	Status
1	Bracket Fixing Work	Khalasi Gang (Nazrul Sheik) to increase Manpower	Delay in Bracket fixing acticity	Manpower augmentation required	Mr. Nazrul Sheik	Completed
2	Rebar Tying	Rebar Gang (Krishna Mondal) to increase Manpower	Delay in Rebar tying	Manpower augmentation required	Mr. Deepak	Completed
3	Concrete	Slab top level to be ensured during concreting	Undulations at slab top level - Rework	Top level check during concreting work thru Autolevel	Tower Incharge	Completed
4	Issue of Materials	Extended time wastage at stores to collect materials	Workmen idling	FW Consumables to be issued at once for every floor	FW Incharge	Completed

Constraint Analysis format



Cycle Time tracker

Workmen Appreciation

Big Room Meetings

Fig. 3 Various lean tools implemented as a part of collaborative planning system

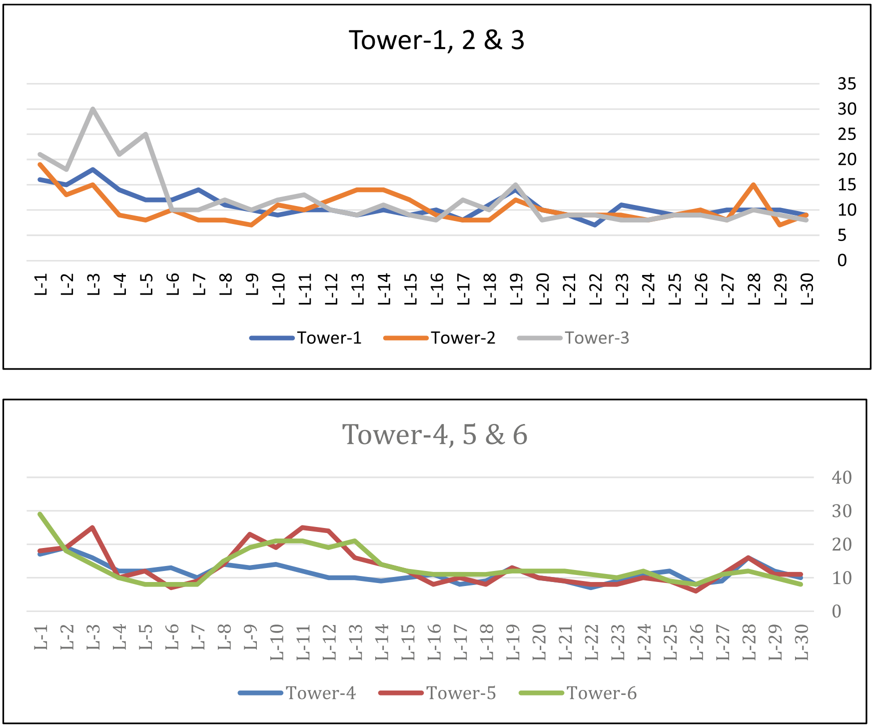


Fig. 4 Cycle-time trend

And the collaborative planning system is a team-based system where everyone becomes responsible to achieve the milestone by reducing process constraint. Overall the phase was completed 53 days ahead of the schedule.

Tower-wise cycle-time details are shown in Fig. 4.

The early completion had many benefits, and a few of the major ones are listed below:

- Early handing over to customer;
- Early demobilization of resources that enabled savings on indirect cost;
- Created a benchmark for the upcoming projects;
- Cultural change due to improved coordination and communication by breaking the silos;
- Reliability on resource planning was improved;
- Improved productivity through innovation as the external stakeholders are also involved and they bring diverse perspective into the process;
- Indirectly enhanced performance on ESG parameters such as controlling material waste and reduction in carbon emissions.

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Making Scrap Disposal System More Lean and Mean

Ashish Kumar Saxena, V. Ramani, and Praveen Reddy

Abstract Construction waste generation is inevitable at project sites. Though there have been advancements in the resource monitoring tools which have reduced the wastes considerably, but still, construction industry continues to be the major waste and scrap generator. The large quantity of scrap generated not only affects the environment but also has very severe impact on the project execution. As the building projects have interdependency of large number of activities and are related to have parallel operationality. Considering the logistic issues at a space-constrained project site like the one in this study, timely and efficient scrap disposal is crucial. To ensure this, a well-defined process chart is designed. Since the system involves a lot of approvals, reconciliations, and collaborations, this process chart facilitated rigorous follow-ups and timely identification of the bottleneck. The scrap disposal is reviewed along with the construction program to have seamless coordination and reverse-phased scheduling. With this incorporation, the project site was able to dispose approximately 1500MT of scrap in a planned manner which was in alignment with the construction program.

Keywords Scrap management · Reverse-phased scheduling · Logistic management · Constraint analysis

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1 Introduction

Construction sector is one of the major generator of waste and scarp. As per the study, approximately 50–60% of the is attributed to material and around 9–10% of the purchased material ends up as scrap [1]. With the limited space in project premises and stringent timelines, disposal of scrap has gradually become one of the most crucial aspect for success of any construction project. The scrap that is continuously getting generated along with the construction activity taking place in the surrounding needs to be taken out of the location for better space and resource management. Most of the times, it starts posing hindrances to the main activities due to poor logistics or space constraints that have arisen due to large volume of scrap that has got accumulated over a period of time. Furthermore, poorly managed logistics can be one of the most obvious and major factor in lost productivity [2]. As material and equipment forms a major share of the project cost, poorly managed materials and equipment consume between 60 and 70% of a project's total budget, and hence, it is one of the vital part of project management to manage these effectively [3, 4].

Construction scrap further poses hindrance to the execution of the surrounding activities as well. These kind of activities are generally considered as non-value-added activities considering their relation to the main activities. While these activities do not directly form the part of the construction program (neither activity nor sub-activity), these activities (should be treated as necessary activities) do affect the actual execution of work. The sub-sections of this paper presents the impact of micro-planning on the overall efficiency of the project.

2 Objective

Scrap disposal system is rarely considered as a part of project execution planning. Major focus is attracted toward scrap during the commissioning stage only. This leads to a lot of resources getting stuck for a longer time with minimum productivity or returns. This paper tries to fulfill the following objectives with a motive to formalize a system for scrap disposal:

1. Implementation of 5S audit system;
2. Strategically planning the scrap disposal considering the salvage value and logistic concerns;
3. Incorporating scrap disposal as a part of the execution of main activities;
4. Optimizing the scrap disposal system through robust planning and monitoring.

3 Research Methodology

Resource management plays a vital role in successful project completion. Even a minimum stay of resource, longer than anticipated may pose drastic cost implication on the project. The project under consideration is a residential project with space constraints due to densely populated locality. Contemplating the commencement of construction activities and their dependency on the site clearance a detailed plan was framed. This included 5S audits, and based on the findings of the audit, scrap was strategically demobilized. This further integrated the auctions, payments, approval systems, and physical lifting of material from site. The robust monitoring and control system enabled the team to surpass the bottlenecks in the whole process. The demobilization plan was prepared and acted upon to the whole process with a birds' view perspective. This guaranteed that the process is optimized as a whole and not in silos. This took care of the transition across the various systems (site level and system approvals) and facilitated efficient demobilization through parallel tracking of progress. This included follow-ups, daily tracker monitoring, and eliminating the bottlenecks.

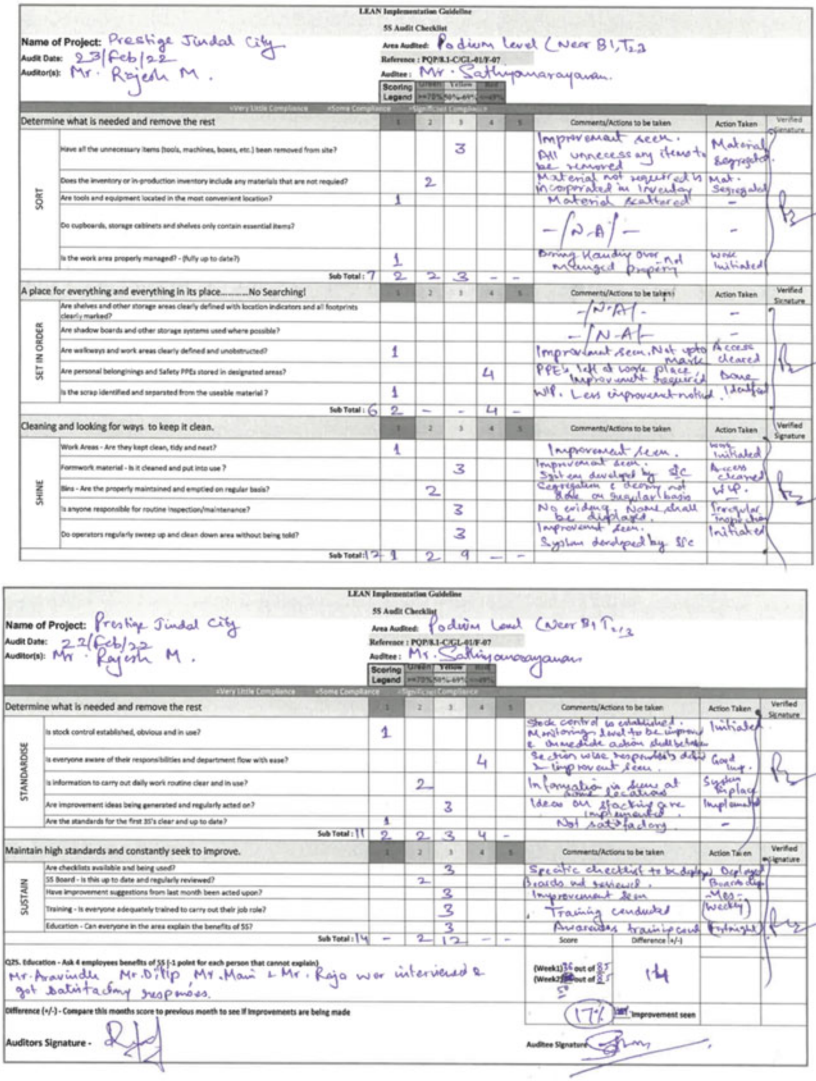
The study also encompasses the use of reverse-phased scheduling with the additional relationship provided to the scrap disposal without disturbing the completion (and handing over) commitments.

4 Importance of Focus on Scrap Disposal System

With the project timelines getting more stringent and the generation of scrap getting increased due to frequent change of instructions, there developed a demand of giving special focus on the logistics and timely scrap disposal system. This was also intended to facilitate the execution of main activities without any hindrance caused.

Scrap disposal has always been given the lower priority in a construction project. It is considered as the non-value-added activity, but the study has identified it as a non-value-added but necessary (NVAN) activity and mapped it to the schedule of the main activities. A well-defined plan was prepared and followed till the lifting of material.

As a part of the regular practice, 5S audits were conducted (Fig. 1) and poor score highlighted the access-related issues and constraints related to working space. The scrap disposal system was plotted on a process chart with well-defined responsibilities. With rigorous follow-ups and systematic planning, the number of days for scrap disposal was monitored and optimized as per the company norm. Furthermore, the same was linked to the construction schedule.



LEAN Implementation Guideline
5S Audit Checklist

Name of Project: Prestige Jindal City
Audit Date: 23/Feb/22
Auditor(s): Mr. Rajesh M.
Area Audited: Podium Level (Near B1, T2,3)
Reference: PQP/8.1-C/GL-01/F-07
Auditee: Mr. Sathyanarayanan.

Scoring Legend	Green	Yellow	Red
	>=70%	50%-69%	<=49%

	Determine what is needed and remove the rest	1	2	3	4	5	Comments/Actions to be taken	Action Taken	Verified Signature
SORT	Have all the unnecessary items (tools, machines, boxes, etc.) been removed from site?			3			Improvement seen. All unnecessary items to be removed	Material segregated.	
	Does the inventory or in-production inventory include any materials that are not required?		2				Material not required is incorporated in Inventory	Mat. Segregated	
	Are tools and equipment located in the most convenient location?	1					Material Scattered	-	
	Do cupboards, storage cabinets and shelves only contain essential items?						-/N-A/-	-	
	Is the work area properly managed? - (fully up to date?)	1					Bring Handing over not managed properly	Work initiated	
	Sub Total : 7	2	2	3	-	-			
	A place for everything and everything in its place........No Searching!	1	2	3	4	5	Comments/Actions to be taken	Action Taken	Verified Signature
SET IN ORDER	Are shelves and other storage areas clearly defined with location indicators and all footprints clearly marked?						-/N-A/-	-	
	Are shadow boards and other storage systems used where possible?						-/N-A/-	-	
	Are walkways and work areas clearly defined and unobstructed?	1					Improvement seen. Not upto Mark	Access cleared	
	Are personal belongings and Safety PPEs stored in designated areas?				4		PPE's left at work place. Improvement Required	Done	
	Is the scrap identified and separated from the useable material?	1					W.I. Less improvement noticed.	Identified	
	Sub Total : 6	2	-	-	4	-			
	Cleaning and looking for ways to keep it clean.	1	2	3	4	5	Comments/Actions to be taken	Action Taken	Verified Signature
SHINE	Work Areas - Are they kept clean, tidy and neat?	1					Improvement seen.	Work initiated	
	Formwork material - Is it cleaned and put into use?			3			Improvement seen. System developed by S/C	Access cleared	
	Bins - Are the properly maintained and emptied on regular basis?		2				Segregation & clearing not done on regular basis	WIP.	
	Is anyone responsible for routine inspection/maintenance?			3			No evidence. Name shall be displayed.	Regular Inspection	
	Do operators regularly sweep up and clean down area without being told?			3			Improvement seen. System developed by S/C	Initiated	
	Sub Total : 12	1	2	9	-	-			

LEAN Implementation Guideline
5S Audit Checklist

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Audit Date: 22/Feb/22
Auditor(s): Mr. Rajesh M.
Area Audited: Podium Level (Near B1, T2,3)
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Auditee: Mr. Sathyanarayanan

	Determine what is needed and remove the rest	1	2	3	4	5	Comments/Actions to be taken	Action Taken	Verified Signature
STANDARDISE	Is stock control established, obvious and in use?	1					Stock control is established. Monitoring level to be improved & immediate action shall be taken	Initiated	
	Is everyone aware of their responsibilities and department flow with ease?				4		Section wise responsibility defined & improvement seen.	Good Imp.	
	Is information to carry out daily work routine clear and in use?		2				Information is seen at some locations	System in place	
	Are improvement ideas being generated and regularly acted on?			3			Ideas on stacking are implemented	Implemented	
	Are the standards for the first 3S's clear and up to date?	1					Not satisfactory	-	
	Sub Total : 11	2	2	3	4	-			
	Maintain high standards and constantly seek to improve.	1	2	3	4	5	Comments/Actions to be taken	Action Taken	Verified Signature
SUSTAIN	Are checklists available and being used?			3			Specific checklist to be displayed	Displayed	
	5S Board - Is this up to date and regularly reviewed?		2				Boards not reviewed.	Boards disp.	
	Have improvement suggestions from last month been acted upon?			3			Improvement seen	Meg.	
	Training - Is everyone adequately trained to carry out their job role?			3			Training conducted	(Weekly)	
	Education - Can everyone in the area explain the benefits of 5S?			3			Awareness training conducted	Fortnightly	
	Sub Total : 14	-	2	12	-	-	Score	Difference (+/-)	

Q25. Education - Ask 4 employees benefits of 5S (-1 point for each person that cannot explain)
Mr. Aravindh, Mr. Dilip, Mr. Mani & Mr. Raja were interviewed & got satisfactory responses.

(Week1) 36 out of 85
(Week2) 50 out of 85
Difference: 14

Difference (+/-) - Compare this months score to previous month to see if improvements are being made
17% Improvement seen

Auditors Signature -
Auditee Signature

Fig. 1 5S audit report

5 Composition of Scrap

Construction projects typically constitute of variety of materials. These include concrete debris, rebar, formwork material, chutes, drums, etc. The vendors also vary as per the type of material and hence the lead time. Composition of the scrap for the project under consideration shown in Figs. 2 and 3 shows some real pictures which shows the different types of scrap available at project site.

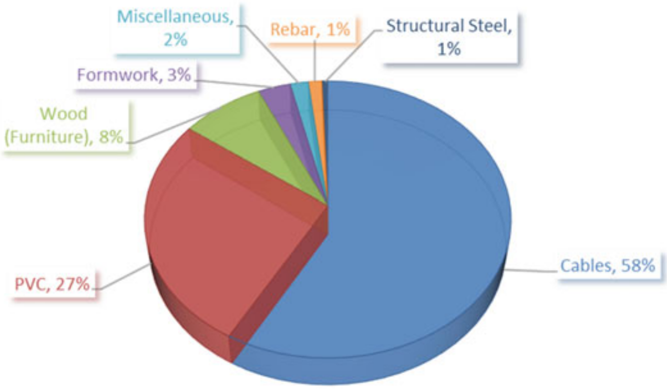

Fig. 2 Composition of scrap (by weight)

Fig. 3 Composition of scrap. *Source* A residential project, Bengaluru

6 Scrap Disposal System

Scrap disposal framework (Fig. 4) is one of the most crucial and yet overlooked process in construction industry. Facilitating a timely disposal of the scrap not only ensures that the logistics at the site are maintained but also the salvage value is realized upfront.

The site first declares the material as scrap with an official intimation to the regional office and issues a manual scrap disposal request (SDR). From the date of SDR, the inspection gets scheduled for 4 days. After the inspection, an e-auction happens, and after the due approval from operations, procurement, and accounts team, an intimation is sent to the vendor for payment. Once the headquarters confirms the payment, a sales order is issued which is shared to the vendor and HQ for delivery challan (DC) linking. This is followed by scrap lifting which may continue for multiple days, post which system DC is generated and invoice is created by the site accountant. After the invoice is approved and reconciled for taxes, it is issued to the vendor which completes the cycle of scrap disposal for the raised request.

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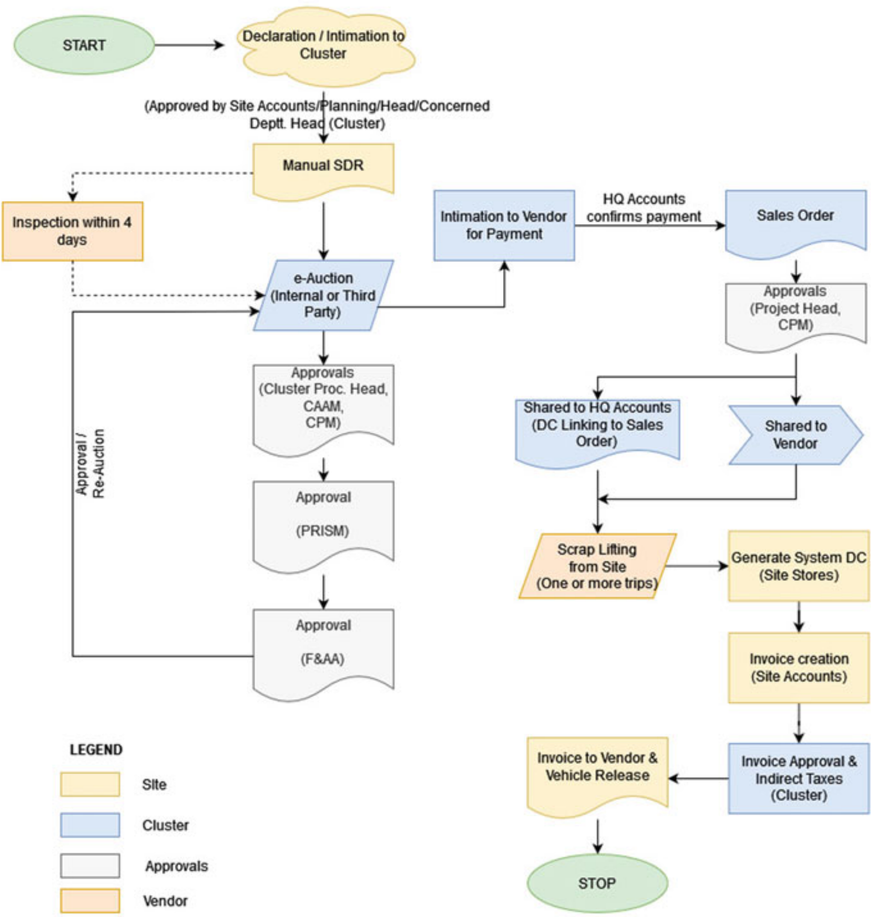


Fig. 4 Scrap disposal system framework

after the due approval from operations, procurement, and accounts team, an intimation is sent to the vendor for payment. Once the headquarters confirm the payment, a sales order is issued which is shared to the vendor and HQ for delivery challan (DC) linking. This is followed by scrap lifting which may continue for multiple days, post which system DC is generated and invoice is created by the site accountant. After the invoice is approved and reconciled for taxes, it is issued to the vendor which completes the cycle of scrap disposal for the raised request.

The site first declares the material as scrap with an official intimation to the regional office and issues a manual scrap disposal request (SDR). From the date of SDR, the inspection gets scheduled for 4 days. After the inspection, an e-auction happens, and after the due approval from operations, procurement, and accounts team, an intimation is sent to the vendor for payment. Once the headquarters confirm the payment, a

Item Descreption	Quantit	UOM	Received at Cluster	Target for completion	No. of Days from SDR Received	Left over days from Target date	Auction Date	Status								Vendor Name	Current Status
								Cluster Proc.	Cluster CPM	Cluster CAAM	HQ - Proc.	HQ Accounts	Payment Received	DOD Created	Material removed from Site		
wooden H Beam Scrap	40	MT	11-May-22	08-Jun-22	192	164	17-May-22	√	√	√	√	√	X	X	X		8 mt lifted Vehicle will be placed today,
Miscellaneous Scrap	15	MT	14-May-22	11-Jun-22	189	161	27-May-22	X	X	X	X	X	X	X	X		Auction completed
Debris chute scrap	120	Nos	14-May-22	11-Jun-22	189	161	27-May-22	X	X	X	X	X	X	X	X		Auction completed
Structural steel Scrap	15	MT	14-May-22	11-Jun-22	189	161	27-May-22	X	X	X	X	X	X	X	X		Auction completed
TMT Scrap	30	MT	21-May-22	18-Jun-22	182	154	27-May-22	X	X	X	X	X	X	X	X		Auction completed

Fig. 5 Daily scrap disposal tracker

sales order is issued which is shared to the vendor and HQ for delivery challan (DC) linking. This is followed by scrap lifting which may continue for multiple days, post which system DC is generated and invoice is created by the site accountant. After the invoice is approved and reconciled for taxes, it is issued to the vendor which completes the cycle of scrap disposal for the raised request.

Based on the process shown in figure, a daily tracker was prepared and used for the follow-ups with the concern. This captured quantity and type of scrap, date of declaration, and the target date for completion, i.e., 28 days from the date of SDR creation. This tracker also projected the status of approvals at different levels which facilitated the approval process.

7 Scrap Disposal Tracking

As the scrap disposal process is a hybrid system of on-site and off-site workings, a detailed process mapping and tracking the lead time or service-level agreement (SLA) is required to be monitored. The daily tracker is shared with the concerns on daily basis. With regular follow-ups and micro-level tracking, the scrap was disposed in a more efficient manner. Figure 5 shows daily tracker followed for the scrap disposal from the regional office based on the process explained in Fig. 4.

8 Incorporating Logistics in Construction Program

Typically, any construction project starts from the activities which are considered in the work order or the payment schedules. With scrap getting generated in huge volumes, it is inevitable to keep prolonging the disposal which will hamper the progress of the surrounding activities.

Many faced delayed start or intermittent halts. Work sampling technique along with the brainstorming sessions was used to identify the main cause of the delay in the main activities' execution. Results persuaded to link the scrap removal to the relevant activity as a predecessor or as applicable. The scrap disposal was made a part of the construction program with necessary relationship (finish-to-finish or start-to-start). This reverse-phased schedule made the with finish-to-finish relationship. After carrying out brainstorming sessions and relating it to the lean wastes (Table 1), these traditionally considered non-value activities (NVA) were now considered as non-value-added but necessary (NVAN) activities.

The scrap disposal and logistics constraints are incorporated in the construction schedule for more reliable planning. As clear from Fig. 6, scrap disposal activity is added as a predecessor of the main job activities to ensure the dependency and resource planning.

The same thought was replicated while repairing these schedules for the connected activities. Figure 7 shows the inclusion of scrap disposal activity in the external development activities in the reverse-phased construction schedule. This schedule is based on the final date as committed for handing-over. This considers the project final date as the hard-stop deadline.

Table 1 Lean wastes generated due to scrap accumulation near construction activity

Lean waste	Waste identified	Description	Root cause
Traveling	Yes	Taking longer routes for machinery, material and manpower pavement	Heap of scrap material accumulated on/near the work location
Waiting	Yes	Longer lead to shift material to the designated area	
Inventory	Yes	Increase due to delay in material shifting and slow progress	
Movement	Yes	Wasting energy and time	
Over-production	No	–	
Defects	No	–	
Excessive processing	No	–	

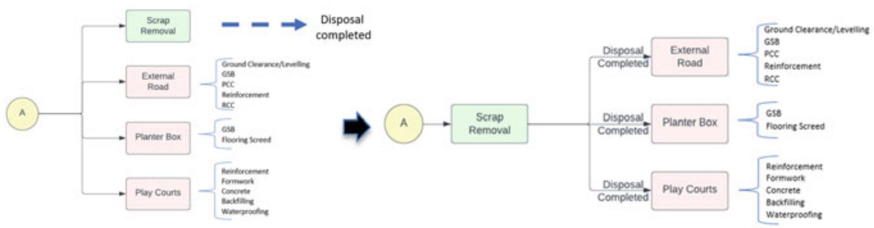
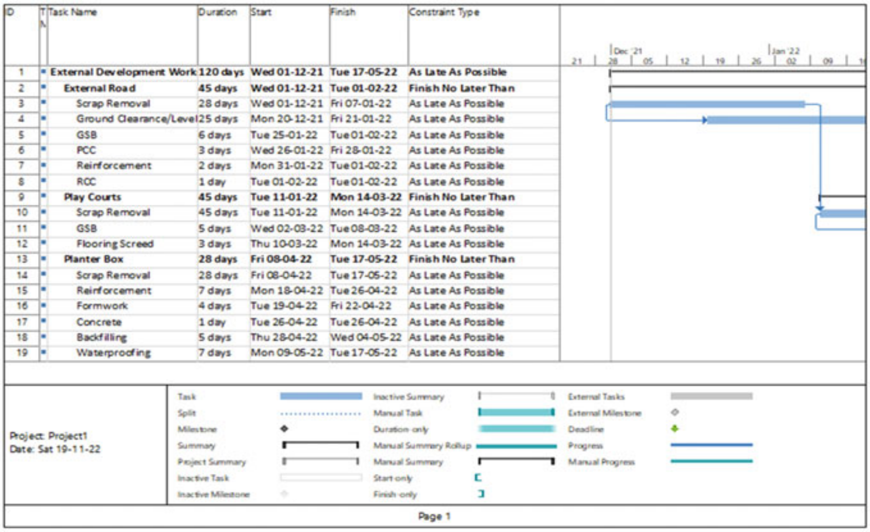


Fig. 6 Incorporating scrap disposal as a part of the construction program



ID	Task Name	Duration	Start	Finish	Constraint Type
1	External Development Work	120 days	Wed 01-12-21	Tue 17-05-22	As Late As Possible
2	External Road	45 days	Wed 01-12-21	Tue 01-02-22	Finish No Later Than
3	Scrap Removal	28 days	Wed 01-12-21	Fri 07-01-22	As Late As Possible
4	Ground Clearance/Level	25 days	Mon 20-12-21	Fri 21-01-22	As Late As Possible
5	GSB	6 days	Tue 25-01-22	Tue 01-02-22	As Late As Possible
6	PCC	3 days	Wed 26-01-22	Fri 28-01-22	As Late As Possible
7	Reinforcement	2 days	Mon 31-01-22	Tue 01-02-22	As Late As Possible
8	RCC	1 day	Tue 01-02-22	Tue 01-02-22	As Late As Possible
9	Play Courts	45 days	Tue 11-01-22	Mon 14-03-22	Finish No Later Than
10	Scrap Removal	45 days	Tue 11-01-22	Mon 14-03-22	As Late As Possible
11	GSB	5 days	Wed 02-03-22	Tue 08-03-22	As Late As Possible
12	Flooring Screed	3 days	Thu 10-03-22	Mon 14-03-22	As Late As Possible
13	Planter Box	28 days	Fri 08-04-22	Tue 17-05-22	Finish No Later Than
14	Scrap Removal	28 days	Fri 08-04-22	Tue 17-05-22	As Late As Possible
15	Reinforcement	7 days	Mon 18-04-22	Tue 26-04-22	As Late As Possible
16	Formwork	4 days	Tue 19-04-22	Fri 22-04-22	As Late As Possible
17	Concrete	1 day	Tue 26-04-22	Tue 26-04-22	As Late As Possible
18	Backfilling	5 days	Thu 28-04-22	Wed 04-05-22	As Late As Possible
19	Waterproofing	7 days	Mon 09-05-22	Tue 17-05-22	As Late As Possible

Fig. 7 Reverse-phased schedule for external development works

9 Results

Various lean tools such as root cause analysis, 5S, waste identification, work sampling, reverse-phased scheduling, and big room meetings were implemented and used to optimize the operational time and the flow of work.

With rigorous follow-ups and effective coordination clustering the approval system through parallel approvals and timely feedbacks, there was a visible improvement on the operational scrap disposal time and further project operation. Major benefits can be summarized in the following points:

1. The time taken to dispose the scram nearly became one-third. The month-wise trend is shown in Fig. 8. Though there were other supporting factors contributing to mass demobilization as well such as vendors' willingness and workmen availability, the major impact can be attributed to the robust tracking of approvals and monitoring till the demobilization.
2. With timely scrap disposal, it could be sold at a higher salvage value (than the depreciated vale at a later stage).
3. Reverse-phased scheduling ensured a system of channelized effort and energy. This also facilitated timely completion of work.
4. Clean and scrap-free material ensured the following compliances as well:
   - (a) Clean, tidy, and healthy workspace;
   - (b) Reduced exposure to potential hazards;
   - (c) Encouraged better working conditions;
   - (d) Improved productivity and reduced operational cost.

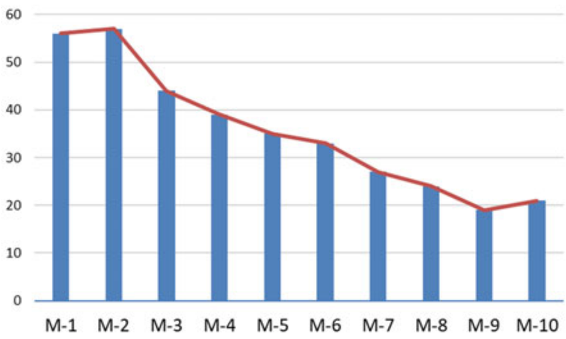


Fig. 8 Monthly trend for number of days required for Scrap Disposal

10 Conclusion

The study captures the robust monitoring of scrap disposal system and incorporating the same in the project schedule as a predecessor activity to the main construction work. The results have aided the overall understanding of the project activities and the importance of NVAN activities in alliance with the value-added activities. The modified approach has been able to reform the thinking of the project team, and the learning is continuing with the similar approach for other operational functions as well. The indirect benefits such as productivity improvement and timely completion organized work location and have provided added cost benefits and have helped in modifying the approach of the individual and team to plan the project as a whole instead of separate activities and work toward total project excellence.

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Integration of BIM and Lean Implementation in the Construction Industry—A Literature Review

Saurabh Jindal, Indrasen Singh, and Venkatesan Renganaidu

Abstract Building information modelling (BIM) has evolved in recent years to become much more than a simple simulation and information-sharing tool. The coordination between numerous construction-related components has been enhanced owing to this technology. Construction sector harnesses the potential of BIM for client-driven requirements such as increased productivity and quality through savings in cost, time, material waste, carbon emissions, and resource usage. Integrating BIM and Lean concepts in the pre-construction stage may benefit from better decision-making in several areas, including documentation, procurement, and financing. Several publications have discussed how these two concepts are specifically combined. The majority of papers address the use of a specific Lean tool in conjunction with BIM. Some papers investigate the difficulties in implementing the BIM and Lean combination. However, very few studies have looked into how different Lean dimensions can be combined with BIM for use in the construction industry. Though, there have been many literature reviews on the Lean–BIM integration; however, the current study differs from previous studies in that it sought to investigate the various techniques and Lean dimensions that are integrated with BIM, as well as highlight the major adoption issues in the construction industry. Thus, the present study adds to the body of knowledge or profession as it reviews the literature on the relationships between BIM and Lean while also investigating the opportunities and challenges of using this combination to address cost and time overrun issues. Furthermore, the study's findings highlight the key barriers to using BIM for Lean construction and offer solutions for overcoming them.

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Keywords Lean · Lean construction · Building information modeling (BIM) · And construction industry

1 Introduction

Nowadays, construction projects are confronted with the challenges of increasing construction productivity and efficiency of building processes. A project is conventionally separated into stages, and the whole project is then optimized by selecting alternatives that optimize each of these phases. Given that project phases are interconnected and therefore optimizing one stage may result in waste at the linkage of another stage, the Lean approach advocates optimizing the project as a whole rather than individual stages [15]. Lean construction focuses on minimizing waste, optimizing resources, continuously improving the system, and ensuring end-user satisfaction [41]. Several papers discuss the Lean construction management approaches, and one of the research topics is integrating the Lean construction management system with BIM technology. BIM allows for digitally developing a building and its facilities before it is created, simulating how it will be built in the real world, thus minimizing potential flaws. Doan et al. [18] examined that BIM is a collaborative process and tool for carrying out particular construction projects, and not just a simple 3D model. It does this by enhancing communication among the team of managers, designers, consultants, contractors, and other stakeholders in the project by utilizing digital technologies and information exchange.

The objective of this research is to investigate how integrated BIM and Lean practices can increase the construction process' efficiency and the challenges associated with their implementation. This study first discusses the preliminary research on BIM and Lean construction in order to accomplish this goal. Second, the current available literature shows the applications, strategies, and major obstacles of implementing BIM–Lean integration into practice are examined. The authors' concluding remarks on integrating Lean and BIM for the construction industry are presented in the third section after a discussion of the literature review's findings.

2 Lean Construction Management Techniques

Lean construction, which first became popular in construction management in the 1990s, has Lean manufacturing as its theoretical foundation [29]. The core tenets of Lean construction were to reduce waste, deliver projects on schedule, and maximize project value via system design, management, and continuous improvement [7]. Lean construction expanded the traditional view of a project by considering time, uncertainties, and customer satisfaction. It includes not just transformation but also flows and value generation to the project. Since it can impact a project's bottom line, Lean construction techniques are becoming more and more prevalent.

The "last planner system", which Ballard [8] established, necessitates workflow management to ensure the flow of concept, delivery, and adjustment via production units. It is a system that involves the individuals who are ultimately responsible for completing the work in the planning and execution of the project. In order to decrease waste while carrying out material management tasks including reducing idle time, processing time, and physical waste, Arbulu et al. [3] showed how "Kanban", an inventory control Lean approach for the automotive industry, may be implemented in the construction sector. The main strategy for achieving this objective is streamlining the procuring, holding, distributing, and disposing processes.

Ballard [6] examined the applicability of a Lean design technique in the construction sector. Throughout the development process, "set-based design (SBD)", a Lean design technique, keeps requirements and design possibilities as flexible as is practicable. Instead of choosing one answer up front, SBD searches and concurrently evaluates many possibilities, gradually eliminating the less desirable ones. Shang and Pheng [49] described the features of "kaizen". This quality management technique was developed from the "PDCA cycle" and applied in construction projects via continuous improvement based on continuing positive adjustments rather than top-down alterations. Deming [16] developed the PDCA cycle as a defect management technique for continuously improving processes and projects. Singh and Kumar [50] examined "visual management" tools to raise the construction project's effectiveness and value. These tools help improve workplace communication and reduce obstacles to information flow. Instead of using textual writing, it presents the information using visual elements like graphs, charts, colour coding, and BIM models, which makes it simpler for all project stakeholders to comprehend. Sacks et al. [45] investigated that BIM can enhance worker safety owing to its visual simulation models that consider last-minute schedule alterations while implanting the last planner system, thus improving workers' knowledge of the risk they face. The authors demonstrated that how visualizations assist in avoiding uncertainties and misunderstandings, having this information centrally documented in an ordered and immediately accessible way promotes transparency while minimizing the loss of workers' time. The following section of this study explores whether BIM contributes significantly more than a visual component.

3 Integrating BIM and Lean Tool in Construction

Lean approaches developed in the manufacturing industry and subsequently adopted by the construction industry are still not substantially addressing the concerns of cost and schedule overruns, which are the most common worries in developing any infrastructure or real estate project. Therefore, more potent technological intervention is needed. The present study aims to find out how BIM, a tool utilized in the Architecture, Engineering, and Construction (AEC) sector, may be used as a Lean management technique to address concerns about cost and schedule overruns.

Using a single platform, BIM is a graphical simulation tool that aids AEC professionals in managing project planning, design, and construction. BIM may find errors, omissions, and disagreements before building begins, cutting waste and hastening the construction process. For instance, on its common platform, the Navisworks software can evaluate outputs from many other programmes, including Revit, CAD, and Excel, such as architectural, mechanical, electrical, and plumbing (MEP), and quantity take-off data. Additionally, it finds conflicts, which helps spot issues even during the design phase. BIM is "a combination of tools, methods, and technologies made feasible by digital, machine-readable documentation about a building's performance, planning, construction, and future operation," according to Eastman et al. [19] definition. By removing inefficient waiting times in the construction processes and cutting down on design time by roughly 50%, BIM encouraged prefabrication and assembly operations to stimulate execution time savings of up to 1.5 months [20].

The benefits of utilizing BIM over traditional building methods have been very well documented by Ullah et al. [54]. The authors point out that BIM can enhance concepts [19], analyse sites effectively for resource-related issues [4], conduct appropriate design reviews [27], resolve design conflicts [30], and provide more accurate cost estimation at the pre-construction stage [27]. It facilitates the pre-construction phase of the building process by efficiently managing resources [19], improving site use [17], using prefabrication effectively [22], and decreasing site congestion [27]. Some of the benefits of BIM after construction include improved decision-making for facility operations utilizing BIM data [28], efficient asset management, and access to stored information during maintenance [22].

Sacks et al. [44] created a framework that incorporates Lean construction and BIM ideas. The authors concluded that combining both strategies will lessen building obstacles by enhancing quality and speeding up the process. Furthermore, Bhat et al. [12] have created a matrix to increase the construction sector's productivity by addressing the BIM features and Lean construction concepts. Through the course of a project's life cycle, integrating BIM with Lean implementation may increase project value [53].

4 Literature Review

Although Lean and BIM are often examined separately, they are also frequently coupled, according to the analysis of the literature. However, the integration of BIM and Lean in construction has received less attention in the literature, and even fewer studies demonstrate how doing so will save costs and schedule delays. This literature review is a non-systematic review. The primary keywords, BIM and Lean, were identified based on the study's objectives. The search of various literature including both "Lean" and "BIM" together as keywords were carried out from Scopus database using the application of Harzing's perish or publish software. The research discussing about either BIM or Lean and fields other than construction were excluded. The Scopus database from 2010 till November 2022 contains a total of 106 such works including

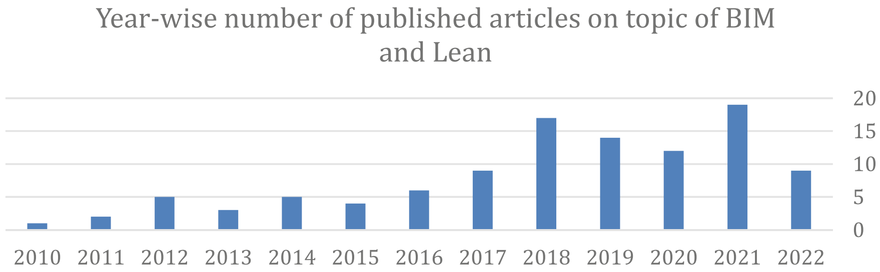

Fig. 1 Trend of papers published from 2010 to 2022 related to the importance of implementing lean with BIM. *Source* Authors compilation from Scopus database on the topic of BIM and Lean

books, journals, review papers, conference papers with the keywords "BIM" and "Lean", and 1503 citations. All 106 papers were taken into consideration for initial screening in order to ensure the process's quality and no bias in the selection of the studies for the review process. The number of published papers with the keywords "Lean" and "BIM" is shown in Fig. 1 which highlights the research trends in these publications. The terms "Lean and BIM" were scarcely ever used in literature before 2010. From 2010 to 2018, there were 1 to 17 articles each year. However, there was a little dip in 2019 and 2020. These two keywords are increasingly being used in papers, which often indicates a rise in the importance of these topics in study.

The database of Scopus revealed that half of the papers were published in conference proceedings, particularly at the "Conference of the International Group for Lean Construction" held annually. A few were published in Construction Research Congress. 41 articles were published throughout the 24 journals. Despite Lean and BIM's importance to the construction sector, more than half of the related research was only published in five publications. With seven papers published, or 17% of the total, the "Journal of Construction Engineering and Management" has the highest percentage. Second with 15%, "Engineering, Construction and Architectural Management" is followed by "Buildings", "Sustainability", and "Automation in Construction" with each having 7%.

Figure 2 depicts the network built with the help of VOSviewer application, which is based on the database and the main keywords that occurred with its strength used in the selected database. This figure interpretations provide us insights of keywords associated with BIM and Lean. For instance, most of the words directly associated with BIM are project, application, BIM model, use, and sustainability, whereas words like interaction, integration, implementation, and construction are closely associated with both BIM and Lean.

For all 106 published literature that discussed both BIM and Lean together and was made available by the Scopus database, the trend of studies shown in Fig. 1 and the keyword analysis map in Fig. 2 were created. Out of these 106 papers, the papers discussing only the related softwares or examining the integration of Lean and BIM without addressing any specific techniques and Lean dimensions were eliminated. The analysis of the remaining papers is presented below in Tables 1 and 2, considering

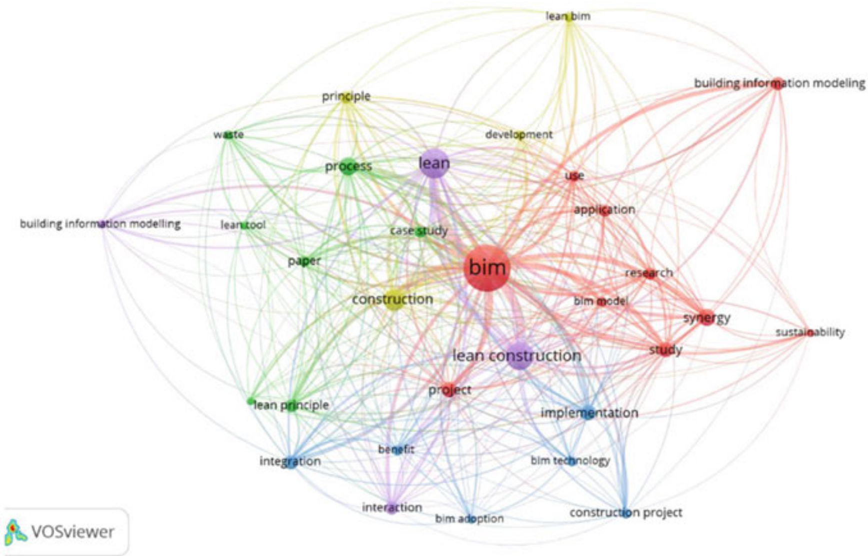

Fig. 2 Keyword analysis map built from all 106 papers. The minimum 10 co-occurrences result in a total of 31 keywords being shown. Note that various hues represent various keyword clusters. *Source* Authors compilation from Scopus database

the research's objective. It presents the key research found after looking through the selected papers in the literature on Lean construction and BIM used for this review.

The authors' literature analysis is presented in Table 1. Table 1 was formed by examining different techniques in various papers and the outcomes obtained after utilizing Lean techniques. According to analysis, the best results are obtained when the "last planner system"—a Lean technique, and a "visual management" technique using the BIM tool for 3D modelling, clash detection are integrated. The key benefits of employing this combination are facilitating collaboration, effective workflow, waste reduction, time and cost efficiency, and therefore enhanced productivity and value of the construction project.

Though this combination provides huge value to the construction projects, but still it is not widely implemented. Thus, the authors investigated the challenges for its implementation. According to the literature review in Table 2, the main barriers to integrating BIM and Lean in the construction industry are "lack of standards" and "lack of skilled staff." Other major reasons for construction organizations not embracing BIM include "resistance to change," "inadequate training," "lack of awareness," and "budget restrictions" to transition from conventional approaches to new ones.

Table 1 Techniques and lean dimensions integrated with BIM

Technique	Lean dimension of BIM	References
4D scheduling, predictive analysis, and look ahead planning	Effective management of waste during demolition processes, design coordination, and time and cost management	Marzouk and Elmaraghy [37], Bhat et al. [12]
Analytical network process	Improve communication, production, and visualization	Bayhan et al. [11]
Big room, knot working, and target value design	Design management of structural and building services	Tauriainen et al. [51]
Bottom-up approach	Increase productivity, efficiency, and quality	Arayici et al. [2]
Last planner system	Effective collaboration, improved documentation, optimized workflow, minimize waste, reliable flow of information, cost reduction, improved construction quality and productivity, continual improvement, and reduced construction time	Michalski et al. [35], Maraqa et al. [39], Marte et al. [36], Sbiti et al. [46], Schimanski et al. [48], Andújar-Montoya et al. [1], Bataglin et al. [10], Dallasega et al. [14], Erusta and Sertyesilisik [23], Gómez-Sánchez et al. [25], McHugh et al. [38], Schimanski et al. [47], Uusitalo et al. [55], Zhang et al. [57], Mahalingam et al. [33]
Plan-do-check-act (PDCA) framework	Improve workflow, improve planning, and design of infrastructure projects	Wang et al. [26], Herrera et al. [56]
Set-based design	Minimize waste of materials and time, and increase value	Chuquín et al. [13]
Visual management—3D modelling and clash management	Reduction in waste, reduce design time, evaluation of multiple design alternatives—improves value, and increase value	Mahmood and Abrishami [34], Eldeep et al. [9], Rashidian et al. [20], Barkokebas et al. [40], Pedo et al. [42]

5 Discussion

According to the study, the construction sector has been using Lean techniques such as the last planner system, Kanban, set-based design, kaizen, root-cause analysis, and bottleneck analysis for the last 20 years. Moreover, these technologies support the construction process in various ways, including workflow management, inventory control, defect analysis, and quality management. One of Lean techniques is visual management, which focuses on enhancing information flow across the workplace

Table 2 Challenges to the implementation of BIM and lean construction

Key challenges	References
Lack of skilled personnel	Likita et al. [31], Tezel et al. [52], Elhendawi et al. [21], Tauriainen et al. [51], Liu et al. [32]
Opposition to change	Likita et al. [31], Evans and Farrell [24], Elhendawi et al. [21], Sacks et al. [43]
Adequate organizational infrastructure	Likita et al. [31], Sacks et al. [43]
Lack of regulation/standardization	Likita et al. [31], Aziz and Zainon [5], Evans and Farrell [24], Elhendawi et al. [21], Sacks et al. [43], Liu et al. [32]
Cost of implementation	Likita et al. [31]
Lack of backing from top management	Aziz and Zainon [5], Tezel et al. [52]
Comprehensive training	Aziz and Zainon [5], Evans and Farrell [24], Sacks et al. [43], Tauriainen et al. [51]
Financial constraint	Aziz and Zainon [5], Tezel et al. [52], Elhendawi et al. [21], Liu et al. [32]
Workload/time constraint	Evans and Farrell [24], Tezel et al. [52], Elhendawi et al. [21]
Lack of awareness of BIM/Lean	Evans and Farrell [24], Tezel et al. [52], Elhendawi et al. [21], Tauriainen et al. [51]

using visual components like BIM, enhancing the project's value. This investigation's findings indicate that the applications of integrating BIM and Lean range from design simulation to clash detection, cost estimation, construction operations, worker health and safety, facility management, resource management, supply chain management, and communication management, among other construction aspects. This research looks at how BIM and Lean implementation work together to reduce cost and time overruns, ultimately providing value to construction projects. The "last planner system" is mostly considered by academics to be one of the greatest Lean construction tools when used in conjunction with the 4D models that BIM's visualization management digital tool made available. The design, construction, and maintenance teams can use it to promote collaborative decision-making, efficient communications, improve quality and productivity, and identify standards violations. As a result, conflicts are reduced, increasing workflow effectiveness, saving cost and time, and enhancing the project's value. However, implementing the combined BIM and Lean model faced significant challenges, including a lack of trained personnel, inadequate training, reluctance to change, a lack of regulations and standards, and financial assistance. As a response, the organizations must handle these challenges by employing standards and setting benchmarks, providing appropriate training to acquire new skills, fostering cooperation and teamwork, and seek for long-term benefits.

6 Conclusion

The construction industry experiences constant development since it uses cutting-edge methods, tools, and legal frameworks. The basic objective of construction management is to carry out the project within the bounds of schedule and budgetary constraints while reducing time and expense overruns caused by uncertainty. In that regard, Lean construction concepts should be fully explored and implemented over conventional ways to reduce waste and, thus, construction costs. Further research can be conducted to determine how Lean tools other than the “last planner system” can best function in conjunction with BIM to provide various opportunities for the construction sector. Furthermore, developing more robust frameworks and models for BIM and Lean implementation is necessary. It will assist in lessening implementation challenges and make the BIM–Lean combination more widely applicable in the construction sector. It can be inferred that there is a need to comprehend BIM–Lean training mechanisms and appropriate implementation models to be developed. These mechanisms and models must be reliable, affordable, accessible, and simple. One limitation of this research is that the statistical analysis received less attention since the results of this publication were based on previously published literature findings. The authors tried to use more general terms to convey results to match the research conducted in this work. The gap can be filled by case study-based research in this area.

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A Case Study on Implementation of Lean Tool in Indian Infra Project

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Abstract India's construction industry is currently experiencing substantial delays, due to low productivity and inadequate labor management. Lean construction is a method that seeks to minimize waste and increase production. The goal is to examine how well the Lean methodology works for managing projects. Value stream mapping, a Lean tool in construction, plays a vital role in resolving this problem since it increases productivity. The non-value-added activities can be found using value stream mapping. By shortening the duration of these non-value-added activities, productivity can be increased. The value stream mapping Lean tool was utilized in a case study of pier cap building in a bridge construction project, and a potential gain in productivity was identified. The present state of the activities in the erection process was mapped first, followed by the preparation of the future state map of the activities after the non-value-adding jobs were eliminated.

Keywords Lean construction · Value stream mapping · Indian construction · Cast-in-situ · Productivity

1 Introduction

Over the past 50 years, around 40% of development investments have gone toward India's construction. Construction provides a living for about 16% of the country's working population. Over 30 million people are employed in the construction sector in India, which also generates assets worth more than 200 billion. Some of the problems India's construction and infrastructure projects face are substantial cost overruns, time overruns, and lack of skilled workers. There are few drawbacks such as reduction in labor productivity, underuse of technology, improper communication

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and coordination between higher and lower management. One of the biggest causes of decreased productivity in building projects is the existence of "waste," or objects that bring no value to the existing construction process. Here, waste might not be only material waste but also inventory waste, unwanted movement of people, waiting (people waiting for material or equipment, and equipment idle time), overproduction, over processing, not utilizing talent, and defects.

This waste can be reduced by using some of the Lean tools in Construction Industry. Lean technique is a method of doing more with less—less work, less equipment, less time, and less space—while still giving consumers exactly what they want. The fundamentals of the Lean approach essentially entail the removal of waste and the creation of continuous flow. Lean technique consists of a total 40 tools. Some of the Lean tools include value stream mapping, last planner, visual management, line balancing, work structuring, multi-process handling, and daily huddle meetings.

The Lean tool that is used for this case study is value stream mapping. Value stream mapping (VSM) is a Lean technique that uses flowcharts to illustrate each stage of the process. Many Lean practitioners consider VSM to be a crucial instrument for waste identification, process cycle time reduction, and process improvement. Value stream mapping (VSM) is a technique for representing the existing process and the necessary changes that must be made in the current process. VSM examines the existing status of the process and aims to boost productivity through three strategies: process reform, the elimination of unnecessary labor, and activity improvement. The purpose of this paper is to look at the adoption of Lean in construction by utilizing the VSM tool on a case study of bridge pier cap building in a highway project. It also intends to critically examine the mapped streams of these operations in order to detect wastes and give better VSMs in the future.

2 Value Stream Mapping (VSM)

The VSM methodology generates a process-flow diagram of project activities and other data. It is a standardized method of documenting the stages and sequence of work items, followed by the adoption of a methodical approach to analyze these processes and create a strategy for improvement. VSM includes current state map and future state map. Current state map elaborates about the present process which represents activities, and the process will be analyzed. Then, based on the output, future state map will be drawn which will improve productivity and completes the project in optimistic time.

Value stream mapping involves the following steps:

(i) Keep track of the current procedure.
(ii) List each activity in the process and identify it.
(iii) Find the value of the end user.
(iv) What would the ideal procedure look like?
(v) Determine the elements of the present process that impede excellence.

(vi) Identify significant waste reduction or elimination projects.
(vii) Assign duties and tasks.

3 Literature Review

Handayani et al. [6] studies Lean construction and six sigma methodologies were used to reduce waste in light brick installation. The findings of this study reveal the presence of rework as a result of installation process faults and material quality. The effectiveness of the Lean approach in managing construction projects was documented in a case study of a structural steel erection project where the value stream mapping Lean tool was used and probable productivity improvements were identified. The present state of the activities in the erection process was mapped first, followed by the preparation of the future state map of the activities after the non-value adding jobs were eliminated. It results in reduction of duration of 13 days and resulted in 30% savings. Ramani and KSD [10].

On a real construction project of underground pipeline installation, value stream mapping (VSM) was adapted as a sustainable construction tool to reduce the high percentage of non-value-added activities and time wastes during each construction stage, and the paper searched for an effective way to consider the cost for studied construction of underground pipeline. This study seeks to discover, develop, and use a cost-based VSM idea in the construction industry, which can serve as a new way forward for future cost estimates [5].

Leite and Neto [7] recommended changes to information flow in the design of housing firms based on Lean Thinking concepts (LT). Due to the wide range of projects, activities, and products generated by design firms, the number of hours spent by each expert in the group, as well as the deadlines for completing certain services, is quite complex. Through the proposal of alternate control mechanisms, VSM can enhance the information stream in the design process. Lima et al. [8] investigated the development of the architectural executive design of low-income housing projects at Habitafor. Lean can bring to the public sector its implementation faces some challenges, e.g., taking the customer perspective, managing end-to-end processes, freedom to expose problems. This paper used VSM to investigate a process in the public sector and make attributes of the process visible to those involved.

Pasqualini and Zawislak [9] described the modifications and application of the VSM in a Brazilian construction company, with the goal of introducing the ideas of Lean Production in construction in a more systematic manner, identifying its main problems and proposing actions for improvement throughout the value flow. VSM is regarded as one of the Lean Production entry points since it allows for a systematic perspective of the production process (of the value flow), the identification of genuine issues and wastes, and the proposal of remedies.

Firoozi and Heravi [4] studied of VSM used in precast mass housing construction along with a case study. Applying VSM improves the erection rate and therefore achieves a better collaboration between production and erection rates and can solve inventory-related issues. Value stream mapping (VSM), just-in-time (JIT), last planner system (LPS), concurrent engineering, and visual management are some Lean tools which may be applicable for improving precast technology. Bhat and Shivakumar [1] studied on "Verbio biogas plant" project, which was located in Punjab. Bulhões et al., it initially faces an enormous amount of waste (time and cost) generation, and later it was minimized by implementing an effective Lean approach: "value stream mapping" (VSM) [2]. Firoozi and Heravi studied the lean concept from the non-physical waste perspective [3]. The main objective of this article is to address, "How the challenges that occurred during critical path activity of the project which is the erection of I-girder on the top of eight air and watertight RCC fermenters silos of the gas plant have been tackled by adopting VSM".

4 Objective

The objective of the study is to find the benefit of Lean tools for cast-in-situ construction process in Indian infrastructure projects.

5 Case Study

This case study is construction of pier caps in a bridge of 6 lane highway project which is located in Vijayawada, Andhra Pradesh, India. The 6-lane highway consists of a 3.2 km long bridge on the river Krishna in Vijayawada. The bridge consists of a total of 106 pier caps on both L.H.S & R.H.S.

Pier cap construction is one of the major activities in bridge construction which takes more time when compared to other activities like piling, pile cap construction, or segment erection. And the complete construction of pier cap is done using on-site construction methodology. If we try to reduce the construction time of pier cap, it leads to reduction in total time for construction of bridge.

On spending of two months during internship period, on-site conducting comprehensive observation and examining the actual job being done. This is how the data from the project site were gathered. The project site engineers were questioned, all of the operations there were physically watched, and data on activity durations were gathered. The amount of time spent on each activity is determined by averaging the recorded observations. The process's current state map was created after the actions in the work were identified (Fig. 1).

Details of Pier cap are:

Pier cap size: 6.5m*4.2m

Size of bars used = 16mm, 20mm, 28mm,32mm

Quantity of steel required = 14 tonnes

Quantity of concrete required = 48 cum

Time taken for casting a single pier cap = 14days (approx.)

M50 grade concrete is used.

For concreting it takes about 3 hours.

It requires 8 transit mixers of capacity 6cum.

Pouring time of concrete for 1cum = 3.125 minutes

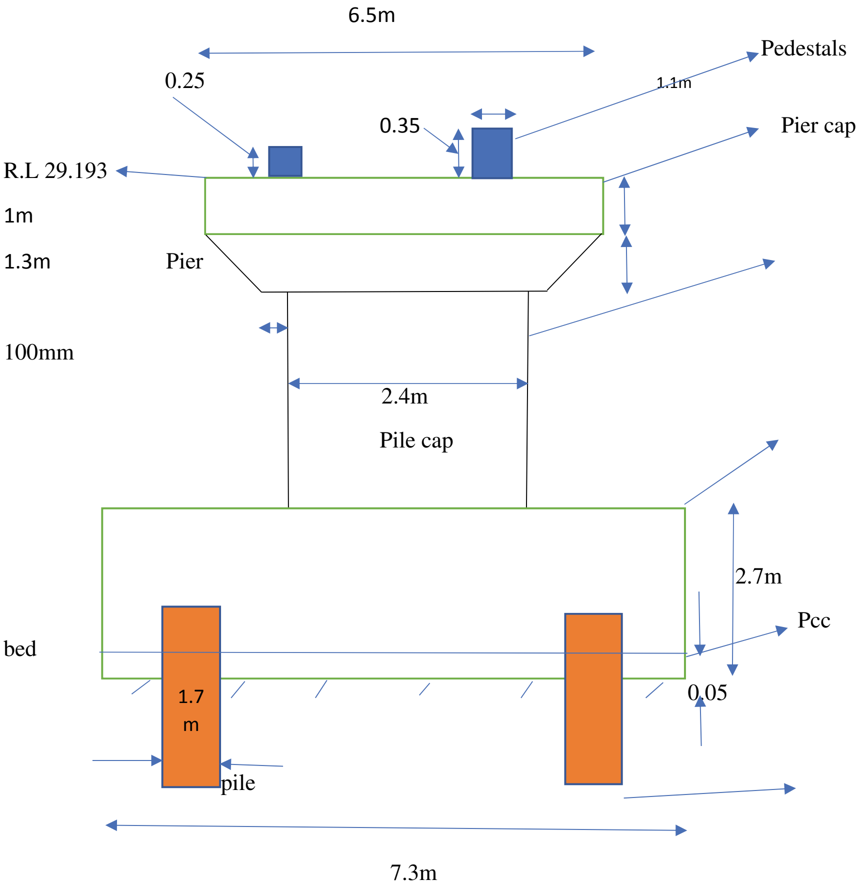

Fig. 1 Plan of pier

6 Current State Mapping

Work breakdown structure for pier cap construction is obtained. The construction of pier cap starts with chipping of pier shaft, if necessary, which is carried out using chipping machine and requires 2 labors. And then shuttering is placed using the hydraulic cranes and requires 3 labors. Using an auto leveling instrument, surveying is conducted to determine if the shuttering is installed properly or not. Once marking is done, reinforcement of steel bars is done which is the important and time-consuming step in the construction of pier cap. After completion of placing of reinforcement, shuttering is placed for the top section of the pier cap. Concreting is done using concrete pump. After the concreting is finished, curing is carried out using the sprinkling method for 7 days. De-shuttering, which must be done after curing, requires five unskilled workers and a hydraulic crane. Table 1 shows the information regarding number of labor and equipment required for each individual activity (Fig. 2).

Where,

VA Value-added time (h)
NVA Non-value-added time (h)
CT Cumulative time (h).

Most of the activities again have several sub-activities. Table 2 shows the sub-activities and their duration.

Table 1 Number of labor and equipment required for each individual activity

S.No.	Activity	No. of labor	Equipment/instrument
1	Chipping of pier shaft	2 unskilled	1 chipping machine and 1 air compressor
2	Shuttering	1 skilled, 2 unskilled	1 hydraulic crane
3	Surveying	1 skilled, 1 unskilled	1 auto leveling instrument
4	Reinforcement	1 skilled, 6 unskilled	1 hydraulic crane (for lifting of reinforcement bars)
5	Dust removal	2 unskilled	1 air compressor
6	Concreting	1 skilled, 4 unskilled	1 hydraulic crane, 1 concrete pump, 2 needle vibrators, 8 transit mixers
7	Curing	1 unskilled	1 water motor
8	De-shuttering	3 unskilled	1 hydraulic crane
9	Transportation of shuttering pads	2 unskilled	1 hydraulic crane
10	Ladder erection	4 unskilled	1 hydraulic crane

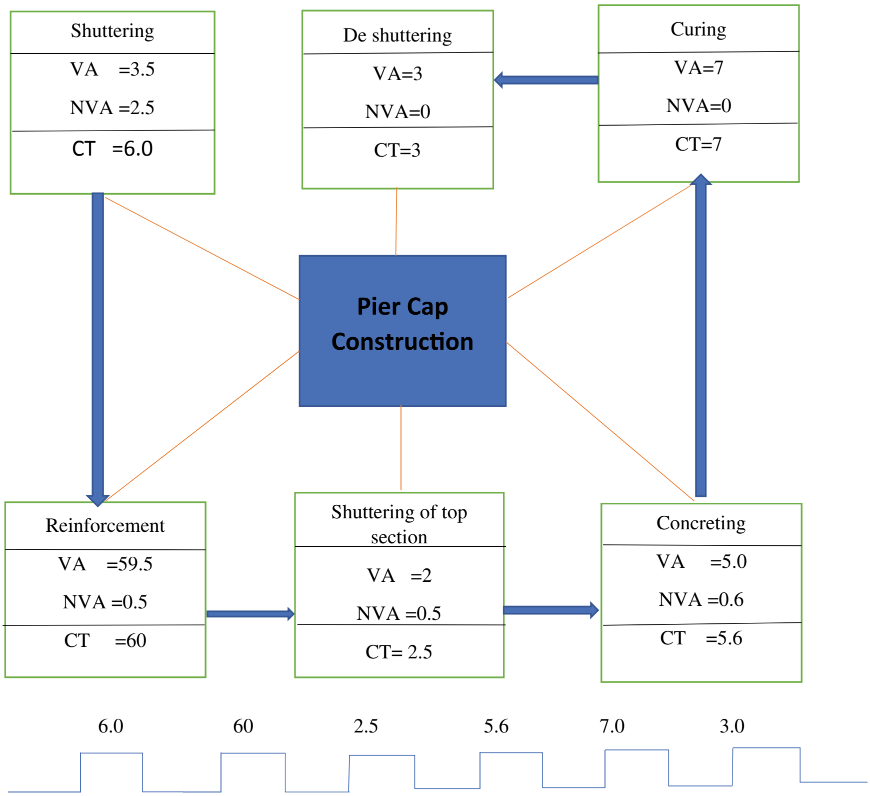

Fig. 2 Current state map of pier cap construction

7 Analysis of Current State Mapping

It is possible to find wastes that may be removed to increase productivity by analyzing the current state map activities (Figs. 3, 4, 5, 6, 7, 8, 9, 10 and 11; Table 3).

8 Improvement Measures

In Shuttering activity, while chipping of pier shaft going on we have scope of Transporting of shuttering pads parallelly. And laying of Nets for Ladder and Surveying activities can be done parallelly. So, we can reduce a total of 1 h duration in Shuttering Activity.

For, both top reinforcement and bottom reinforcement, as per site 6 number of labor assigned to this activity completed work in 24 h, instead of 6 we can add extra 2 labors, such that we can reduce the time from 24 to 18 h for both top and bottom

Table 2 Activities and their sub-activities with man hour durations

S.No.	Activity	Sub-activity	Duration of sub-activity (working man hours)
1	Shuttering	Chipping of pier cap	1 h
		Transportation of shuttering pads	30 min
		Placing of scaffolding	2 h
		Ladder erection	30 min
		Nets for ladder	30 min
		Surveying	30 min
2	Reinforcement	Marking	30 min
		Bottom reinforcement-2	24 h
		Top reinforcement-2	24 h
		Placing of inserts-2	5 h
		Bearing reinforcement-3	6 h
		Dust cleaning	30 min
3	Shuttering for top section of pier cap and scaffolding for concrete pump	Transportation of shuttering pads	30 min
		Placing of shuttering pads	2 h
4	Concreting	Transportation of RMC from plant to site	30 min (for each truck)
		Testing of approval of concrete	10 min (for each truck)
		Concreting	3.5 h
		Compaction	1 h
		Finishing	30 min
5	Curing	Nil	7 h (curing should be done for 7 days, each day 1 h)
6	De-shuttering	Nil	3 h

reinforcement each. For placing of inserts, as per site 2 number of labor assigned to this activity completed work in 5 h, instead of 2 we add extra 2 labors we reduce the time from 5 h to 2.5 h. = 2.5 h. For bearing reinforcement, as per site 3 number of labor assigned to this activity completed work in 6 h, instead of 3 we add extra 3 labors we reduce the time from 6 to 3 h. A total of 17.5 h can be reduced for reinforcement activity.

Fig. 3 Scaffolding

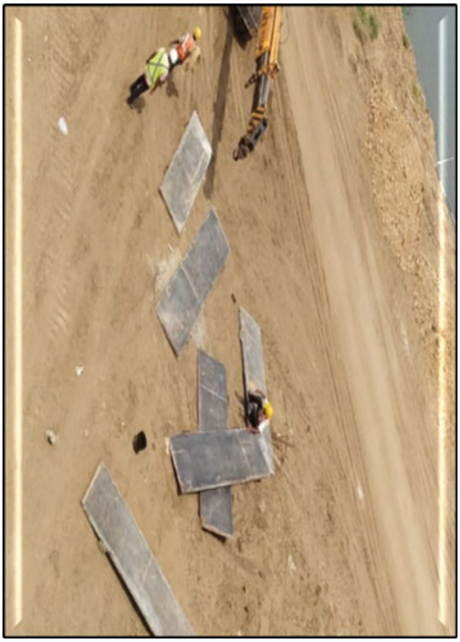

Fig. 4 Transportation of shuttering pads

Fig. 5 Reinforcement

Fig. 6 Placing of inserts

Fig. 7 Pedestal reinforcement

Fig. 8 Scaffolding for concrete pump

Fig. 9 Transit mixer

Fig. 10 Concreting

Fig. 11 Curing

Table 3 Analysis of current state map

Activity	Variables	Remarks
Shuttering	5 h 30 min 2 skilled, 13 unskilled	Here, time is the variable and parallel activities can be done
Reinforcement	60 h 1 skilled, 30 skilled	Number of labors can be increased such that total duration of reinforcement comes down
Shuttering for top section	2 h 20 min 1 skilled, 4 unskilled	Transportation of shuttering pads can be done parallelly with dust cleaning
Concreting	6 h 10 min 2 skilled, 12 unskilled	Testing of concrete for the next truck can be done while concreting is going on the 1st truck
Curing	1 unskilled	No improvement
Deshuttering	3 unskilled	No improvement

Transportation of shuttering pads for top section can be done parallelly along with dust cleaning such that we can reduce a duration of 20 min and we can avoid waiting time of labor and equipment. Testing of concrete for the next RMC truck can be done during the concreting works are going on for the previous truck. So that we can reduce a duration of 10 min for each truck.

9 Future State Mapping

A future state value stream map (VSM) is simply a projection of how a value stream should look in the future. When a current state map is created, problem areas become apparent. The bottlenecks where inventory piles up, processes with poor quality, and operations requiring excessive coordination should all be marked, which indicate areas of focus for the future state value stream map. Operations where work is pushed downstream should also be highlighted.

Preparation of future state map is the last step in value stream mapping, before implementing the improvement measures to our activities. From the improvement measures, we can observe that the total duration of 20 h approximately can be reduced for construction of single pier cap (Fig. 12).

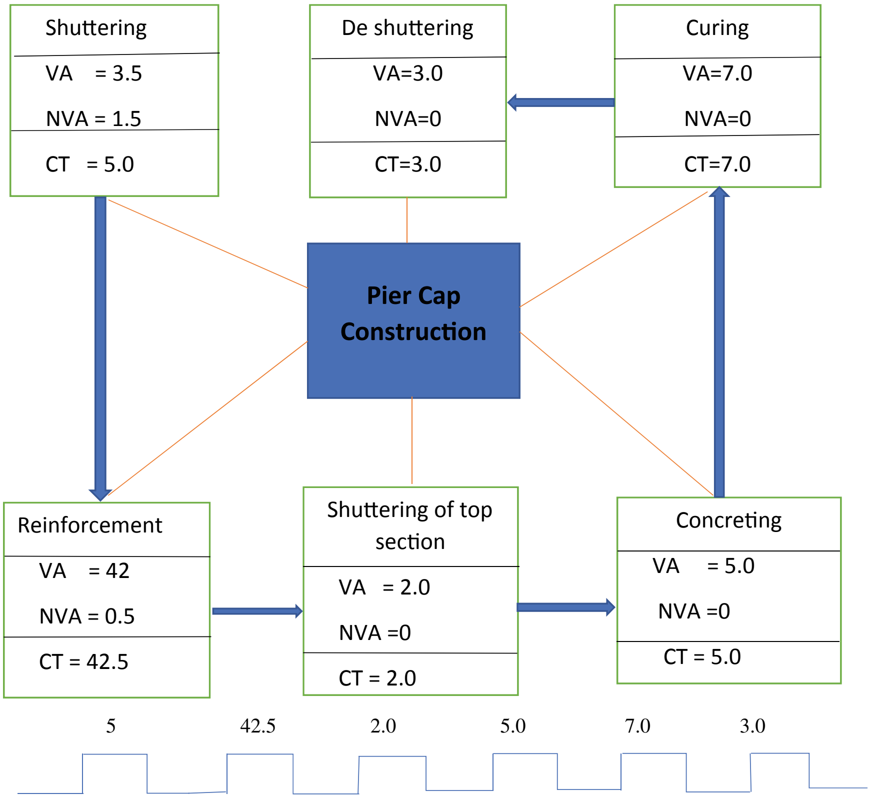

Fig. 12 Future state map of pier cap construction

Table 4 Results after applying VSM

	Current state	Future state	Difference after optimization	Observation
Number of working hours	85 h	68 h	17	Working hours reduced
Number of labor	63	72	9	Number of labor increased
Cost incurred (labor charges only)	25,906.25	25,838.79	67.46	Cost difference is minimum

10 Results

According to the current state map, duration required for casting for one pier cap is approximately 14 days or 85-man hours (if we consider 12 h working day). After analyzing the current state map and implementing the VSM, the duration of casting of pier cap will come down to 12 days or 68-man hours. Thus, we can save the duration of 2 days for construction of pier cap. As mentioned above, the total number of pier caps needs to be constructed are 104. Therefore, a savings of 200 days is achieved by cutting 2 days from each pier cap (Table 4).

11 Conclusion

It was allowed to see a step of the building productive process in a holistic fashion thanks to the adequacy and use of the VSM. This representation is systemic in the sense that it incorporates the process's productive activities, consumers, and suppliers, as well as the value flow. In this way, rather than merely identifying wastes, systems visualization demonstrates the reasons wastes occur or their genesis. As a result, the suggested enhancements are intended to address the issues. By applying VSM, these were the results attained. Even though if we increase the number of labors, the cost incurred is minimum, and we can reduce the duration effectively. So, adopting VSM for pier cap construction gives better results in reduction of duration.

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Exploring Defects in Construction—An Experimental Study

Aman Ashish, Himank Chawla, Ujan Sengupta, and Shobha Ramalingam

Abstract Lean construction approach to project management incorporates the ideas of Lean thinking and lean principles to minimize waste and add value to the customers. Several firms have reported benefits through enhanced productivity by adopting Lean techniques on project sites worldwide. Some of the popular tools implemented include the last planner system and value stream mapping. While these are popular, there seems to be a dearth of studies that address the eight types of Lean wastes which include defects, overproduction, waiting, motion, unused talent, transportation, inventory, motion, and extra-processing. To this end, an experimental study was conducted across two universities wherein students from NICMAR Pune and Nottingham Trent University, UK, collaborated for a period of two months to identify different types of waste on project sites and explored strategies to minimize them. This experiment aimed to identify and mitigate Lean waste and suggests the path of moving towards zero waste in construction aligned with the United Nations goal for a sustainable development. This particular paper focuses on the 'defects' type of Lean waste. Using a fishbone diagram and 5-why analysis, the root cause for defects was analysed, and strategies to overcome defects were suggested. Recommendations included effective construction management including people, processes, advanced technology, and effective training and education in Lean methods and incentivizing good workmanship. The measures were tested on the project sites and validated. The findings of the study are expected to add as a stepping stone to standardize processes that can minimize waste in the construction processes.

Keywords Construction process · Lean wastes · Defects · Sustainable Development Goals (SDGs)

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1 Introduction

In order to thrive in today's cut-throat market, construction organizations are aiming to improve the quality of their work, increase job effectiveness, cut wastes and cost, and raise profit. Most project managers concur that the chronic problem of this sector is numerous wastes, overruns, delays, and inefficiency. Literature also demonstrates that, despite the availability of a number of Lean tools and techniques, some of which have also shown an apparent improvement in productivity, there is a dearth of in-depth analyses of Lean wastes and practical solutions to address them by integrating people, process, and technology holistically. Due to this, building projects rarely wrap up on schedule, within budget, and at a standard of quality that the consumer accepts. Hence, various project management strategies have arisen to enhance construction performance, such as Lean project management, and Lean construction.

Although significant number of stakeholders in the industry are still unfamiliar with this idea, prior research has shown that utilizing Lean approaches can significantly reduce costs when compared to the conventional project management methodology [3, 8]. Ballard and Howell [2] claim that countries including the United Kingdom, Australia, the United States, and Brazil have reaped major benefits from adopting Lean construction principles. Studies and applications related to Lean construction may be found in Senaratne and Wijesiri [12], Höök and Stehn [6], and Thomassen et al. [13]. Leach [9] provides information about Lean project management based on the methodology of the Project Management Institute. Alarcon [1] has more information on the Lean construction methodology along with Diekmann et al. [5], Salem et al. [11], Koskela [7] and Conte and Gransberg [4]. However, there is less information on how to address Lean waste.

According to the Lean Construction Institute (LCI), Lean construction is a project delivery method based on production management that places a strong emphasis on the reliable and on time delivery of value. Lean construction is a new approach to project management that incorporates the ideas of Lean thinking and Lean principles from production management, which were first established at the Toyota manufacturing system in the 1950s [14]. Lean waste is typically categorized into eight categories in the context of construction and production processes that include: errors (defects), over processing, excess inventory, wasteful transport and conveyance of materials and equipment, and superfluous motions and movements of people, waiting, unused talent, and over production [10].

Further, the need for sustainable development is growing worldwide. United Nations has put forth 17 Sustainable Development Goals that aim towards sustainable growth for all. The wastes in the construction industry are irreversible and have a negative impact on sustainable growth due to excessive use of natural and limited resources. To tackle this challenge, a fundamental shift towards sustainable construction is essential. Lean and sustainability are concepts that hold certain common objectives in the form of promoting resource efficiency and eliminating or minimizing waste. The objective of this paper is to investigate and categorize the waste caused by 'Defects' at construction sites to address the following research questions:

(a) What are the various kinds of defects in construction projects?

(b) What are the impacts of Defects on UN Sustainable Development Goals?

2 Methodology

The experimental study was conducted for a period of two months across two universities, namely NICMAR Pune, India, and Nottingham Trent University, UK. Around 30–40 students from each university participated in this collaborative online study to identify the 8 types of Lean waste and aim towards zero Lean waste in construction. This paper focuses on the 'Defects' type of Lean process waste. Teams across both countries met online as and when required and conducted the study to foremost perform a Gemba walk in their accessible site premises both in the UK and India to identify Defects. Around 44 defects were captured as visual assets from (i) Ashoka University North Campus, Sonipat Haryana, (ii) Sunteck City, Goregaon Mumbai, and (iii) JUSNL Grid Sub-station at Kurdeg Jharkhand (iv) Residential Building, Balewadi, Pune, which were then categorized into six categories which included Honeycombing, Mis-alignment, Cracks, Design defects, Improper Compaction, and Miscellaneous. The next step involved identifying the root causes through Ishikawa diagram and the 5-why analysis by interviewing multiple personnel on the site that included site supervisor, field engineer, and project manager. The negative impacts of the defects on Sustainable Development Goals (SDG) were further mapped. Based on the team brain storming sessions, strategies to minimize defects were proposed and recommended on the project sites. The proposed suggestions were discussed with the site in-charge personnel to identify its feasibility in implementation and its relevance.

3 Results and Findings

The visual assets of the defects identified have been presented in Fig. 1.

Root-cause analysis was performed through 5-why analysis technique. Figure 2a, b shows the 5-why analysis and the Ishikawa diagram for improper compaction. Several reasons emerged during the interview conducted with the project team that included lack of training, lack of pre-and-post inspection, adopting wrong specification of concrete mixture, using 60 mm vibrator instead of 30 mm. Some of the practical constraints that emerged included poor maintenance of tools because the tools were maintained by third party. Similarly, the availability of technicians was also an issue. When probed it was evident that the project manager had failed to

Honeycombing	Mis-alignment	Cracks
		
Defect: Honeycombing in Column **Site Location:** Kurdeg, Jharkhand, India	**Defect:** Brick work course not in alignment **Site Location:** Sonipat, Haryana, India	**Defect:** Column developed cracks after de-shuttering. **Site Location:** Goregaon, Mumbai, India
Design Defect	**Improper Compaction**	**Uneven Shuttering**
		
Defect: Inadequate loading taken, and wall from height 45 meters fallen due to high speed winds. **Site Location:** Sonipat, Haryana, India	**Defect:** Cold joint crack due to poor compaction. **Site Location:** Pune, Maharashtra, India	**Defect:** Shuttering not in level due to mixed type - System and conventional formwork **Site Location:** Sonipat, Haryana, India

Fig. 1 Visual assets—categories of defects

inform the HR team about the requirements of the workforce. Probing deeper, the root cause turned out to be 'improper planning' by the project team.

Figure 3a, b shows the 5-why and root-cause analysis for the mis-alignment of columns. One of the major reasons for this type of defect was due to the formwork that got distorted during the concreting process (why) because the amount of support given was not sufficient (why) because the props came 30 min before concreting and were not adequate (why) because there was no clear instruction given and there was a miscommunication between day and night supervisor (why) because there was no proper handover procedure between the shift managers and the supervisors.

A similar approach was used for all defect types. Table 1 explains the identified root cause for the six types of process and product defects.

Figure 4 shows the 17 Sustainable Development Goals (SDGs) as put forth by United Nations that aims for fewer wastes, better infrastructure and overall improved living condition. The aim for a sustainable future through these 17 goals is to end poverty and protect the planet to ensure peace and prosperity. The impact of defects was mapped to Sustainable Development Goals. Defects can directly or indirectly impact all the 17 SDGs.

Figure 5 shows the effect of the defects on the SDGs. For instance, defects could have an adverse effect on consumption and production (#12 SDG), re-work leading

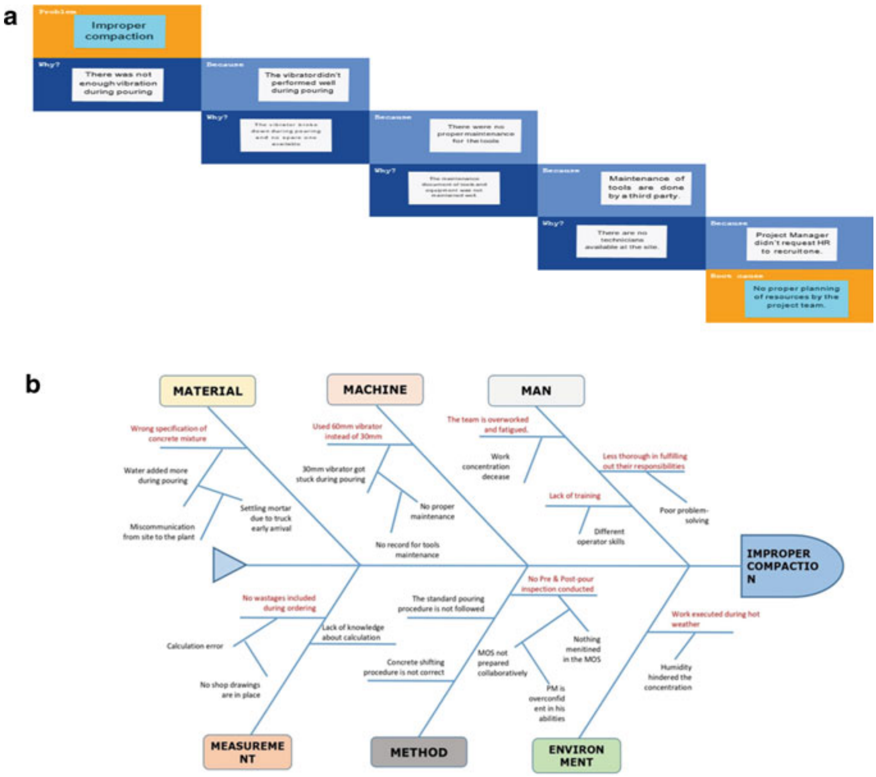

Fig. 2 **a** 5-why analysis: improper compaction. **b** Root-cause analysis: improper compaction

to lesser clean energy (#7SDG) inadvertently leading to global warming and climate change (#13SDG). On parallel lines implementing these SDGs could help reduce defects in projects. For example, providing quality education (#4 SDG) to workers through schemes like Skill India will upscale job opportunities, enhance the standard of living (#1, #2, #3), and decrease defects on site.

This led to finding possible solutions to overcome the identified root-caused as shown in Fig. 6a, b. The solutions focused on proper planning of resources, proper communication of the procedure, proper adherence to the method statement and proper planning with buffers to accommodate the client desired changes in design. The proposed strategies/solutions were discussed with the site personnel and validated to test their feasibility (Fig. 7).

The strategies included the creation of a knowledge repository, effective training and educating the workers on the merits of good workmanship, gradual implementation of digital tools to enhance early detection, proper coordination, use of the last planner system to avoid delays and resolve constraints early-on, ensuring quality control in design and construction through inspection and use of advanced tools and techniques and last but not the least sustaining the Lean implementation efforts.

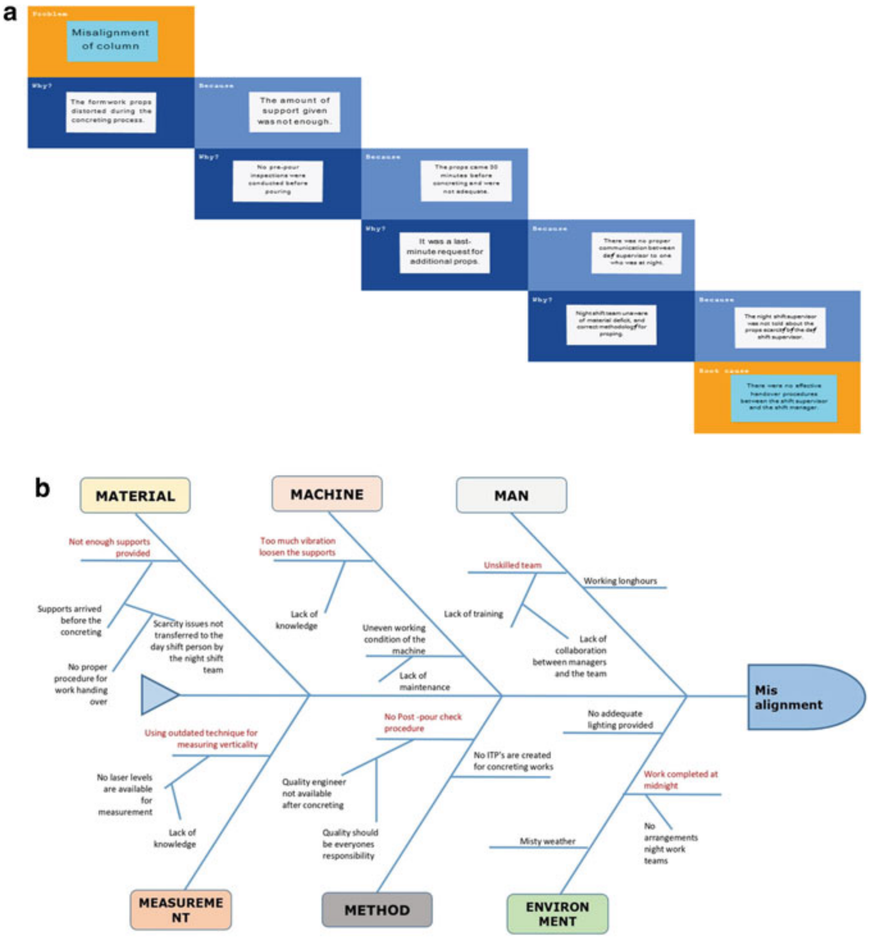

Fig. 3 **a** 5-why analysis: mis-alignment of columns. **b** Root-cause analysis: mis-alignment of columns

Table 1 Defects and root causes

Honey combing	Mis-alignment	Cracks	Design defect	Improper compaction	Miscellaneous
Poor training about the procedure	Lack of procedure to communicate	Method statement not followed	Client urgency to complete the work	No proper planning of resources	Improper planning of construction equipment

Fig. 4 Sustainable development goals

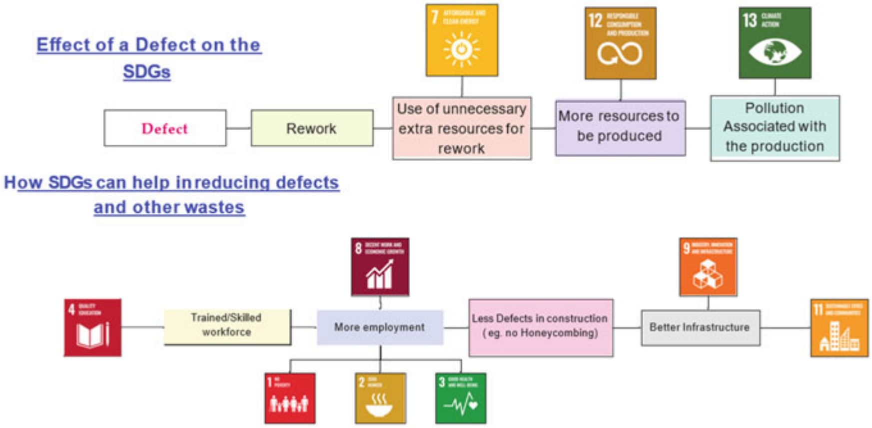

Fig. 5 Negative impact of defects on sustainable development goals

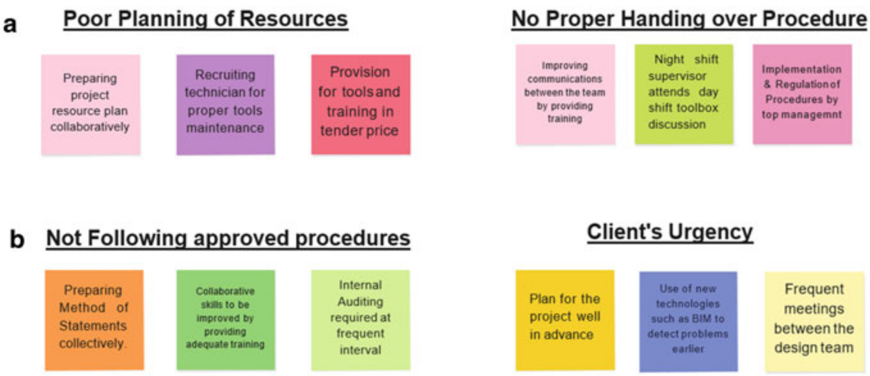

Fig. 6 **a** and **b** Identified root-causes and suggested remedial measures

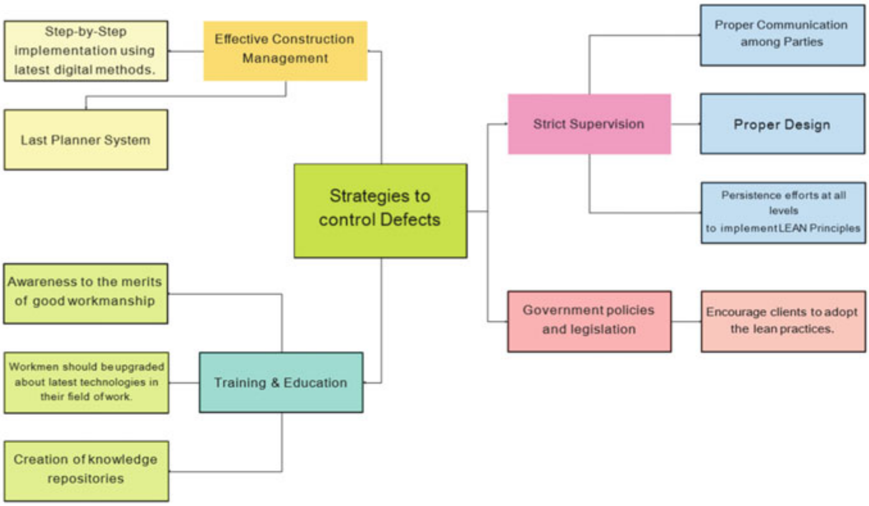

Fig. 7 Proposed strategies to mitigate the defects on project sites

The suggested methods for defect control underwent a pilot test (Fig. 8a, b) and defect-free outcomes were observed (Fig. 8c) which further reinforces that the suggested strategies can be practically implemented at large.

Further we also computed the impact of defects on the project cost as shown in Fig. 9a, b. The rates and quantities were computed based on real site data and in discussion with the project site team.

The estimate showed that if wastage was allowed at the current rate, it would yield an extra expenditure of approximately Rs. 8 Lacs. Below is the cost for a typical defect with the current rates of labour, material, and equipment costs.

Fig. 8 Training and education of workers and observed outcome

a

Description	Qty	Unit	Rate	Total Amount	Remarks
Allowed breakage / defects as per IS 2185-3 1984	5%				
Total required AAC blocks for this project (A)	1500	Cu.m			As per Site Data
Accepted limit of breakage / defects (B)	75	Cu.m			5% of (A)
But, Actual breakage/ defects at the project-10-15%	12.5%				As per Site Data
Difference between Actual vs allowed	7.5%				
Additonal requirement of AAC blocks	112.5	Cu.m	₹ 6,500.00	₹ 7,31,250.00	7.5% of (A)
Adding 10% for Frieght and Handling Charges				₹ 73,125.00	
Total amount invested due to breakage/defects				₹ 8,04,375.00	
Total requirement of Project	**15000**	**Cu.m**			
This cost does not include the cost of man hours lost because of rehandling of material and manual unloading.					

b

Cost of Unskilled labour for 8 hours = ₹600
Cost of Skilled labour for 8 hours = ₹800

S.No	Description of Item	Time (hrs)	Cost (INR)
1	Surface preparation by chipping and grinding the surface (1 skilled + 1 unskilled labour)	2	₹ 350.00
2	Filling of groove and the crack using micro-concrete (Fosroc Rendroc RG)		
2.1	Labour Cost(1 skilled+ 2 unskilled labour)	2	₹ 500.00
2.2	Material cost (15 Kgs)		₹ 450.00
3	Curing of the finished surface after it dries(1 unskilled labour)	8	₹ 600.00
4	Cement mortar plaster for surface finish		
4.1	Labour Cost(1 skilled+ 2 unskilled labour)	2	₹ 500.00
4.2	Material cost		₹ 300.00
	Total		**₹ 2,700.00**
	This analysis if for one such defect on construction site as shown in the photo attached.		

Fig. 9 **a** Impact of defects on project cost. **b** Impact of a typical defect on the project cost

4 Conclusions

This experimental study aimed to investigate and categorize the wastes caused by 'Defects' in construction projects. The outcomes were derived through a study conducted across two universities. Student teams across the universities tried to explore the various kinds of defects in construction projects and identified strategies to mitigate them. It was evident from the study that process defects resulted from non-standard operations, variations in how processes were carried out by various operators and due to erroneous approaches adopted such as failure to maintain fixtures, machines, and other equipment. Some of the reasons identified included a lack of desire, a lack of knowledge, a lack of communication, defective building materials, insufficient supervision, and flawed design.

Based on the identified root cause, project-specific solutions were offered to the executing agencies. Root causes being common across various projects made us propose a common set of practices to reduce and control defects. These included:

1. Effective construction management: Implementation of systems such as Last Planner® for effective planning and well-defined role for each staff with proper monitoring of PPC. 'Empowerment' as a Lean tool can be an effective way to enable the site team to adopt any measure required to control defects.

2. Training and education**:** A very important essence of the construction industry are its people; hence their workability and skills need to be kept in check at all times. In the current scenario, scarcity of skilled manpower is a major contributor to defects at any site. Thus, it is a necessity to constantly upgrade the workforce with the latest tools and techniques and also create knowledge repositories.
3. Effective supervision**:** Process and product-related defects could occur due to negligence or due to a lack of inspection at the appropriate time. Promoting regular and strict supervision can aid in minimizing defects. 'Cross-Training' is a Lean tool to understand about supervision of various parallel disciplines occurring on site.
4. Government policies and legislation**:** The adoption of Lean tools and techniques needs to be encouraged by the Government that aims to eliminate waste. This can be achieved by providing incentives and support to Lean-enabled projects.

In summary, this study opened our eyes to look for waste and especially defects on project sites. It sensitized and trained our minds to the Lean approach. The experiment brought out rich international exposure. We learned the benefits of global collaboration and the challenges of working virtually. The time zone difference was challenging, but we could overcome it with proper coordination and planning from either end. Nonetheless, this was an enriching experience.

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Enhancing Lean Tools and Practices with Digital Solutions

S. Kamal and Umar Belal

Abstract The lean tools like last planner system have a great impact on the project schedule tracking and ensuring that the planned activities are completed and emerging reasons are resolved at a daily basis. But, in order to have a detailed plan per engineer at a daily basis while ensuring the client objectives are also being met, a lot of manpower is required to plan activities at a daily basis and update the same. This is where digital solutions come into place, where the repeated tasks of quantification and schedule updating can be automated, and the manpower can be better utilized. The entire process is further explained in the paper.

Keywords Digitalization · Process improvement · Lean tools · Collaborative planning system™ · Planned percent completion (PPC)

1 Introduction

The lean principles and tools have a positive impact on the projects in identifying in increasing the success of the tasks planned by better collaborations and identifying and correcting the issues arising during construction through collaborative planning system™, but in order to track all the activities taking place and identifying all the constraints, variances, and resolving them at a daily basis to ensure continuous increase in productivity, additional manpower requirement is needed at projects. The noted benefits observed through the lean tools were not sufficient to justify the additional manpower requirements, and there was hesitation in the project teams to implement the solutions.

In order to mitigate the increase in manpower requirement to generate the data for last planner system and analysis of the large amount of data collected, an automated

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solution is needed. This meant that the overall process was refined at the cost of additional manpower dedicated to lean management. In case of projects where the profit margins are slim or there is a resource constraint, this poses a new challenge. This was worked out by introduction of a digital solution for data collection, compilations, and preparation of reports.

This removed the repeated tasks and freed the project members to look into the actual constraints and increases the overall productivity. The digital solution required an overhaul in the current process of project monitoring and required additional training and handholding to ensure that the engineers were utilizing it effectively.

2 Literature Review

There has been a complete digitalization of the manufacturing and the automobile sector in the last decade, and the industry has been reaping the benefits of it, similarly automobile industry was the birth place of the lean management system that we follow today. These benefits have been recorded in multiple papers such as "Lean practices and the adoption of digital technologies in production" by Robin von Haartman, Lars Bengtsson, and Camilla Niss, and many other similar papers, but the digitalization in the construction industry along with lean tools is a relatively new sector and its adoption in the Indian construction industry is minimal.

Jakob von Heyl and Selim-Tugra Demir talk about how building information modeling (BIM) helps in the lean management at construction sites in their paper "Digitizing lean construction with Building Information Modelling," but in projects where BIM is not mandated by the client, the cost for implementing BIM does not justify the results as the client submittals do not match the BIM outputs and requiring additional rework.

"Boosting Productivity in Construction with Digital and Lean" by Roland Haslehner, Frédérik Jobert, Jacopo Brunelli, Andrea Nogara, Roberto Rodio, and Davide Véroux talk by using the digital solutions for better communication, collaboration, and transparency in the process leading to better productivity at projects. The paper shows benefits in terms of reduction of issues due to coordination between various stakeholders, but there are a lot of further benefits if the entire workflow is digitalized which will take up in the paper. There have been a lot of hypothesis and implementation in silos of the industry, but a large-scale success story in a mega project has not been achieved. This paper shows how large organization can also move toward digitization while integrating it with the existing practices in the organization [1–5].

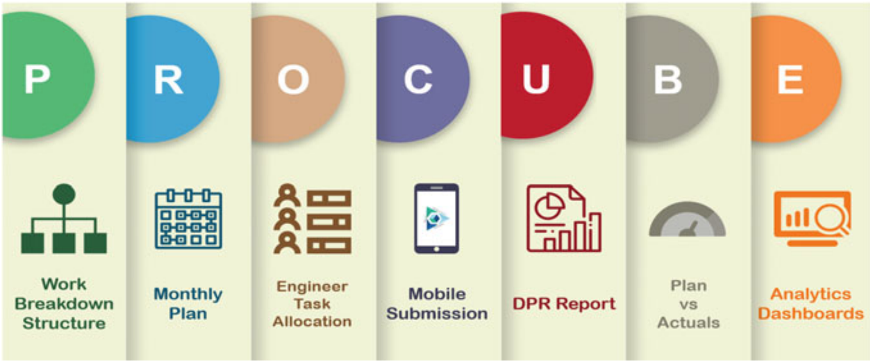

Fig. 1 Solution deliverables

3 Need for Study

Once the decision of utilization of digital solution for automation of the repetitive tasks in the last planner system was taken, it was noticed that there was no system or existing solution that can fulfil this requirement. This meant designing of a new solution of modification of existing solution to resolve the issue. This is where the study comes in place, to identify the requirements that need to be fulfilled by the solution and the data points required to satisfy the demand, the method of collection of data, and the output that has to be generated by the solution.

The design of the solution must be future proof and simple, so that it is intuitive to use, and the future needs must be anticipated and accounted for during the initial design, or at the least the solution must be flexible, so that future changes do not disrupt the existing processes which were identified and addressed during the course of the development (Fig. 1).

4 Case Study

The initial study with the project team was geared identification of the process flow between the various stakeholders at the project and mapping the workflows of the different lean tools in the digital solution (Fig. 2).

The above workflow was developed, and the same was conveyed to the entire project team to ensure that the information flow is smooth and the team is on the same page. Based on the workflow, a digital solution was designed which would incorporate the monthly look-ahead plans created during the big room meetings and assign it to engineers as per set targets. This part is done on the Web interface of the solution where an Excel schedule can be uploaded which contains daily or weekly targets for the engineers. These targets can be any number of activities that the engineer is performing (Fig. 3).

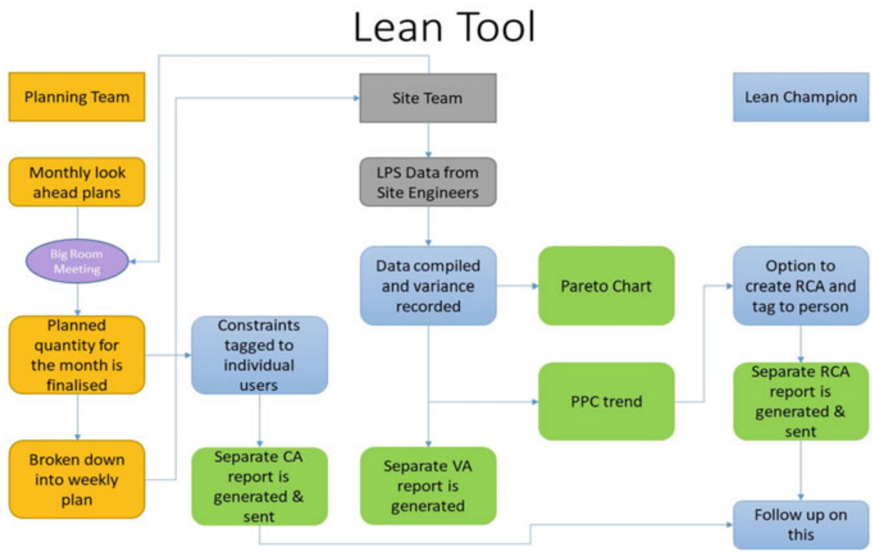

Fig. 2 Workflow of the solution

Fig. 3 Screenshot of mobile application

Once the targets are set for engineers, they receive them in the form of cards on the mobile version of the solution. The site engineers can fill these progress cards on a daily basis where the progress is recorded long with the reasons for not achieving the tasks, if any. This get compiled and gives the percent planned completion (PPC) and a compiled list of reasons for variances.

These reasons when compiled along with the Pareto analysis would give a list of causes for shortfall along with its frequency of occurrence. This is done at a weekly basis; the 80–20 rule is applied here which provides the most frequently occurring cause of shortfalls. These reasons are isolated and discussed on the weekly big room meeting. Based on the severity of issues and its complexities, they are resolved during the meeting or a separate meeting is conducted with the respective stakeholders to resolve the issue. These responses are collated, and a variance analysis report is generated. This report is then circulated across the project site to ensure that the key members responsible for each task are aware of it and the tasks are completed on time.

For issues that are complex, a root-cause analysis is done to ensure that the issue/ issues causing the delay are identified correctly and the correct stakeholder is assigned for resolving the issue. Both the root-cause and variance analysis are filled in the Web interface of the application which generates a report which is printed and circulated across the project site and with all the engineers.

Furthermore, the daily PPC data that is collected is represented as a trend line, and this provides the projects with insights when there is significant dip to conduct a root-cause analysis; and if the PPC value is greater than 90% for a significant period, then the project team can look into increasing their weekly targets to maximize the productivity of the workmen on site.

5 Results

Prior to the introduction of the digital solution, there was a dedicated manpower who was responsible for creation of monthly targets for the teams based on the big room meetings, tracking the progress at projects, recording the reasons for failure, and preparation of various reports. In case of larger projects, the single resource for this task was not sufficient and required multiple people or the implementation suffered. By digitalizing the software:

- The manpower requirement has been eliminated, and now, the same person is being utilized for monitoring multiple solutions at the same time.
- Guarantee of data collection and report generation on time (Fig. 4).

6 Conclusion and Way Forward

The digital solutions have proven to integrate with lean tools and practices, but this is the tip of the iceberg, the construction industry is still predominately labor intensive. These solutions look at the ways in which the redundant tasks can be automated thus reducing the requirement of engineers doing these tasks. But, as per studies at site, the labor utilization is still below 60% on average in the company, this means there is a scope to increase the productivity by at least 75%, and this needs a collaborative effort from all the stakeholders in the project. Due to a large number of different teams collaborating, the lack of information and delays from one team cascading to rest must be curbed.

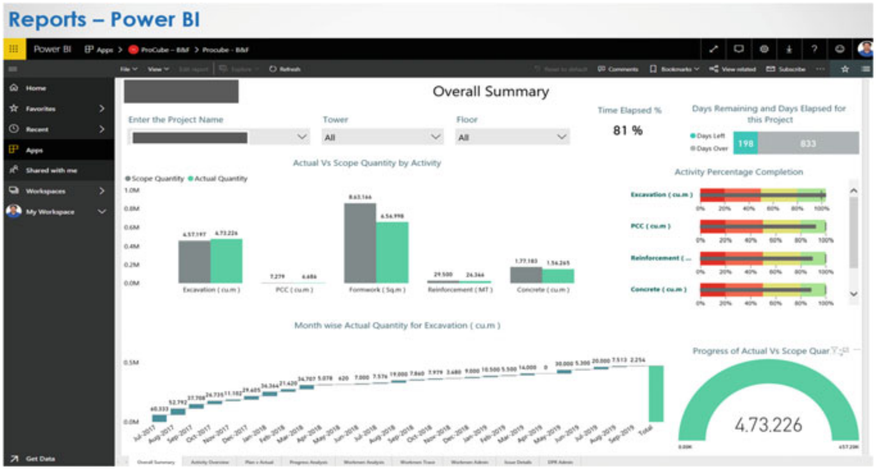

Fig. 4 Sample reports generated by the solution

To do this, digital is the right way forward, but increased lookout toward the common goal rather than maximizing one's profit must be an outlook for all the members in the project.

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Web-Based Visual Project Progress (4D BIM) to Plan and Monitor in a More Lean and Efficient Way

Aswani Reddy Kovvuri

Abstract The architecture, engineering, and construction (AEC) industry is facing many issues in commissioning the projects within the scheduled time and budget. Planning and monitoring the progress of a project plays a vital role in the success of any construction project by avoiding schedule and cost overruns. 4D building information modeling (BIM) is a reliable way to visualize the project's progress and make timely decisions. On the other hand, lean construction is an effective and time-tested way to complete the project within a specified time and budget. We have implemented both BIM and lean construction in one of our project development of logistics park for one of our prestigious customers at Kakinada, Andhra Pradesh. This paper shows how we got benefited from implementing BIM and lean construction in our project and on how 4D BIM could empower the lean construction methods for effective planning and monitoring progress.

Keywords Lean construction · Building information modeling (BIM) · Look-ahead plan · Planned percentage completion (PPC) · Root-cause analysis

1 Introduction

Building information modeling (BIM) has helped many projects to complete with in the planned time and cost parameters over many years. BIM can be used in various planning functions like taking out bill of quantities (BOQ), visualization of various disciplines, integration of structural, architectural, and MEP models to do better clash detection, look-ahead planning, visualization of delayed activities, etc.

Lean construction on the other hand is using the various tools like last planner system, root-cause analysis, constraint analysis, value stream mapping, etc., to reduce the wastage and increase the value to the customer.

Although BIM and lean construction are totally different, studies showed that using technologies like BIM has enhanced the KPIs of construction and reducing

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the wastage [1]. Studies also showed that last planner system supported by BIM can eliminate the drawbacks of implementing the look-ahead plans in traditional construction practices [2].

Implemented at the early stages of the project (pre-construction), BIM will eliminate the many design wastes, thus enhancing the project efficiency [3]. The benefits of BIM and lean construction increase when integrated, and there is a need for a comprehensive frame work for integration of BIM and lean construction [4]. Adrian [5] showed that there are only few studies related to combine use of BIM and lean construction and a significant research gap in this area.

In this paper, we are trying to bridge that research gap between combined use of BIM and lean construction through the case study.

2 Project Brief

Development logistics park at Kakinada, Andhra Pradesh, comes under Factories Business Unit of Larsen and Toubro construction. Considering the importance of project and its stringent timelines, management had decided to implement both BIM and lean construction in this project.

Project scope consists of design and construction of G + 3 office building, 10 nos. of PEB sheds along with utility buildings, roads, open yards, and external development.

3 Methodology Adopted

Figure 1 shows the detailed methodology adopted for the implementation of BIM and lean construction in the project. We have in-house developed 4D platform to visualize the project progress.

All the structural, architectural, and MEP models are prepared by our in-house design team by using the Revit software. Then, all the separate models are combined into one integrated model and analyzed for any clashes using Navisworks. If any clashes are found, then the design team will modify the design to mitigate the clashes (Fig. 2). Then, all the sequential activities are planned, and project schedule is prepared.

The project schedule is linked with integrated model using unique simulation ID's, transforming integrated model into 4D BIM model. Now each element of the model is having a defined start and end date. The 4D BIM model is then uploaded into the in-house developed 4D platform in which we can visualize the project schedule. The 4D platform is an online tool, developed for the visualization of the project progress. With a good Internet connection and Google Chrome browser, anyone with the access to platform can visualize the project progress from any device at any given time without need of any special software.

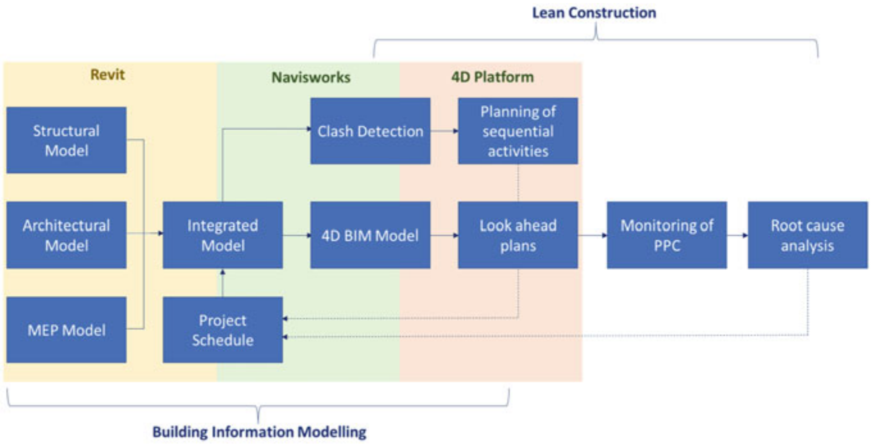

Fig. 1 Methodology adopted to implement BIM and lean construction in project

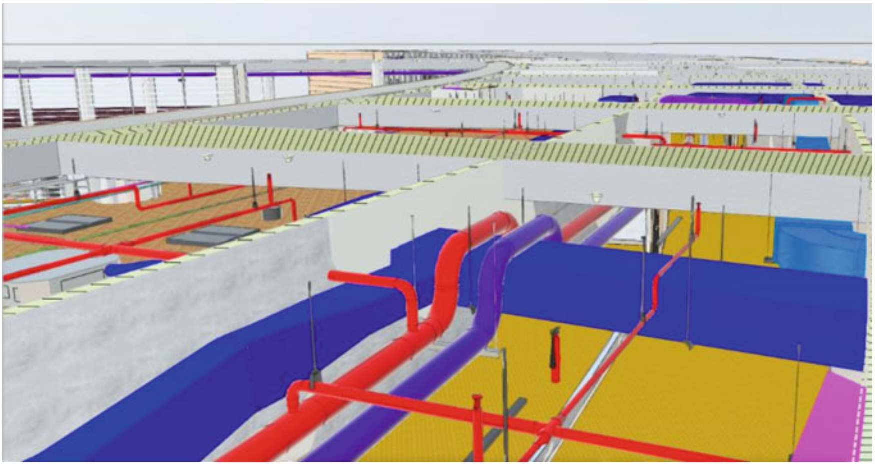

Fig. 2 FPS pipe line rerouted above the HVAC duct after clash detection

The actual site progress is updated regularly by the site BIM coordinator, and one can visualize the on-time, ahead, and delayed activities by the predefined color codes in 4D platform as shown in Fig. 3.

Also, we can visualize the activities that are to be completed at any given point of time in the future by using the forecast option in 4D platform. We have extracted monthly, weekly look-ahead plans using the forecast option. We have monitored the daily PPC and analyzed for root causes for the activities with PPC less than 100%.

We have conducted daily huddle meetings (Fig. 4) to discuss that day's plan and previous day's progress and reviewed the bottle necks. We have also conducted weekly PPC review meetings and monthly constraint analysis meetings involving

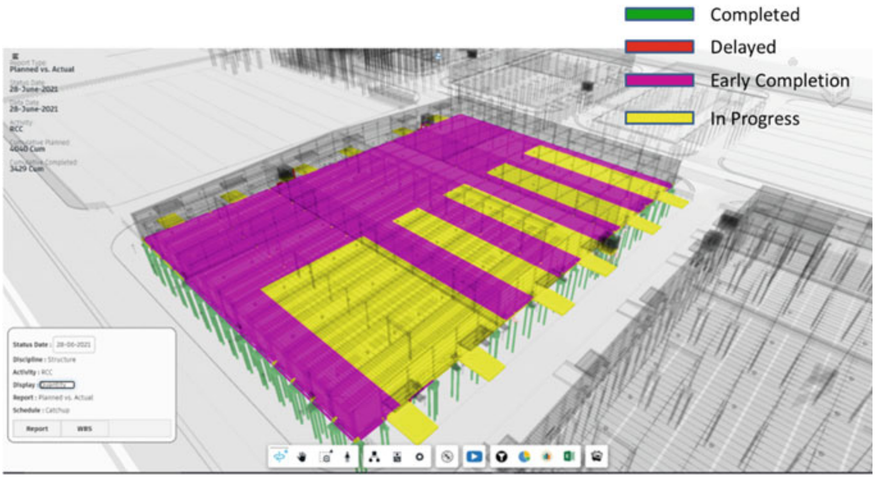

Fig. 3 Visualization of project progress in 4D platform

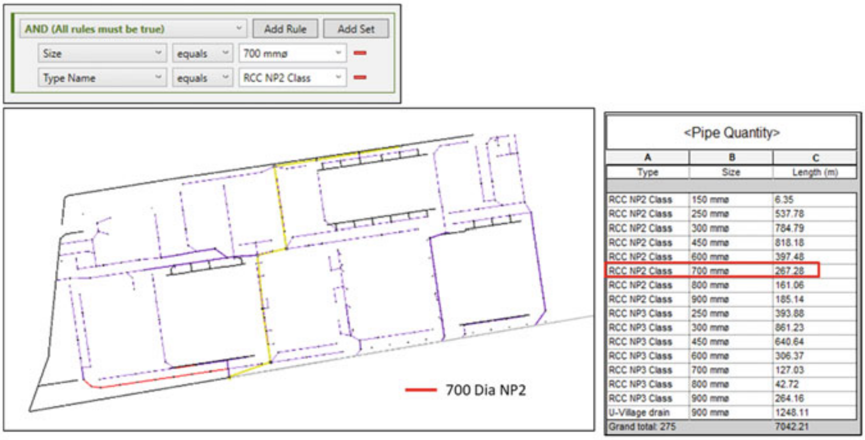

Fig. 4 Quantity take off using revit

all the stakeholders to analyze the constraints for the look-ahead plans and to take timely actions to mitigate the same.

4 Benefits Realized

We have realized the following benefits by implementing the BIM and lean construction in our project.

5 Visualization of the Structure

Reading from multiple 2D drawings of various disciplines and understanding them takes a lot of time of site engineers, and it is sometimes misleading. Instead, the visualization of integrated 3D models of various disciplines enabled the site engineers and construction managers with the better understanding of the structure. Site engineers were able to put more time in planning of the construction activities as time taken for them to read the drawings has reduced drastically. In this way, we have avoided a lot of rework, and productivity of the resources had increased as we have put more time in planning the activities.

6 Quantity Take Off

We have used the 3D models to take out the quantities of concrete, length of pipe lines, and MEP items. It saved a lot of time as we were able to get the accurate quantities of the items with the single click of a button. Apart from taking out the quantities, we have used the 3D models to identify the locations of the particular dia. of pipes for better planning as shown in Fig. 4.

7 Look-Ahead Planning

Instead of following excel and MSP for taking out look-ahead plans, which is time consuming, we have used 4D platform to extract and visualize the look-ahead plans. As the site engineers and construction managers were seeing the elements that are already completed and elements that needs to be completed in the coming weeks, they planned the resources earlier and without any conflicts with other disciplines, which helped in reducing the idling of resources for the want of work clearance from other disciplines.

We have used the visualization of look-ahead plan in the big room meetings to show the plan to all the stakeholders for better coordination between various disciplines.

8 Progress Monitoring

With the visualization of the project progress, we had kept an eye on the delayed activities and identifying the root causes of delay helped us in eliminating the root causes faster. By understanding the certain activity is delaying earlier, we were able to review and mitigate its impact on the subsequent activities, thus reducing the impact of the overall schedule of the project.

9 Conclusion

With the effective implementation of BIM and lean construction, we were able to eliminate the most of the constraints that are impacting the project schedule. We have seen better coordination among the various disciplines as look-ahead planning supported by the visualization of the models in big room meetings helped to plan the activities better, and risk of overlapping of the activities of various disciplines at same location at same time was mitigated.

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Building Trust and Stakeholder Buy-In Through Realization of Collective Benefits in Lean Construction

S. Kamal and Umar Belal

Abstract A lot has been said and done to improve the Lean adoption at construction sites, but still the Lean Champions across projects feel a dearth of motivation from the stakeholder's part. 'If it isn't broken, then don't fix it' attitude correctly represents the inertia, this industry must overcome to achieve the productivity spurt those other industries have achieved decades ago. From a yearlong effort in implementing Lean across 20 project sites, it was well understood that unless we highlight tangible benefit to our stakeholders (own staff, subcontractors, client, material supplier, others) it would be difficult to on-board all of them in our Lean journey. Otherwise, it would be another top down initiative. In order to defeat this notion, we sought ways in which the benefits can be realized at each stakeholder level and once this is achieved a sense of trust in the process can be built.

Keywords Lean benefits · Stakeholders · Culture change · Lean construction · Lean tools · Last planner system™ · Percentage plan complete (PPC)

1 Introduction

The implementation of lean management at a project can be successful when all the stakeholders of a project are dedicated in its implementation and participate willingly to drive it. This can only be done when all the stakeholders are aware of the benefits and the process benefits them in some manner. The challenging part is to put ourselves into the shoes of different stakeholders and understand what their drivers and what would motivate them to start on the lean journey.

The primary reasons for the failure of any change or a new initiative in an organization is the lack of motivation from the various stakeholders, lean implementation

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is a long-term process and the benefits increase as the entire supply chain starts to adopt it. The concern here is once the person driving it leaves the project the entire initiative drops as the various stakeholders have not bought into the process and were doing it to appease the management, this is the cultural change that is focused in this chapter and the best ways to incorporate benefits for all the segments in the lean management system.

2 Literature Review

The primary challenge of incorporating all the stakeholders in the lean management system is spoken by Pramadha, V. and Venkatesan R. in their paper 'Investigation of Advantages, Barriers and Willingness to Adopt Lean Culture in Indian Construction Industry' and also by Karthikeyan, Thamilnathan, and Yuvaraj in their paper Enabling Lean Culture in Indian Construction by Karthikeyan. The gap was in the individual hesitance to adopting the lean principles and tool by the different stakeholders which is being addressed in this paper.

3 Approach and Methodology Adopted

The approach used to in the chapter is first to understand the major stakeholders in the project and take the stakeholders which would be impacted the most and vice-versa would be benefitted the most by the lean implementation at the project. Once the major stakeholders are identified then one on one meetings with them will be organized to understand their driving factors i.e. what would benefit them the most and will make them to adopt lean management.

Once this is completed, then brainstorming sessions with the management team will be done and the lean mentors to identify which lean tolls will satisfy the various stakeholders and how the change management process must be taken up. The same strategy will be discussed with the stakeholders to get their viewpoints and after adjusting the strategies the entire project team must be on the same page with respect to changes to be adopted to implement the lean management at the project site.

Frequent review meeting must be done to ensure the lean practices and tools are being adopted and any concerns or issues that arise must be cleared immediately. Once, the various tools have been implemented at site for a minimum period of two weeks then the differences or the benefits form lean management must be recorded. This will be done by comparing the Original state mapping with the current state mapping and finding the reduction in time taken for the various steps, checking the improvement in productivity for various activities, no of variances and the change in number of variances occurring in a week, PPC trend.

Based on these matrices we can identify the changes that the lean management has brought to the project site and if these changes are having a positive effect or not.

4 Case Study

For the study the major stakeholders considered in the lean management system are:

1. Construction team
2. Project planning team
3. Workmen
4. Suppliers
5. Sub-contractors.

The key drivers and the benefits for each of the stakeholders are different and to identify these interviews were conducted with multiple people from each category to identify the common drivers and benefits and how lean management can satisfy that.

5 Construction Team

Key drivers:

- On time construction
- Availability of resources (man, material, machinery)
- Availability of skilled workmen.

Value addition:

- The Collaborative planning system™ ensures that the plans for the month is broken into smaller daily or weekly targets. These targets are then passed to the workmen and their concurrence is also taken to ensure the success of the task.
- By involving the workmen into the planning circle their constraints are also noted and planned accordingly this increases the probability of success of the planned tasks leading to the activities being completed time.
- In the Big room meeting all the stakeholders including the resource team, stores, Plant and machinery teams are present. This brings all the stakeholders involved in ensuring the availability of resources at the project site to the same table. Once the resource constraints are identified by any engineer for a task, the resource teams can immediately take it up and ensure that the constraints are resolved before it hampers the progress.
- Availability of skilled resources are mandatory as the site engineers plan keeping a specific productivity in mind. If the available workforce is not skilled then plans are not reliable as productivity is not guaranteed. To resolve this the resource team along with the Time Office staff (the team who inducts the workmen into project) are brought to the big room meeting. Once the engineer requests for resources he can specify the skill checks the Time office team can conduct before inducting the workmen to project. This ensures that the project has a skilled workforce.

Fig. 1 Morning huddle meetings for constraint analysis

6 Project Planning Team

Key drivers:

- Reliability of completion of planned tasks
- On time reports of progress from the project team
- Availability of resources as per the planned targets.

Value addition:

- The Collaborative planner system™ takes the inputs for tasks planned till the last level at a project and with the concurrence from all the stakeholders the success factors the planned tasks are very high. Additionally, the PPC along with the list of variances gives the reasons for failures of the planned tasks which can be eliminated in the Big room meetings which further increase the reliability of planned tasks.
- The Collaborative planner system™ once implemented at a project site successfully results in daily progress reports along with the reasons for not completing the tasks automatically to the planning team which saves a lot of effort and time.
- Along with the engineers sharing the requirements for the month, the planning team can add to it and bring the resource requirements for the upcoming quarter. This would provide the resource team adequate time to ensure that requested resources are available on time. With work sampling and PPC the productivity for different activities are available to provide accurate requirements.

Fig. 2 Lean room at construction site

7 Workmen and Sub-contractors

Key drivers:

- Continuous work front
- Availability of resources to do the work on time
- Appreciation for the work performed.

Value addition:

- By discussing the constraints in the weekly big room meeting the site engineers could achieve better coordination with other teams and ensure that each of them had the required clearances form the other team in advance. This led to continued work front to perform tasks and reduction in idling of the work force.
- With coordination with the resource teams and the timely availability of machinery to move the material to the project location the engineers received the material

Fig. 3 Monthly plan discussion being done in the big room meeting

required for construction on time. Furthermore, enabling works for the activity to take place such as quality and safety checks, access to the location, client approvals, etc. were also discussed and resolved in the big room meetings and ensured that work never stopped.
- By ensuring the continuous work from the workmen did not idle and it resulted in better pay for them too.
- Workmen appreciation programs were initiated and mandated across projects were the workmen who adopt the lean principles along with getting high PPC scores were recognized and appreciated in from of the entire project.

8 Suppliers

Key Drivers:

- On-time payments
- Advance information on the future orders to ensure proper planning
- Return of delivery vehicle on time.

Value addition:

- The lead time for bill generation, verification, approval till the payment was tracked and the value stream mapping was used to identify the current state mapping of the process and in the big room meetings with the site engineers who prepare the bill, the payments team who process the bill and the planning team who validate the quantity of work done, the desired future state mapping was generated. Based on the inputs and the limitations of the system the best possible time was finalized and monitored across the future billing cycles. This dropped the overall payment time by two weeks on average.
- With the monthly planned and the future plans finalized with a high degree of certainty in the big room meetings the same plans were shred with the suppliers where there was a material requirement. This provided them with enough time to ensure that production capacities were matched to produce the order.
- A major pain point of multiple suppliers, especially suppliers of bulk material such as reinforcement or cement was the delay in unloading and return and transportation vehicles. This impacted their future deliveries and increased the cost due to idling of vehicles. A separate meeting was organized were the constraints which caused additional wait duration of these vehicles were noted and bottlenecks were removed. This involved changing the vehicles movement for material unloading, planning the delivery timings along with tower crane availability, availability of material inspection team as the delivery occurs, etc. All the steps were taken to ensure that the overall vehicle delivery timings were brought to less than two hours and any outliers were evaluated and the learnings were passed to the team to ensure repetitions did not occur.

9 Results

Based on the discussions with the various stakeholders and the value additions identified in the process the implementation of lean management system was taken from the pilot project to 31 projects across Larsen and Toubro.

Across these 31 projects a cumulative of 2983 staff and sub-contractor engineers were brought into adopting the lean principles.

In the initial pilot we spent 3–5 months in bringing the stakeholders on board whereas in the subsequent projects the entire process was completed in 2 months on average where the entire project team had adopted the lean tools and practices.

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Overcoming Barriers to Adopting Lean Practices in the Construction Industry

S. Kamal, Umar Belal, and Rahul Kisku

Abstract An organization who starts implementing Lean are not able to sustain the implementation level and its slowly deteriorating due to various barriers at different levels. Intuitively we may feel that implementation of Lean Construction (LC) has got to do only with the inertia, but it is often more than that. As complex as a construction project already is, it gets even more difficult to manage numerous constraints for its success. Let us take an example where the project itself is "Implementing Lean Construction." As a last planner, the lean champion needs to list down all the actionable steps for its implementation. Further, a constraint analysis for each of these activities would bring forward the hindrances of LC implementation. For past two years, we have been implementing Lean in our project sites and faced many issues while implementing them. We have been able to implement Lean in our construction projects by overcoming the various barriers. This chapter elaborates how the organization can tackle the various barriers and have strategic approach to tackle all the issues and improve the implementation level.

Keywords Lean construction · Barriers · Lean tools · Quality-cost-schedule · Last planner system™ · Value stream mapping · Work sampling

1 Introduction

Many companies which are trying to implement lean in their projects are struggling to sustain the implementation level and encountering many issues at Human resources level. This chapter will help to identify various barriers in advance which affects the

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adoption of the lean in construction industry and arriving various solution to tackle the barriers and improve the implementation level.

When potential causes have been identified and proper risk mitigation plan in place, the organization/project can overcome barriers and tackle all the issues smoothly.

2 Literature Review

The primary issues identified by Al Balkhy et al. [1] were primarily focussed towards the support from top management and the lack of awareness of lean concepts and principles which hindered the adoption of lean at projects. On the other hand, Devaki et al. [2] primarily focused on data from the questionnaire to the sample size and worked towards analysing the data from the results. This process was the starting point for a similar survey taken to find the exact causes for barriers within the organisation rather than the country. Gupta et al. [3] process of categorisation and ranking of data was understood for development of processes.

3 Methodology Approach

The factors for success and barriers to success are done through questionnaires sent to various stakeholders i.e., Clients, Contractors, Architects, Suppliers, and Consultants. The data is then collected and analysed through statistical models and the results are presented based on its relative pervasiveness.

Identification of Factors for Success

Lean Construction as a new school of thought in Construction industry, compels to review traditional engagement with stakeholders and project delivery metrics (Cost-Quality-Schedule). Refocusing to wastage minimization policy needs a string of initiative for its success. The key factors for success (Fig. 1).

Identification of Barriers for Success

The barriers found through the surveys showed that all the stakeholders had similar perceptions about the problems facing Lean adoption. Irrespective of the differing economic environment, the construction industry in countries stroke a similar chord when it came to application of Lean Construction. The most significant barriers to adopting lean were as follows (Fig. 2):

Strategies to Overcome

To improve the adoption of Lean Construction, the following steps can be taken based on these broad themes. Specific intervention/ initiatives should be driven by construction companies as per its choice.

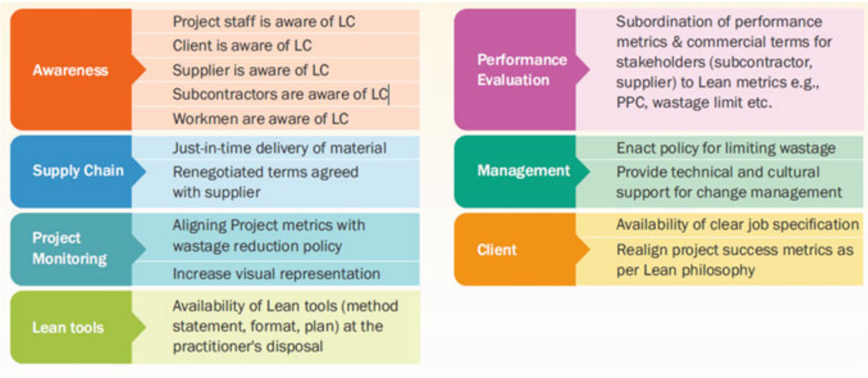

Fig. 1 Key Factors for Success

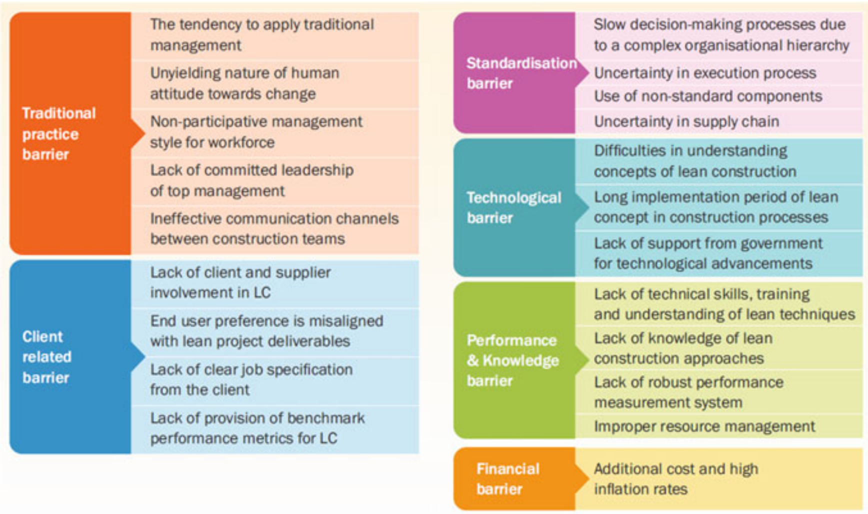

Fig. 2 Most significant barriers to adopt lean

- **Traditional practice barrier**
  - **Breaking hibernation**: No amount of 'Lean' clamor can break the management slumber unless they themselves roll up their sleeves and get serious about implementing lean. Management should be open and committed to make changes in such a way that it has a profound effect in organization culture. Enacting new policy, attaching bonus compensation with lean metrics are a few amongst low hanging strategies to adopt.
  - **Process orientation**: A project needs to be understood from a perspective of an unbroken chain of value generating activities. Rather than focusing on

maximizing efficiency of individual activity and productivity out of a resource, concerted effort should be put into removing wastage, idling of resources and removal of bottlenecks from the process. Many a times focus on productivity and efficiency in individual activity leads to sub-optimal outcome. This often baffle conventional thinking 'if I finish my job on-time, the whole project will be finished on-time'.

  – **Collaborative leadership**: The complexity in a construction project lies in its interdependency. So, a robust communication and cooperation strategy is indispensable. Traditional systems of individual contracts and functional specialization obscure our ability to see and understand all the interdependencies in a typical project. LC requires rigorous collaborative leadership through the project life cycle, and adoption of a "whole systems" perspective.

- **Client-related barrier**
  – **Overhauling contractual term**: One of the most prominent influencers in a project is invariably the client. So, the onus of effecting LC is also on client. If they insist on the adoption of LC in the delivery of their projects by inserting lean construction clauses in their contracts, the contractors will automatically oblige and implement.
  – **Project delivery metrics**: Clients need to desist from evaluating the success of their projects primarily based on quality, cost, and time. Although these metrics are consistent with the outcome of lean application, but it has an intuitive effect on promoting same traditional methods one is trying to shed.
  – **Quality-cost-schedule counterbalancing fallacy**: Traditional wisdom argues 'Quality-Cost-Schedule' are competing metrics. If one is paid more attention to, the other parameters suffer and vice-versa. So, a fine act of balancing is necessary for project success. However, a single-minded focus on reducing process variability will lead to better reliability (less rework), better flow (less waste) which improves the Quality-Cost-Schedule triad.

- **Standardization barrier**
  – **Forging strategic partnership**: Construction companies should engage in long-term relationships among themselves to strengthen their working relationships in the construction supply chain to be aware of each other's style of managing projects with minimal uncertainties.
  – **Standardization**: Usage of standards such as the International Standards Organization (ISO) frameworks to benchmark performance requirements in a standardized format in the construction supply chain can be explored. Common metrics which can be followed by various stakeholders (contractors, suppliers, subcontractors) to implement LC should also be developed in the construction supply chain.

- **Technological barrier**
  – **Start small**: Rather than an aggressive and one-off implementation approach, a step by step or simplified implementation of LC is necessary to enable

stakeholders to gain conviction and adapt to the technological sophistications involved.
  - **Visualization mechanism**: These sophistications can also be reduced by supporting the implementation of LC with visualization mechanisms such as building information modelling (BIM) to enable contractors to easily monitor the process.
  - **Generate knowledge**: The basis of knowledge is theory, and when facts contradict theory an active effort should be taken to understand why. Merely capturing data points does not suffice. Emphasis should be put into generating insight and uncover the underlying phenomenon. This is how construction companies can contribute to the riches of LC and benefit the industry.

- **Performance and knowledge barrier**
  - **Training of workforce**: Adequate training should be provided to the workforce, which includes own staff, suppliers, subcontractors, and other parties involved in a project. Focus should be given on those construction professionals who are responsible for daily activities. Apart from specific tools (LPS, VSM, Work Sampling) the trainings should also emphasize on other lean philosophies, that is, Just-in-time delivery, pull planning and principles of wastage reduction to ensure a balanced understanding required to undertake the concept.
  - **Empowered staff**: Management should support the involvement and the innovation of the employees from various levels by providing training, motivating, and empowering them to take decisions.

4 Conclusion and Way Forward

The above discussed topics will provide a clear idea to the companies who are planning to implement Lean Construction in terms of the future issues they might face and a way to address the issues their corporation is currently facing.

The information about the discussed barriers and ways to overcome them can provide the corporates to take a preventive approach as to address the problems before they may arise and thus saving valuable time and effort.

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Utilization of Augmented Reality in Construction Projects

Kishore Kumar Dasam and Umar Belal

Abstract The primary causes of delays in construction projects and the drop in planned percent completion is the lack of coordination between various stakeholders. This issue can be addressed by Building Information Modeling (BIM) and especially the use of augmented reality in BIM. BIM is a popular information handling process. Despite its potential, the utilization in construction phase is very limited due to the lack of interaction between real and virtual worlds. As technologies evolve, so does our nature of imagining and visualizing something. Construction design is heavily dependent upon visualization, so it is no wonder that new data visualization technologies like AR and VR would influence and enhance BIM in leaps and bounds.

Keywords Lean construction · Building Information Modelling (BIM) · Augmented reality · Lean management · Digitalization · Digital solutions

1 Introduction

Introducing Augmented/Virtual/Mixed Reality into BIM is believed to greatly increase the utilization of BIM in construction phase. Of these, AR (Augmented Reality) was chosen as the primary visualization tool, as it had the least utilization of hardware (mobile or tablet is sufficient) and the most scope in terms of utilizing BIM in the traditional construction process, over Virtual Reality. Mixed Reality or Augmented Reality creates a layer of the model over the On-site or real-world scenario.

For implementing this technology, an institutional project is chosen. This Project comprises the construction of the Permanent campus of the institute with 3 Design packages: (Academic Zone), (Hostel Zone) and (Residential Zone).

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The software adopted for the federation and interaction with BIM model were: Revit (.rvt), Navisworks (.nwd,.nwc) and IFC (Industry Foundation Class). For visualisation of the BIM model in Augmented Reality, Trimble Connect AR was chosen as the mobile application.

2 Literature Review

Visualizations of construction projects helps the various stakeholders in identification of issues in areas where multiple services or disciplines interact in an easier manner and augmented reality assist in that. By extending 4D BIM to planning site layouts and logistics the teams can make effective decisions from a view point of constructability.

The 3D models are very effective in visualizations of projects but this is limited to a device and the real-world scenarios are very different in which AR can provide assistance as explained in by Christian Schranz, Harald Urban and Alexander Gerger in their paper "Potentials of Augmented Reality in a BIM based building submission process" [1]. Similarly, there were a lot of documentation explaining the possibilities and the benefits of AR in construction industry [2, 3].

The paper looks at from the lens of a practitioner implementing the AR at a construction project and the challenges and benefits realised.

3 Need for Study

For the purpose of implementation of AR/VR technology in BIM, several Use Case scenarios were identified. Using a survey questionnaire, the preferred software and Use Cases with most potential were ascertained. Out of these, Quality Inspection was identified and chosen for the implementation use case.

The Workflow development involved the federation and upload of the particular BIM models onto the Trimble server and further visualizing it on the mobile app and utilizing various features within the application. The implementation of the Workflow thus created, was executed by demonstration of the app live On-site for the Execution team.

4 Case Study

Project Chosen: Institution Building

Building Name: Health Center

See Figs. 1 and 2.

Fig. 1 Health center

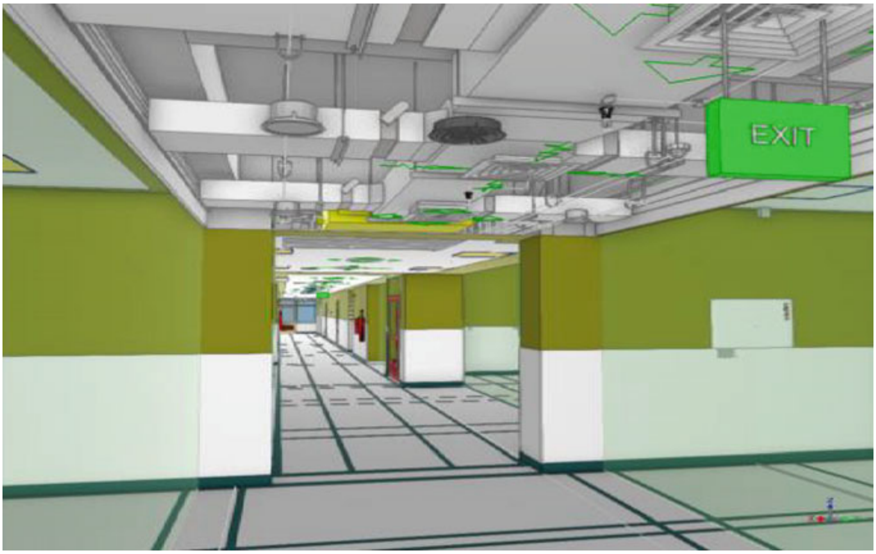


Fig. 2. 3D view of OPD hall

5 Workflow for AR Utilization

- Federation and coordination of the Revit Models and uploading into Trimble Connect Cloud in different Formats: .rvt, IFC, .nwc, .nwd.
- Generation of QR code digitally inside the model at a convenient and pre-determined location to place it on site.
- QR code placement: The requisite number of QR codes required, the network, i.e., the appropriate placement and spacing to achieve optimal distribution.
- Scanning of QR code: for loading and alignment of the model on site.
- Use and application of various features of Trimble Connect, facilitating easier visualization (Figs. 3, 4, 5 and 6).

Fig. 3 QR code placement

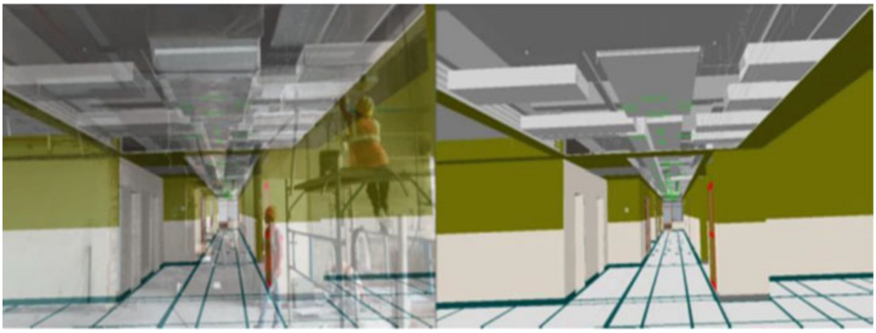


Fig. 4 Superimposing of 3D model in real world

Fig. 5 Utilizing tablet/mobile to view block work models

6 Results

6.1 Benefit Realization

6.1.1 Pre/Postactivity Quality Inspection to Ensure the Construction is as Per Designed Intent

Traditionally Quality Inspection is carried out before and after the execution of specific activities along with a predefined checklist for concurrence. One of the key check points is the reference to Design information/drawings and ensure the execution is carried out as per Design intent. One of the challenges here is to refer

Fig. 6 Utilizing tablet/mobile to view false ceiling models

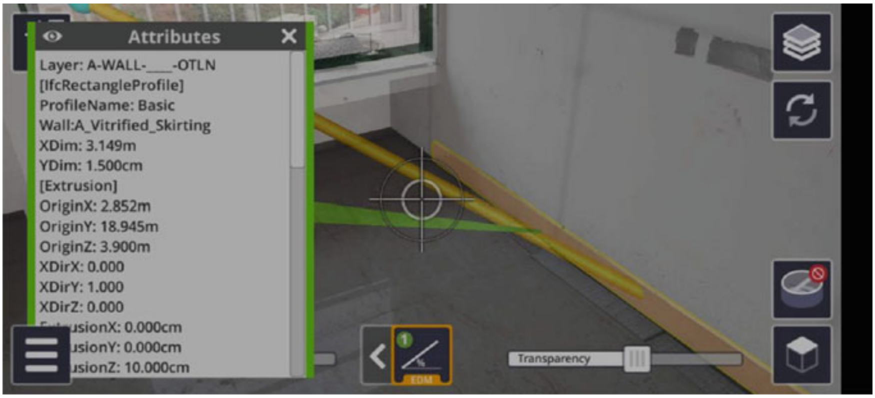


Fig. 7 Parametric information of elements over mobile device

to multiple Drawings (Sections, Elevations, coordinated layouts, etc.) to understand the Design intent and any missing information during this stage would delay the Inspection process and can impact the subsequent activities.

So, utilizing AR would allow for access to complete activity specific information in a single view over mobile device (Fig. 7).

Fig. 8 Comparison of actual condition and 3D models

6.1.2 Interface Management, Allowing to View Multi-disciplinary Model Elements in the Same View Before Execution

Interface management being one of the critical activities for successful closure of activities without rework. It is crucial to ensure the availability of relevant information for better Interface management.

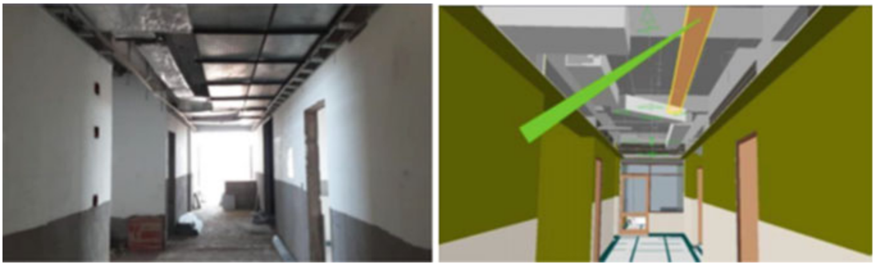
AR technology would allow the access to multi-disciplinary 3D model information that could be visualized over mobile devices (Fig. 8).

6.1.3 As Built Markups, Capturing the Changes/Deviations at Site

On site changes are inevitable because of the complex coordination challenges. It is important to capture such changes in a proper documented way to further record and submit the As Built information to client.

Traditionally, this is done using Red line markups on drawings along with relevant photographs for reference. However, there are many instances where data mismatch and incomplete information would be populated, leading to incorrect output.

AR technology helps in visualizing the design intent and the actual constructed form at the same time and allows the user to capture information on the deviations using markups and snapshots in the same view. This gives more clarity on the deviation and helps the team to update As Built drawings more accurately.



In the above case, Cable tray has been placed below the HVAC duct due to on site cable pulling constraints. However, design intent was to place the cable tray above the duct.

By super imposing the Design model on the actual construction view, the required deviation was easily captured and recorded for further reference and update.

7 Challenges

- Initial/operating cost
- Lack of BIM trained personnel
- Frequent Revision of Design models
- Reluctance to change/non-adaptiveness
- Interoperability issues
- Visibility of the BIM model over mobile devices in day light
- Creation of network of markers and QR codes (Fig. 9).

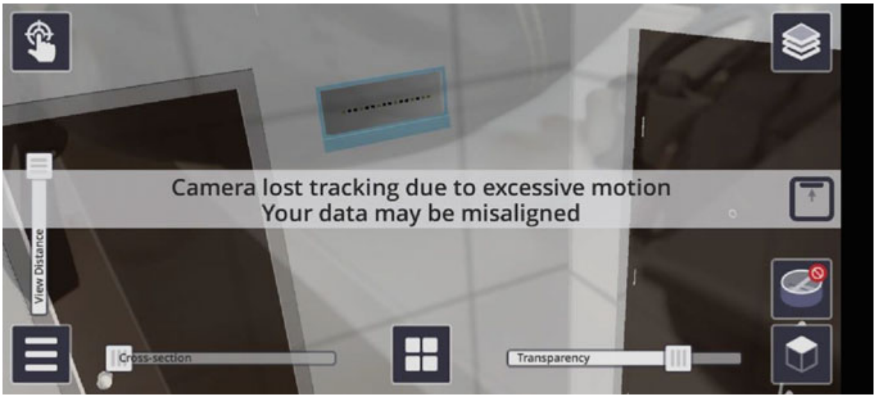


Fig. 9 Misalignment of 3D model due to drift

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CO_2 Life-Cycle Assessment of Prefabricated and Cast-In-Situ Structure Using Monte Carlo Simulation

Shyam Kumar Inturi and Venkatesan Renganaidu

Abstract CO_2 emissions have become a part of common vocabulary as a result of the significant negative effects of climate change. Through the supply of buildings and infrastructure for the smooth operation of a business, the construction sector plays a vital role in the growth of an economy, both directly and indirectly. However, due to carbon emissions from materials and energy, this business is currently facing significant challenges. Prefabrication has grown in popularity in nations as a result of its several benefits, including quality control, waste minimization, onsite and offshore parallel to coordination, and so. It's also been identified as a crucial approach for reducing carbon emissions caused by buildings. However, there has been little study into reducing carbon emissions in prefabrication through the use of advanced technical artefacts such as Building Information Modelling (BIM), which are emerging from the technology realm. The goal of this article is to provide a BIM-based method for calculating carbon with the usage of the PLCA method. During the materialization stage of a prefabricated construction project, there is a decrease. Partial Life-cycle Assessment (PLCA) is an efficient and effective technique for estimating carbon emissions from new building construction, according to the study's findings, and prefabrication reduces carbon emissions when applied. After computation, the comparison is being done using the Monte Carlo simulation to find the percentage difference and this software helps to find the iteration for different scenarios. The study adds to the corpus of knowledge on carbon emissions reduction through prefabrication. Contractors, house buyers, and authorities who are continually looking for methods to build a circular economy should be aware of life cycle assessment of CO_2. In this study, we are exploring how pre-fabricated structures are the need of the future and their usefulness to the very extent to determine the emissions at the production, transportation and construction phases of the building life cycle. And determine the amount of CO_2 emissions in the pre-fabricated structure by comparing it with the

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cast in situ and to differentiate the result by creating a simulation through Monte Carlo analysis.

Keywords CO_2 emissions · Buildings and infrastructure · Building Information Modelling (BIM) · Partial life cycle assessment (PLCA) · Monte Carlo simulation

1 Introduction

Concrete's environmental impact is critical for the building sector to ensure long-term sustainability. Researchers are actively working on creating a 'green' and sustainable concrete construction. CO_2 emission is frequently used to determine if a product is ecologically friendly due to its relevance of global climate change and greenhouse gases. The goal of achieving environmental sustainability and carbon neutrality in concrete manufacture and products may be seen from two perspectives. In the construction business, concrete is one of the most often utilized building materials. Its progress towards environmental sustainability will, in turn, influence the construction sector as a whole to become more ecologically conscious. Furthermore, the manufacture of concrete necessitates a large amount of energy. According to studies, each kilogramme of Portland clinker emits almost one kilogramme of CO_2 into the environment. The total carbon emissions from precast concrete units are substantially higher.

Thus, due to the faster rate of construction, fire protection, productivity improvement, etc. and also the reduction of waste can be achieved with the precast building. Which the demand for the prefabricated housing is very high in other developed countries include the United Kingdom, the Netherlands, Germany and other. Precast technology concrete is said to provide 'environmental' advantages. Using a specific form of precast concrete construction, this study intends to begin estimating the embodied carbon of precast concrete goods. The methods and findings of this study will help any construction sector establish an environmental inventory of construction materials and products. It can also aid in the development of an eco-labelling system.

Very few Indian studies is there on the pre-fabricated work which need not conclusively support the findings of the foreign authors more works in Indian sector context is needed.

Only the emission of CO_2 is mainly focused but for the overall air pollution other harmful gas emission should also be considered and measured.

Optimization of this CO_2 emission and the process involved in this should be mentioned and how different Prefabrication technique shows variation in the CO_2 emission.

This study aims to rectify the emission of CO_2 from the prefabricated construction and a comparative study between the conventional type of concreting or cast-in-situ and Prefabricated structures with the life cycle boundary from cradle to end of construction and how it is affecting the environmental conditions. The difference in

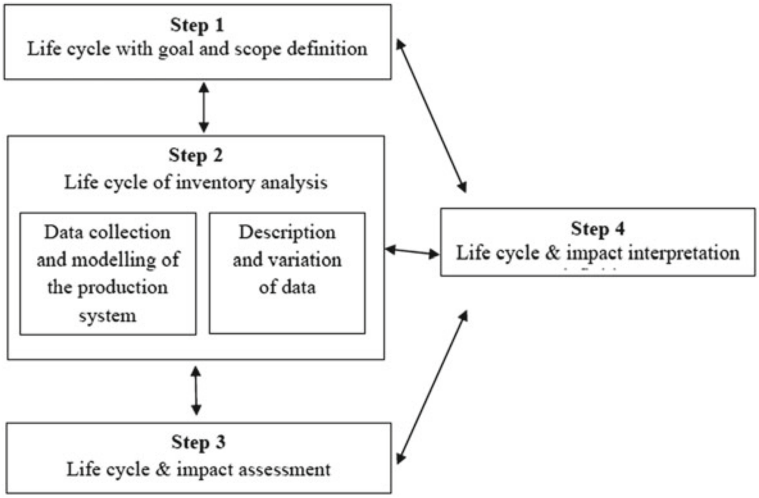


Fig. 1 Four steps in conducting a PLCA study

the CO_2 Gas emission from both types of construction which at the end affects the climatic change in a minor level.

2 Methodology

The study is based on evaluating CO_2 emission by comparing a cast-in-situ and a precast building of same Built-up area by using Process Life Cycle Assessment (PLCA) of a building in with combining it with BIM model study in this PLCA we need to trace and identify the physical flow of goods and services of carbon emitting materials. Compiling the inventory of the relevant inputs and the outputs of product system, also evaluation of potential environmental impacts.

It will outline four phases to be performed which encompass:

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment, and
4. Interpretation (Fig. 1).

3 Prefabricated Building

A prefabricated building project is selected for a case study, located in Bangalore, Karnataka. The building details are mentioned in Tables 1 and 2.

Table 1 Scope and structural pattern

Purpose	Extension of Nh 704a which includes manufacturing, logistics, office space, extension of dining areas, auxiliaries, gate house, scrap yard, fire tender parking shelter, organic waste converter and covered parking at Naganathapura
Built up area	14,900 m^2
Building area	7000 m^2
Excavation area	No basement construction (all footings were of isolated footings with avg. dimensions of 5 m^2 with an avg. depth of 1.5 m
Basic structural pattern	79 no. Isolated footings and 3 combined footings (where lifts and staircases are necessary) the building is of framed structure
External walls	External design was of façade panels, with exposed Basant Beton block work finished with water proof sealer coats and precast RCC façade elements

Table 2 Carbon emission factors of different materials and energies

Materials	CE factor	Units
Concretes	322.54	$KgCO_2$ eq/m^3
Steel bar	2618.71	$KgCO_2$ eq/m^3
Steel plate	2701.21	$KgCO_2$ eq/m^3
Block	234.36	$KgCO_2$ eq/m^3
Stone	235.35	$KgCO_2$ eq/m^3
Diesel	0.78	$KgCO_2$ eq/m^3

4 Quantity Surveying Using BIM

Quantity surveying is an important aspect of the process to calculate the CE for a structure during the materialisation stage, when an accurate interpretation of designs and numerical representations of resource consumption are necessary. Volume surveying must be done the old-fashioned way since the usual computer-aided design (CAD) platform is inappropriate for storing the data necessary for the automatic accounting of resource usage. This method is sluggish and inefficient, and it makes a lot of mistakes. BIM is a database that contains a wealth of engineering data on components and parts that may be utilized to compute precise resource utilization.

To use BIM for CE analysis, you must first create an introduction BIM model of the supplied construction design based on the architectural and structural delineations.

As a result, the model is ready to estimate the structure's bill of quantities.

Erecting factors such as shafts, columns, and staircases are constructed using the parametric modelling technique of BIM by entering shape, raw material, and other parameter information according to the design scheme and CAD delineations. The construction of a single bottom, and hence the entire structure, is formed by colourful components. This allows for the creation of 3D image models of a specified construction (Figs. 2 and 3).

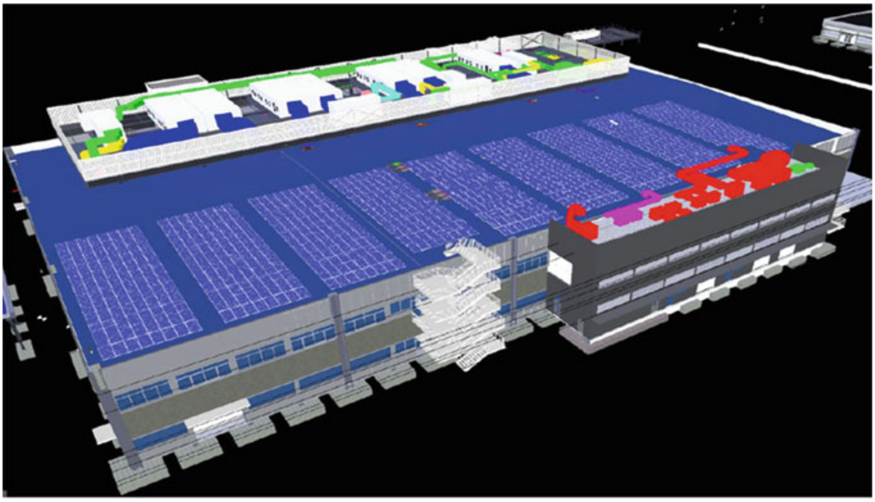


Fig. 2 3D rendering model of the whole building

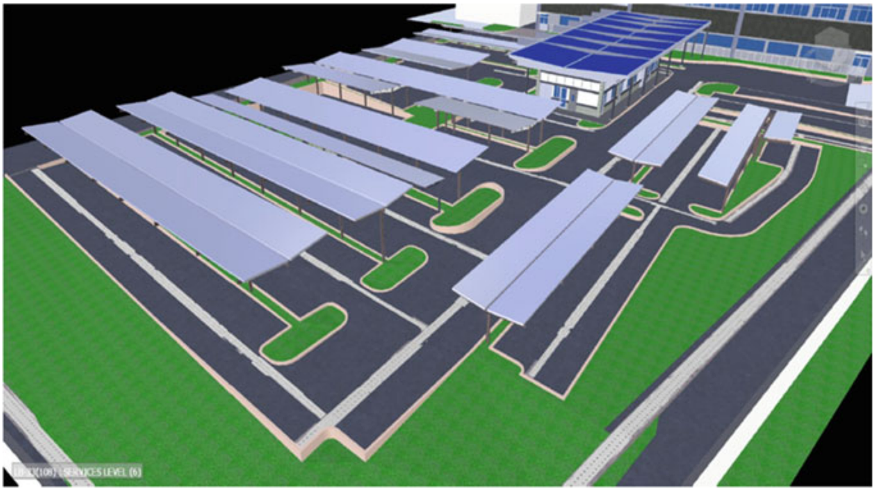


Fig. 3 3D rendering model of a parking area

As base BIM structure is complete, we can enter different component and material to the application, which will do statistical analysis and provide a bill of quantities in the form of table.

The total concrete quantity consumed for the construction of the building can be taken off from the BIM model and it is exported to an excel.

Similarly, the total concrete quantity consumed by the precast slab, core wall, façade wall and the staircase are taken off from the BIM model (Table 3).

Table 3 Total concrete quantity consumed by all the precast components

Components	Concrete quantity (m^3)
Precast column	453.33
Precast beam	
Beam type 1	107.17
Beam type 2	634.04
Beam type 3	127.94
Beam type 4	83.63
Precast slab	
Slab type 1	4275.85
Slab type 2	216.05
Precast façade panel	
Façade type 1	265.10
Façade type 2	255.21
Façade type 3	80.41
Façade type 4	74.80
Precast core wall	252.13
Precast staircase (flights and landing)	66.16
Total concrete quantity	6891.82

Similarly, the total carbon emission during the transportation stage of the precast components from factory to the respective site will be evaluated.

The Katerra industrial precast factory is of 60 km away from the construction site.

The precast components are transported using a 40 feet trailer.

The total of 1028 nos. precast components required for the project which comprises of precast column, beam, slab, core wall, and façade panel.

The arrangement is made on the trailer to fit the maximum tonnage as per the safe load of the trailer.

The data are collected, number of vehicles required for the transportation of components and km is noted.

Hence the kilometre travelled will be multiplied with the CE factor to get the total carbon emission.

5 Cast In-Situ Building

For comparison of carbon emission, the cast in-situ which is of Manasa Sarovar Hotel Project located in Tirupati, Andhra Pradesh is also collected is as bellow (Tables 4 and 5):

Table 4 Scope and structural pattern of cast in-situ project

Purpose	Manasa sarovar hospital building is to anticipate people's future needs and deliver sustainable, inclusive, and resilient care
Built up area	7000 m^2
Building area	4000 m^2
Excavation area	No basement construction (all footings were of isolated footings with avg. dimensions of 5 m^2 with an avg. depth of 1.5 m
Basic structural pattern	59 no. Isolated footings and 5 combined footings (where lifts and staircases are necessary) the building is of framed structure
External walls	External design was of ACP cladding, which improves the aesthetic of the building

Table 5 Total concrete quantity for the cast-in-situ component structures

Components	Concrete quantity (m^3)
Footing	605.25
Column	445.02
Beams	
Raft beam	40.42
Plinth beam	172.67
Floor beam	816.90
Beam type 4	83.63
Slab	
Slab upto 150 mm	1115.42
Slab 150–250 mm	176.62
Slope slab	97.64
Total concrete quantity	3108.55

6 Results and Discussions

PLCA Calculations

The fundamental models that are used for determining the consumption of the three analysed components of the total overall building life cycle CO_2 emissions is

$$\text{Total } CO_2 = P_{CO_2} + F_{CO_2} + W_{CO_2} \tag{1}$$

For calculating the total CO_2 production, we need to find the Electricity, Fuel, and Water consumption calculating its total value then computing the total of it.

For calculation of structure to make both Pre-fabricated and Cast-in-situ structures same for calculation and comparison purpose we have extrapolated the built-up area of Cast-in-situ structure and made it double to match with the build-up area of Pre-fabricated structure. After extrapolation cast-in-situ quantity modified from 3108.55 to 6837 m^3.

Electricity Consumption

For Pre-Fabricated Structures

$$P_{CO_2} = (10017171.06 + 3858960) * 0.1$$
$$P_{CO_2} = 1387613.1$$

For separate calculation of $P_{\text{manufacturing}}$ and $P_{\text{transportation}}$

$$\begin{aligned}
P_{\text{manuf}} &= P_{\text{material}} + P_{\text{transp}} \\
&= \sum_{i=1}^{n} m_i * \left(1 + \frac{W_i}{100}\right) * M_i + \sum_{i=1}^{n} m_i * \left(1 + \frac{W_i}{100}\right) * d_i * V_c \\
&= \sum_{i=1}^{1} 6891 * \left(1 + \frac{7}{100}\right) * 560 \\
&\quad + \sum_{i=1}^{1} 6891 * \left(1 + \frac{1}{100}\right) * 60 * 14.1 \\
&= 4129087.2 + 5888083.86 \\
&= 10017171.06 \\
P_{CO_2} &= (10017171.06 + 3858960) * 0.1 \\
P_{CO_2} &= 1387613.1
\end{aligned} \tag{2}$$

For separate calculation of $P_{\text{manufacturing}}$ and $P_{\text{transportation}}$

$$\begin{aligned}
P_{\text{manuf}} &= P_{\text{material}} + P_{\text{transp}} \\
&= \sum_{i=1}^{n} m_i * \left(1 + \frac{W_i}{100}\right) * M_i + \sum_{i=1}^{n} m_i * \left(1 + \frac{W_i}{100}\right) * d_i * V_c \\
&= \sum_{i=1}^{1} 6891 * \left(1 + \frac{7}{100}\right) * 560 + \sum_{i=1}^{1} 6891 * \left(1 + \frac{1}{100}\right) * 60 * 14.1 \\
&= 4129087.2 + 5888083.86 \\
&= 10017171.06
\end{aligned} \tag{3}$$

Electricity Consumption

For Cast-in-situ Structures

$$\begin{aligned} P_{CO_2} &= [P_{\text{manuf}} + P_{\text{erect}}] \times \bar{\lambda} = \text{cf} = 0.385, \\ hf &= 10, C_{CO_2} = 12.01, Cm = 44.01 \\ P_{CO_2} &= (5867513.4 + 6484157.89 + 3828720) * 0.1 \\ P_{CO_2} &= 1618039.13 \end{aligned}$$

For separate calculation of $P_{\text{manufacturing}}$ and $P_{\text{transportation}}$

$$\begin{aligned} P_{\text{manuf}} &= P_{\text{material}} + P_{\text{transp}} \\ &= \sum_{i=1}^{n} m_i * \left(1 + \frac{W_i}{100}\right) * M_i + \sum_{i=1}^{n} m_i * \left(1 + \frac{W_i}{100}\right) * d_i * V_c \end{aligned} \tag{4}$$

For Concrete

$$\begin{aligned} &= \sum_{i=1}^{1} 6837 * \left(1 + \frac{15}{100}\right) * 560 + \sum_{i=1}^{1} 6837 * \left(1 + \frac{2}{100}\right) * 15 * 14.1 \\ &= 4403028 + 1464485.4 \\ &= 5867513.4 \end{aligned}$$

For Reinforcement

$$\begin{aligned} &= \sum_{i=1}^{1} 617 * \left(1 + \frac{7}{100}\right) * 8890 + \sum_{i=1}^{1} 617 * \left(1 + \frac{1}{100}\right) * 70 * 14.1 \\ &= 5869089.1 + 615068.79 \\ &= 6484157.89 \end{aligned}$$

For Construction Work

$$\begin{aligned} P_{\text{erect}} &= P_{\text{construction}} \\ &= \sum_{j=1}^{Cm} q_j * Q_j \\ &= \sum_{j=1}^{1} 6837 * 560 \\ &= 3828720 \end{aligned} \tag{5}$$

Fuel Consumption

For Pre-Fabricated

$$F_{CO_2} = \sum_{i=1}^{m} \left(\left(F_i * F_i^{ec} \right) - \left(F_i * F_i^{ec} * F_i^{cs} \right) \right) * FCO_i * \bar{\lambda}$$
$$F_{CO_2} = 222.5 + 481.26 + 570.9 + 17097.24$$
$$F_{CO_2} = 18371.9 \quad (6)$$

For 220 Ton Crane (No. of crane = 2)

$$= \sum_{i=1}^{1} ((0.72 * 6 * 2.62) - (0.72 * 6 * 2.62 * 0.5)) * 0.98 * 3.67$$
$$= 111.25 * 2 = 222.5$$

For 10 Ton Crane (No. of crane = 3)

$$= \sum_{i=1}^{1} ((0.44 * 6 * 2.62) - (0.44 * 6 * 2.62 * 0.5)) * 0.98 * 3.67$$
$$= 160.42 * 3 = 481.26$$

For 7 Ton Crane (No. of crane = 2)

$$= \sum_{i=1}^{1} ((0.32 * 6 * 2.62) - (0.32 * 6 * 2.62 * 0.5)) * 0.98 * 3.67$$
$$= 285.45 * 2 = 570.9$$

For 40 Feet Trailer (No. of crane = 4)

$$= \sum_{i=1}^{1} ((0.14 * 108 * 2.62) - (0.14 * 108 * 2.62 * 0.5)) * 0.98 * 3.67$$
$$= 4274.31 * 4 = 17097.24$$

Water Resource Consumption

For Pre-fabricated

$$W_{CO_2} = [W_{manuf} + W_{erect}] \times \bar{\lambda}$$
$$W_{CO_2} = (1042057 + 2584125) * 0.193$$
$$= 699853.12 \quad (7)$$

For separate calculation of $W_{\text{manufacturing}}$ and $W_{\text{transportation}}$

For Concrete

$$\begin{aligned} W_{\text{manuf}} &= W_{\text{material}} + W_{\text{transp}} \\ &= \sum_{i=1}^{n} Q_i * \left(1 + \frac{W_i}{100}\right) * N_i * K_2 + \sum_{i=1}^{n} Q_i * \left(1 + \frac{W_i}{100}\right) * d_i * V_w \\ &= \sum_{i=1}^{1} 6837 * \left(1 + \frac{15}{100}\right) * 130 * 1 + \sum_{i=1}^{1} 6837 * \left(1 + \frac{2}{100}\right) * 90 * 0.2 \\ &= 1022131.5 + 20921.22 \\ &= 1043052.72 \end{aligned} \tag{8}$$

For Reinforcement

$$\begin{aligned} W_{\text{manuf}} &= W_{\text{material}} + W_{\text{transp}} \\ &= \sum_{i=1}^{n} Q_i * \left(1 + \frac{W_i}{100}\right) * N_i * K_2 + \sum_{i=1}^{n} Q_i * \left(1 + \frac{W_i}{100}\right) * d_i * V_w \\ &= \sum_{i=1}^{1} 341 * \left(1 + \frac{7}{100}\right) * 130 * 1 + \sum_{i=1}^{1} 341 * \left(1 + \frac{1}{100}\right) * 70 * 0.2 \\ &= 47433.1 + 4821.74 \\ &= 52254.84 \end{aligned} \tag{9}$$

For Construction Work

$$\begin{aligned} W_{\text{erect}} &= W_{\text{construction}} \\ &= \sum_{j=1}^{Cm} e_j * E_j * K_1 \\ &= \sum_{j=1}^{1} 6837 * 150 * 2.5 \\ &= 2563875 \end{aligned} \tag{10}$$

Total CO_2 Emissions

For finding and calculating the total CO_2 emission we need to sum up the CO_2 form Electricity, Fuel and Water usage in the different stages.

Total CO_2 emission (Kg-CO_2) for Pre-Fabricated Structure

$$\begin{aligned}\text{Total}_{CO_2} &= P_{CO_2} + F_{CO_2} + W_{CO_2}\\ \text{Total}_{CO_2} &= 1387613.1 + 18371.9 + 699853.12 = 2105838.1\end{aligned} \quad (11)$$

Total CO_2 emission (Kg-CO_2) for Cast-in-Situ Structure

$$\begin{aligned}\text{Total}_{CO_2} &= P_{CO_2} + F_{CO_2} + W_{CO_2}\\ \text{Total}_{CO_2} &= 1618039.13 + 31548.5 + 706222.2 = 2355809.8\end{aligned} \quad (12)$$

Percentage difference between the CO_2 emission of both types of structure

$$P\%_{\text{diff}} = 10.61\%$$

See Table 6.

Hence, the main percentage difference of CO_2 between the Pre-Fabricated and Cast-in-situ Structure came to be 10.61%.

Table 6 % CO_2 difference between pre-fabricated and cast-in-situ

Phase of building life cycle	CO_2 emission (kg-CO_2)		Percentage (%)	
	Full prefabricated	Cast-in-situ	Full prefabricated	Cast-in-situ
P_{CO2} (electric usage)	1,387,613.1	1,618,039.13	65.89	68.68
F_{CO2} (fuel usage)	18,371.9	31,548.5	0.87	1.33
W_{CO2} (water usage)	699,853.12	706,222.2	33.23	29.98
Total	2,105,838.1	2,355,809.8	100	100
	Full prefabricated	Cast-in-situ	Full prefabricated	Cast-in-situ
Manufacturing and transportation phase	11,077,599	13,478,527	63.22	67.83
Construction phase	6,443,085	6,392,595	36.77	32.17
Total	17,520,684	19,871,122	100	100

7 Monte Carlo Simulation Approach

7.1 *Need of Analysis*

In the Uncertainty that can impair accuracy in the PLCA when estimating the environmental burden. MCS is known to analyse the environmental loads in order to address this issue. The assessment findings were turned into the probability of distribution in functional values from their deterministic values. MCS lowered the likelihood of decision makers making wrong judgments after misjudging things by taking into account the uncertainty in LCA result.

This is done to find the percentage difference that can be created with difference in the percentage of the inputs that can be wastage, amount of material used for production, transportation distance and many other factors for that variation of 5–10% we need to analyse a correct output that can be created for this the simulation technique is used for creating a multiple iteration so that various factors could be considered for deriving a maximum, minimum and a most likely output.

7.2 *Working of Analysis*

The integrals of values have been supported by MCS. Assume Y is functional value which is to be determined (for example, CO_2 emissions). Where in $g(x)$ is response function of Y: $Y = g(x)$, $X = X_1, X_2 \ldots X_n$ are inputs variables that are composed of the response functions, and $f(X)$ the probability distribution of the variables, the cumulative distribution curve $F_Y(y)$ may be derived.

X_k: is the corresponding to the value of functions at the kth simulation, and $g(X)$ is corresponding to the values of the functions at kth simulation. From each of the variable's probability distribution, the X variable that was extracted from $f(X)$ N times. After a number of series for simulations, the $g(X_k)$ values that were determined. After the sorting of the data by value distribution, by this the cumulative distribution curve for Y was created.

This can be done by using simulation software like @RISK and simulation iteration can be done by using various simulations.

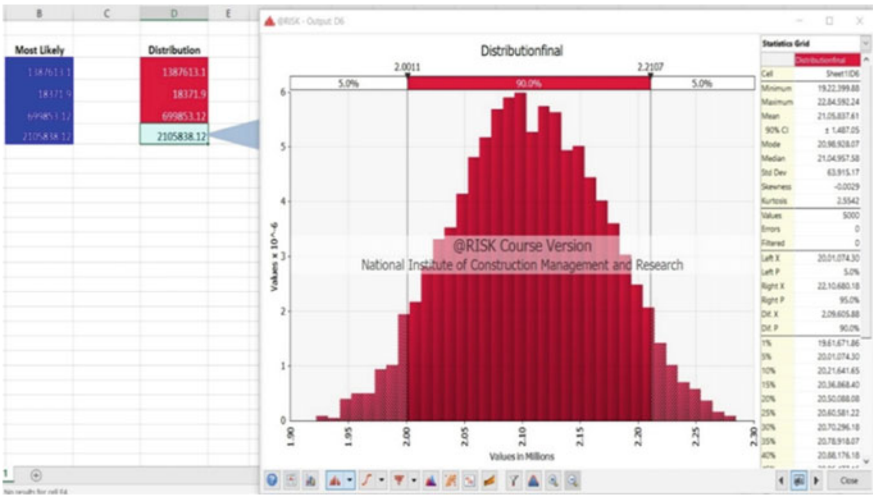
For finding the different simulations cases five thousand (5000) random iterations were conducted to find the uncertainty analysis of the CO_2 emission for the Partial Life Cycle assessment of the structure. A Probabilistic distribution was done using the different distribution curves which were used in it allocating to different variables of triangular and uniform distribution. This helped in illustrating the cumulative distribution curve of the emission per unit of built-up area. The sensitivity analysis was done for the both Pre-Fabricated structures and for the Cast-in-situ structures.

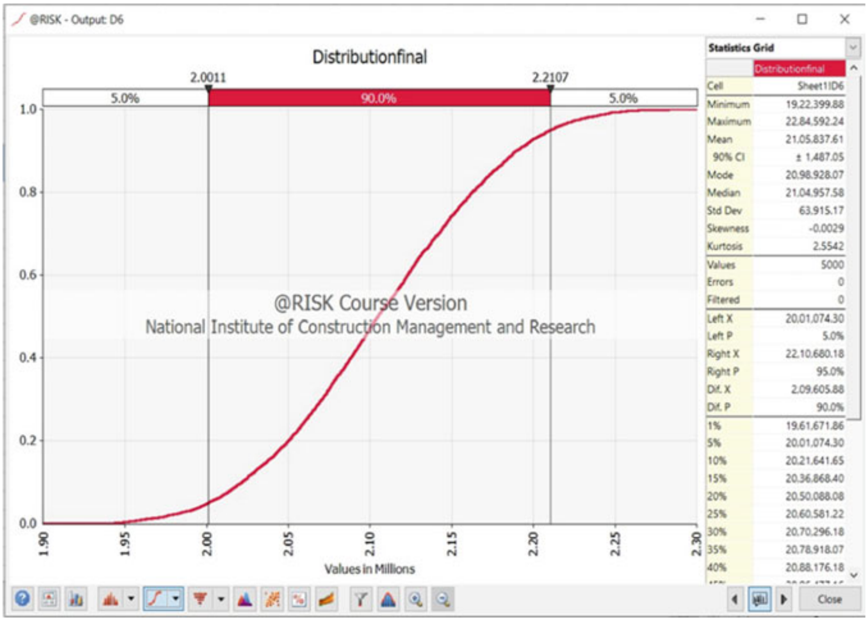
The Monte Carlo simulation work on the method of producing various iteration for finding out various situation to provide a given result for this it is using the following equation for working with the various inputs after putting it into the equation it provides with a specific output.

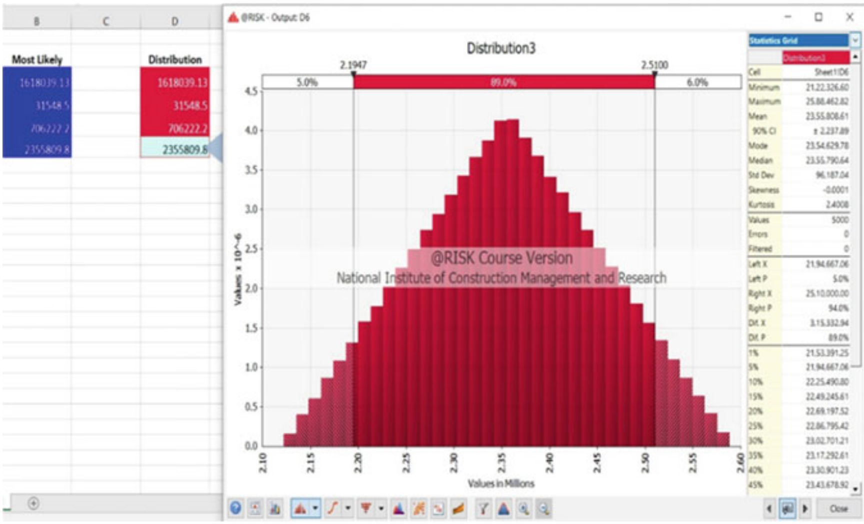
$$\begin{aligned} F_Y(y) = P(Y \leq y) &= \int\limits_{\{g(\vec{x}) \leq y\}} \ldots \int f x_1 \ldots x_n (x_1, \ldots, x_n) \mathrm{d}x_1 \ldots \mathrm{d}x_n \\ &= \int\limits_{-\infty}^{\infty} \ldots \int\limits_{-\infty}^{\infty} I[\mathrm{g}(\vec{x}) \leq y] f x_1 \ldots x_n (x_1 \ldots x_n) \mathrm{d}x_1 \ldots \mathrm{d}x_n \\ &\approx \frac{1}{N} \sum_{k=1}^{N} I[\mathrm{g}(\vec{x}_k) \leq y] \end{aligned} \tag{13}$$

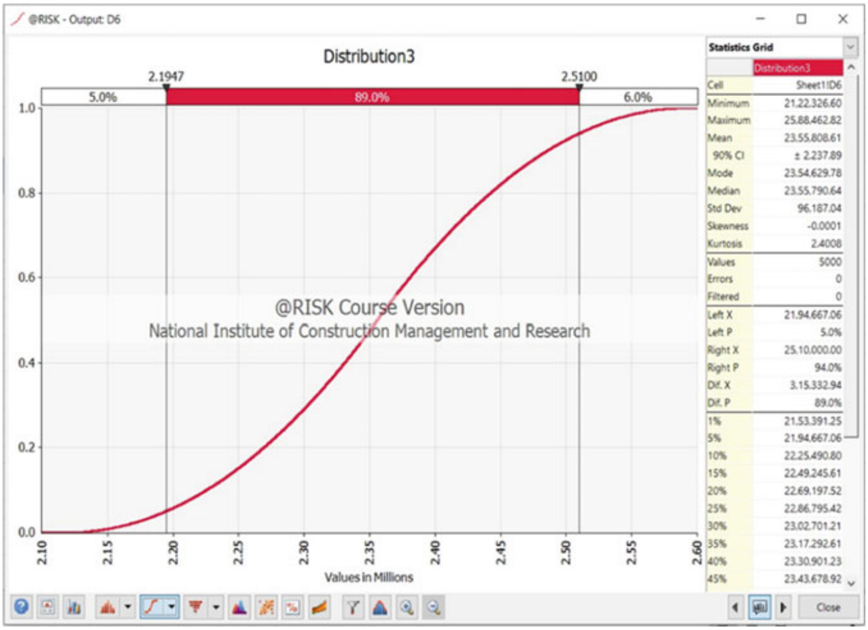
where $I\big[g(\vec{x}) \leq y\big] = 1$; $g(\vec{x}) \leq y$ and $I[g(\vec{x}) \leq y] = 0$; $g(\vec{x}) > y$.

The variable $\vec{x}$ is taken from a probability distribution and each variable $f\vec{x}(\vec{x})$ N time each iteration can be put as $\vec{x} I_k$ and $g(\vec{x}_k)$ is the corresponding value of its function at the kth simulation. After a repeated simulation we obtain the $g(\vec{x}_k)$ values. After the data is organized in accordance to distributed value, the cumulative distribution curve is drawn for Y.




@RISK - Output: D6
Distributionfinal
2.0011
2.2107
5.0%
90.0%
5.0%
1.0
0.8
0.6
0.4
0.2
0.0
1.90
1.95
2.00
2.05
2.10
2.15
2.20
2.25
2.30
Values in Millions
@RISK Course Version
National Institute of Construction Management and Research
Statistics Grid
Distributionfinal
Cell Sheet1!D6
Minimum 19,22,399.88
Maximum 22,84,592.24
Mean 21,05,837.61
90% CI ± 1,487.05
Mode 20,98,928.07
Median 21,04,957.58
Std Dev 63,915.17
Skewness -0.0029
Kurtosis 2.5542
Values 5000
Errors 0
Filtered 0
Left X 20,01,074.30
Left P 5.0%
Right X 22,10,680.18
Right P 95.0%
Dif. X 2,09,605.88
Dif. P 90.0%
1% 19,61,671.86
5% 20,01,074.30
10% 20,21,641.65
15% 20,36,868.40
20% 20,50,088.08
25% 20,60,581.22
30% 20,70,296.18
35% 20,78,918.07
40% 20,88,176.18
Close


B
C
D
Most Likely
Distribution
1618039.13
31548.5
706222.2
2355809.8
@RISK - Output: D6
Distribution3
2.1947
2.5100
5.0%
89.0%
6.0%
Values x 10^-6
Values in Millions
@RISK Course Version
National Institute of Construction Management and Research
Statistics Grid
Close


@RISK - Output: D6
Distribution3
2.1947
2.5100
5.0%
89.0%
6.0%
1.0
0.8
0.6
0.4
0.2
0.0
2.10
2.15
2.20
2.25
2.30
2.35
2.40
2.45
2.50
2.55
2.60
Values in Millions
@RISK Course Version
National Institute of Construction Management and Research
Statistics Grid
Distribution3
Cell Sheet1!D6
Minimum 21,22,326.60
Maximum 25,88,462.82
Mean 23,55,808.61
90% CI ± 2,237.89
Mode 23,54,629.78
Median 23,55,790.64
Std Dev 96,187.04
Skewness -0.0001
Kurtosis 2.4008
Values 5000
Errors 0
Filtered 0
Left X 21,94,667.06
Left P 5.0%
Right X 25,10,000.00
Right P 94.0%
Dif. X 3,15,332.94
Dif. P 89.0%
1% 21,53,391.25
5% 21,94,667.06
10% 22,25,490.80
15% 22,49,245.61
20% 22,69,197.52
25% 22,86,795.42
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40% 23,30,901.23
45% 23,43,678.92
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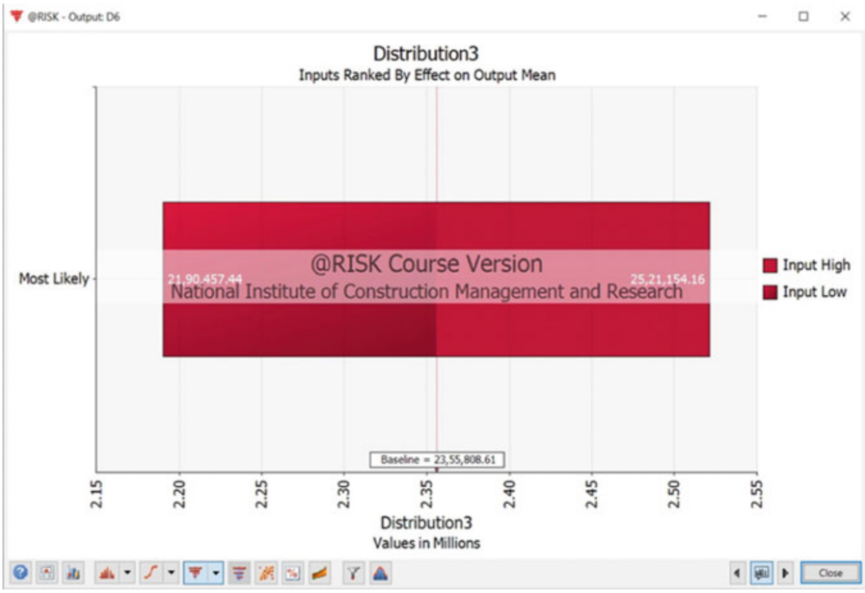
@RISK - Output: D6
Distribution3
Inputs Ranked By Effect on Output Mean
Most Likely
21,90,457.44
25,21,154.16
@RISK Course Version
National Institute of Construction Management and Research
Input High
Input Low
Baseline = 23,55,808.61
2.15
2.20
2.25
2.30
2.35
2.40
2.45
2.50
2.55
Distribution3
Values in Millions
Close

Triangular distribution is based on the probabilistic approach, and so it works keeping on regard various factors for which the result may get differ for this simulation software uses a formula for this type of distribution.

$$= \left(\frac{P + \text{ML} + O}{3} \right) \tag{14}$$

where,

P Pessimistic = a minimum criteria
ML Most likely = a most chances to occur criteria
O Optimistic = a maximum criteria.

This beta-distribution or probabilistic approach works on the system that for occurrence of a situation it depends on various factors and the results depends on those criteria to be stable if any of the criteria varies the result will tend to vary this can be example of variation in the percentage wastage of the material or the percentage of material used for a particular work.

For this a Pessimistic percentage is created for generating the minimum variation a Most Likely percentage is created for generating the most chances occurrence or the true value that will be created and an Optimistic percentage is created for generating a maximum result that can occur due to major changes. All this is put into the simulation and the variation result is created.

For this the variation result was created by the simulation on the basis of percentage difference for the maximum and the minimum difference in the input by the software and on the basis of that an output was provided through the formula used for triangular distribution (5.19) and the iteration formula (5.18) used by the software for creating multiple results.

For Pre-Fabricated Results CO_2 emissions (Kg-CO_2)-

P = Pessimistic = 1,922,399
ML = Most Likely = 2,105,837
O = Optimistic = 2,284,592.

For Cast-in-situ Results CO_2 emissions (Kg-CO_2)-

P = Pessimistic = 2,122,326
ML = Most Likely = 2,355,808
O = Optimistic = 2,588,462.

This simulation was performed to find the different iteration values for the Triangular distribution curve for a maximum value, minimum value and most likely value which may change due to the presence of various changing criteria which may alter the result but a fixed percentage marks were provided for these values. For this, a graphical distribution value, S-curve, and a most likely graph were developed for the both pre-fabricated structures and cast in situ structures for the comparative purposes this can be further elaborated by using different distribution curves.

The distribution in the S-curve helps to find the total change in the results or the difference. The upper slope tends to show the high difference of the pessimistic value the middle slop in the curve shows the most likely value that changes gradually and the lower end of curve resembles optimistic curve and these differences is shown in a percentage difference of 5–7%.

Limitations of Monte Carlo simulation Triangular distribution curve:

- It only helps to provide with the statistical result and not an exact data.
- It works on the method of probability and not in accordance to real life scenario variation.
- It is a complex method and only can be used by using special software.
- It has various distribution method out of which not all combined distribution can be used at once.
- In triangular distribution the Pessimistic, Optimistic values could be gather by fixing a percentage of variation which could be done manually and as fixed it is 5%.
- The complexity in the process can cause errors which may lead to wrong results which could be misleading.

8 Conclusion

This chapter has evaluated the effectiveness of carbon emission reduction by considering a prefabricated and the cast in-situ projects by using a Partial Life-cycle Approach (PLCA). As there are various methods in reducing the carbon emission in the building, as a result we can say that the emission from the precast structures is seen low when compared with the cast in place concrete. For 1 m^3 of concrete, the carbon emission is seen to be 692 kg CO_2 eq, and the precast structures can lead to approximately 10% reduction in carbon emission in comparison to the Cast-in-situ structures.

In this the majority of the CO_2 emission in the case of Pre-fabricated structures was from the Electricity usage then Construction stage and then the transport stage the same case was with the Cast-in-situ structures. The comparison of values for Pre-fabricated structure and Cast-in-situ structure in term of electricity consumption is 14.24%, difference between the both in term of fuel consumption is 41.76%, difference between the both in terms in Water consumption is 0.9%. This percentage shows that the major difference occurs between the both in the Fuel consumption and in Electricity consumption and a very little difference in case of Water consumption.

The different type of comparison in the values for Pre-fabricated and Cast-in-situ in terms of manufacturing and transportation stage difference as 17.81% and for the construction phase difference as 0.78% where the CO_2 emission from Pre-fabricated structure is more than that of cast-in-situ structure.

So according to this Pre-fabricated construction commends for energy efficiency and also less wastage production which goes to sustainable type of construction. Traditional type of construction method require extra material leads to increase in wastage. Since Pre-fabricated assemblies are made in factories materials can be reused and recycled in house. Also, a controlled environment of factory helps in more accurate construction.

This further reduction in the CO_2 emission can help to cater the reduction in the emission of other GHG gasses. As construction practices is also a major contributor of CO_2 gasses emission this percentage of emission can be reduced from the major contributor to a minor one.

Reduction in CO_2 emission could help to maintain the ecological balance and create less pollution in major developing cities developing at higher rate as well as creating pollution at higher rate.

The carbon emission form the Pre-Fabricated structures construction can be further be decreased in the future by using green energy for its production reusing water for its consumption and using of electric vehicles for its transportation and construction methods by this carbon % can be further decreased till 50% in near future.

Since the % of CO_2 emission of Pre-Fabricated structures is less as compared to of Cast-in-situ this helps to reduce the carbon foot print in a great scale at today's time where global warming is a great concern and also for reduction in carbon foot print government also initiate subsidies.

Appendix

- Bill of Quantities (BOQ): https://drive.google.com/drive/folders/1P3SIwyaCL7V201S2v9t_BChu_pz9gGqE?usp=sharing
- https://drive.google.com/drive/folders/1njuk-QT0riMOd38nwxHVOW-SNAVIzPkY?usp=sharing
- Master Drawings https://drive.google.com/drive/folders/1q18JWUaa0KW67mVz-Or-ISUZWJgu8Lr8?usp=sharing
- Quality reports https://drive.google.com/drive/folders/1AZyosjF8SjtJSduqtxI13v7xE0cYUTrq?usp=sharing
- Photo documentation https://drive.google.com/drive/folders/1qNHclmwTtl1UYfSY-n9p6HLHwti5IhUr?usp=sharing

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A Flow-Based Perspective to Streamlining and Transcending Construction Industry like the Manufacturing Industry

Jonnabhatla Teja Manikanta Venkata Sairam, Garuda Veera Venkata Sai Ratna Kumar, Narkadamilli Sathwik, Maddela Sonal Goud, and Mahesh Balasubramani

Abstract The trillion-dollar construction industry is augmenting the cost and time of construction whereas the manufacturing industry on the other side has been multiplying their productivity through state-of-the-art lean production planning systems. While the reasons for cost-time overruns are aplenty in the construction, frameworks for reducing wastes in cost-time remains unfulfilled owing to lack of avenues for understanding construction as a production process rather than as a project-based activity. To this end, our research relies on the need for a new systemic approach to complement present project-based methodologies to better understand the construction industry's production complexity. This systematic approach necessitates a flow-based lens to analyze the feasibility of a productionized concept along the lifecycle of a construction project. Our work intends to derive a flow-based framework for conversion of complex project-based activities into a multi-line production process in construction using Value Stream Mapping and other overarching Lean principles. Though the use of Value Stream Mapping in the construction field is an emerging trend and can help reduce wastes, Value Stream Mapping is constructed to be a simple tool that can be used for only single-line processes. By adopting a flow-based lens in Value Stream Mapping, we thereby aim to operationalize and demonstrate simple, multi-line lean interventions that become vivid in an otherwise complex setting.

Keywords Cycle time · Flow-based approach · Value stream mapping · Optimization · Concrete lining

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1 Introduction

The growth of construction industry has been exponentially increasing over the decades. The trillion-dollar construction industry is augmenting the cost and time of construction whereas the manufacturing industry is multiplying their productivity with attenuating costs and time through state-of-the-art lean production planning systems. Construction is commonly seen as project-based activity where workflow reliability plays an important role yet not recognized. While 'productivity' has received much impetus as a yard stick, productivity-based time and cost estimates are highly variable. In this regard, there is a need for grounding the time and cost estimates on cycle time. As a cascading effect, work flow tends to take the center stage in building construction project management systems around cycle time. However, there has been scant attention in the extant literature and in practice on work flow in construction. For instance, the presence of workflow and cycle time is not recognized for brick masonry. To this end, there is need to develop a better approach to inculcate consistency and coherence in the construction project management systems through a flow-based approach. Flow-based approach in construction allows the conception of construction as a production-based process rather than as a project-based activity. The passage of a product down the production line is represented by process flow, whereas the specific activities done on a product at any given workstation are represented by operations flow. We may improve processes by removing non value-added activities, and operations can be enhanced by balancing the work of operators, improving methods or tools, and so on, utilizing DfMA or Value Stream Mapping. Based on production process that is implicated, flow can be categorized as the following [6]:

- Material flow
- Labour flow
- Plant & Machinery flow
- Information flow
- Work front flow
- Space (location) flow
- External conditions.

In industrial production, material flow systems are employed as automated components as a part of the manufacturing process. The major objective of the method is to transfer or feed blanks, parts, prefabricates, or other components to a machine tool, as well as to remove them once they have been completed. As a flow, it depicts the movement of raw materials, parts, work-in-progress inventory, and finished goods and controlled flow of commodities between producers, suppliers, storage facilities, and customers. Labor flow helps in minimizing man power issues, increasing labor productivity, and reducing project time and expense overruns. In a construction project, P&M flow is a complicated method in which machines must be chosen, delivered to the job site, used, and then withdrawn and returned to the company's plant depot or the hire company when the project is over. Work front is related to opportunities to perform construction works in a given period and space flow represents the

Table 1 The seven flows [6]

Flow	In site construction
Materials	Do I have the necessary bricks, mortar, ties, and other materials to construct this wall?
People	Do I have the operatives to complete the work?
Information	Are all drawings, contracts, method statements, and RFIs complete and responded to the point where I can grasp the terms of satisfaction?
Equipment	Will I be able to use the tools, scaffolding, scissor lifts, hook time, and other resources that I require?
External conditions	NHBC inspector; weather; building inspector; utility provider—Are all of these in order?
Space	Will I be able to complete my work in a secure environment?
Prior work	Is the wall complete enough for plastering to begin?

work deployed should be performed in a confined environment. Identifying dangers for each item and devising a strategy for avoiding them through routine maintenance and inspections. Table 1 illustrates these seven types of flow in construction.

With offsite technologies seeing a huge growth today, it is imperative for the construction industry to re-structure their planning and costing systems from a flow-based perspective. Evidence from the extant literature has shown corresponding improvements in productivity rate, growth rate and customer satisfaction. The following section, in the interest of conference page limits, briefly reviews the extant literature on flow-based perspective in construction and the use of Value Stream Mapping as a lean tool to operationalize this perspective.

2 Literature Review

Extant research on flow-based optimizations in construction has been indicative of the following benefits: productivity is increased, waiting time is decreased, cost is decreased, optimize the number of steps and reduce the flow of waste in each stage of project. Bertelsen and Sacks [2] briefed on how flow in construction process can be determined by using Transformation-Flow-Value for understanding of construction process. The authors argued in favor of treating construction process like a chemical or manufacturing process where outcome is produced by several number of flows.

Arumugam and Varghese [1] attempted to characterize construction workflow and subsequently provide flow measurements at various stages of the construction processes. The authors studied the construction of multi-storey residential building super-structure to observe document and analyze the construction activity flow characteristics. Queuing theory was applied herein to investigate various forms of construction projects and measure different types of flow that exist in the existing state.

Sacks et al. [7] offered a new process-oriented method for construction management called Construction Flow Index (CFI). In recurring building projects, CFI shows the quality of the manufacturing flow and also aids in determining crew work continuity, processing continuity for locations, work in progress numbers, and production rate variance. The author also discussed CFI's advances, CPI's criteria, and the calibration of the CFI function. By providing an alternative to earned-value measurements, the CFI challenges the paradigm of traditional construction management practice.

Henrich et al. [5] briefed about how flow in a typical construction process is different from an assembly-based flow that exists in firms like Toyota. Koskela et al. [6] examined the concept of flow as a more complex way of looking at the construction process. The authors suggest the need for augmenting a flow-based perspective with core lean tools operationalize the perspective successfully in construction. Taking cue from such calls, scholars began to explore Value Stream Mapping (VSM) as a tool for epitomizing a flow-based perspective.

Gunduz and Naser [4] proposed enhancements in the underground pipe-laying by using Value Stream Mapping. Wang et al. [8] established the use value stream mapping to optimize the flow in precast concrete process. Bhatla and Leite [3] has anticipated several linkages between BIM and lean, which could result in increased benefits for project participants and customers. The authors presented a VSM-based framework for incorporating BIM features into the LPSTM, such as 4D scheduling and MEP clash detection, in order to improve work flow consistency during the construction phase.

Even though flow and aspects of flow is considered as an important parameter in construction, frameworks for reducing wastes in cost-time remains unfulfilled owing to lack of avenues for understanding construction as a production process rather than as a complex project-based activity. To this end, there is a need for a new systemic approach to complement present project-based methodologies to better understand the construction industry's production complexity. This systematic approach necessitates a flow-based lens to analyze the feasibility of a productionized concept along the lifecycle of a construction project. Though the use of lean tools like Value Stream Mapping in the construction field is an emerging trend and can help reduce wastes by presenting a flow-based simulation, Value Stream Mapping is constructed to be a simple tool that can be used for only single-line processes. Our work intends to derive a flow-based framework for conversion of complex project-based activities into a multi-line production process in construction using Value Stream Mapping and other overarching Lean principles. By adopting a flow-based lens in Value Stream Mapping, we thereby aim to operationalize and demonstrate simple, multi-line lean interventions that become vivid in an otherwise complex setting. The conference paper attempts to look at the following research question:

How can VSM be operationalized to convert complex project-based activities into a multi-line production process in construction through a flow-based approach?

3 Research Methodology

We adopted a case-based method to answer the above research question. Data collection focused on visualizing a workflow through application of VSM as a lean tool. From the site visits/internship, preliminary and secondary research data, project activities were first simulated as multiple-line, parallel and inter-dependent production activity. Data for our case study was gathered during our internship at Construction of Tunnel T-15 & part T-14 including bridge no: 61 (Sub Structure). (Between km: 73.785 to km 86.848 approx.) on katra-Banihal section of Udhampur-Srinagar-Baramulla New BG railway line project.

Table 2 shows the project details.

Steps in Concrete lining are as follows:

- Bulk Head
- Assembling
- Placing and Shuttering
- Concreting
- Setting Time
- Removing and Cleaning
- Dismantling
- Bulk Head

We used concrete lining as the particular unit of analysis in this paper, and by applying the flow-based lens to the project-based activities connected with concrete lining work. We mobilized value stream mapping to ex-post determine where time, resources, and cost could be optimised in the future. The data utilized as input for VSM was obtained by acquiring cycle times of each activity for the entire concrete lining process. This study is based on present state and future state of concrete lining process.

Table 2 Project details

Name of owner	Northern railway
Name of employer	IRCON international Ltd.
Designer and drawing consultant	d2 consult-pems jv
Tender no	IRCON/J&K cell/jat/14/1014/k-b/t-15/326
Contract duration	36 months
Date of acceptance	17 march 2016
Date of agreement	14 may 2016
Revised date of finish	31 December 2022

4 Observations

The current state of the concrete lining, when done without a cycle-time based approach and with a productivity-driven approach, is depicted in Fig. 1. The following sequence of activities and activity times were observed.

Figure 2 represents the current state of cost for the concrete lining work described.

Subject to permissions and limitations of collecting detailed data, we developed sub-VSM maps for Step 2 (Assembling), Step 4 (Concreting) and Step 7 (Dismantling) which were the most time-intensive and cost-intensive activities.

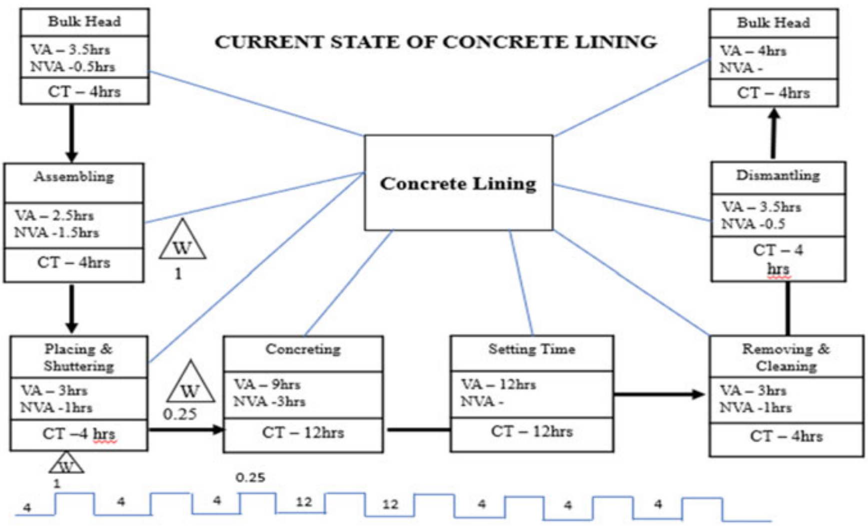


Fig. 1 Current state of concrete lining

COST DETAILS FOR CONCRETE LINING

CURRENT STATE

	TOTAL TIME (hrs)	NO: OF LABORS			COST
		SKILLED	SEMISKILLED	UNSKILLED	COST
BULK HEAD	4			6	1296
ASSEMBLING	4		6		1608
PLACING & SHUTTERING	4	2	6		2280
CONCRETING	9		6		3618
SETTING TIME	12	No labor required			
REMOVING & CLEANING	4		6	2	2040
DISMANTLING	4		6		1608
BULK HEAD	4			6	1296
TOTAL	45	2	30	14	13746
concrete pump	9				2250
concrete motar M30 required fo 1 strech					468000
Total cost required for 1 strech					483996

NOTE	(Rs.)/day	(Rs.)/hr
COST OF SKILLED LABOR	1000/-	84
COST OF SEMISKILLED LABOR	800/-	67
COST OF UNSKILLED LABOR	650/-	54
cost of concrete pumpm per month		126000 rs
no of working days per month		28
No of working hrs of concrete pump per day		18
Cost of concrete pumpm per hour		250 rs
Cost of concrete of M30 per 1 cum		3900 rs
concerete required for 1 strech (12.5m)		120 cum

Fig. 2 Current state of the cost for concrete lining

5 Illustration of Assembling Intervention

- Total cycle time for concrete lining operation is 48 h
- In assembling operation V.A is erecting of elements which is 2.5 h and N.V.A is 1.5 h Total time (hrs) = 4 rs
- No: of semi-skilled labors employed = 6
- Cost of 1 semi-skilled labor per day = 800/- per day and 67/- per h.
- Total cost of assembling activity is 1608/-
- Cost of 1 skilled labor per day = 650/- and hourly rate is 54/-.
- By applying labor flow for assembling activity, assigning 2 more unskilled labors decreases total time by 1 h and total cost becomes around 1530/-

6 Illustration of Concreting Intervention

- In concreting activity V.A is concrete placing which is 9 h and N.V.A is 3 h which is truck change and total time is 12 h
- No: of semi-skilled labors employed = 6
- Total time (hrs) = 9 rs
- Cost of 1 semi-skilled labor per day = 800/- per day and 67/- per h.
- Total cost of assembling activity is 3618/-
- By applying plant and machinery flow for concreting activity, assigning 6 more unskilled labors and adding 1 more concrete pump for concreting operation from other side of tunnel total time becomes 5.5 h and total cost becomes around 4442/-.

7 Optimization

In this activity pumping from one side of stretch taking value added activity around 9 h. So, we assign extra pump and pumping from both sides it reduces the time up to 40% of original duration. It means 9 * 0.4 = 3.6 around 3.5 h. So total cycle time of concreting reduces from 12 to 8.5 h.

8 Illustration of Dismantling Intervention

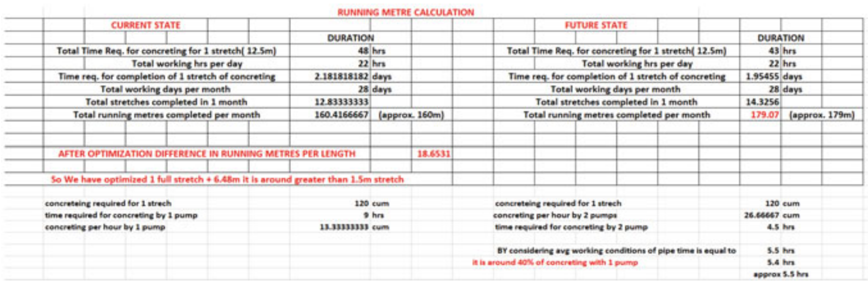
- In dismantling operation V.A is removing of elements which is 3.5 h and N.V.A is 0.5 h and total time is 4 h
- No: of semi-skilled labors employed = 6
- Total time (hrs) = 4 rs
- Cost of 1 semi-skilled labor per day = 800/- per day and 67/- per h.
- Cost of 1 skilled labor per day = 650/- and hourly rate is 54/-.

- Total cost of assembling activity is 1608/- By applying labor flow for dismantling activity, assigning 2 more unskilled labors total time becomes 3.5 h and total cost becomes around 1780/-

9 Discussion and Conclusion

- After optimization, difference in running meters per month is 18.65 m, which is equal to 1.5 stretches.
- After optimization difference in time per stretch is 5 h (48 h-45 h = 3 h)
- After optimization difference in cost per 1 stretch is increased 1400/-.
- After applying flow-based approach cost for 1 month of concrete lining increases by 20,000/- but overall time decreases by:
  - The total stretch of the project is 13 km (13,000 m).
  - According to the status, it will take 13,000/160 = 81.25 months to construct the concrete lining. When converted to years, 81.25/12 = 6.77 years.
  - But, as per site tunnel processing is going through adits in 9 faces. So, as per the plan lining activity must be completed in 3.07 yrs. (1034 days/336 days)
  - Working days per month = 28 days and per year = 336 days.
  - By optimization 13,000/179 = 72.62 months. [By optimizing (1034*160)/179 = 924 days].
  - When converted into years 924 days/336 = 2.75 years.
  - Finally, by applying flow-based approach through, time optimization is done around 4 months and overall cost increased by 660,000/-. This computation is illustrated in Fig. 3. The summarized VSM for the concrete lining is shown in Fig. 4.

This study has shown how complex construction projects that have multiple parallel and interdependent activities can be optimized by adopting a flow-based approach. The work also demonstrated the operationalization of flow-based approach through VSM. VSMs were mapped for labor flow, material flow and P&M flow for



RUNNING METRE CALCULATION

CURRENT STATE	DURATION		
Total Time Req. for concreting for 1 stretch(12.5m)	48	hrs	
Total working hrs per day	22	hrs	
Time req. for completion of 1 stretch of concreting	2.181818182	days	
Total working days per month	28	days	
Total stretches completed in 1 month	12.83333333		
Total running metres completed per month	160.4166667	(approx. 160m)	
AFTER OPTIMIZATION DIFFERENCE IN RUNNING METRES PER LENGTH			18.6531
So We have optimized 1 full stretch + 6.48m it is around greater than 1.5m stretch			
concreteing required for 1 strech	120	cum	
time required for concreting by 1 pump	9	hrs	
concreting per hour by 1 pump	13.33333333	cum	

FUTURE STATE	DURATION		
Total Time Req. for concreting for 1 stretch(12.5m)	43	hrs	
Total working hrs per day	22	hrs	
Time req. for completion of 1 stretch of concreting	1.95455	days	
Total working days per month	28	days	
Total stretches completed in 1 month	14.3256		
Total running metres completed per month	179.07	(approx. 179m)	
concreteing required for 1 strech	120	cum	
concreting per hour by 2 pumps	26.66667	cum	
time required for concreting by 2 pump	4.5	hrs	
BY considering avg working conditions of pipe time is equal to	5.5	hrs	
it is around 40% of concreting with 1 pump	5.4	hrs	
	approx 5.5 hrs		

Fig. 3 Running meter calculation with respect to time

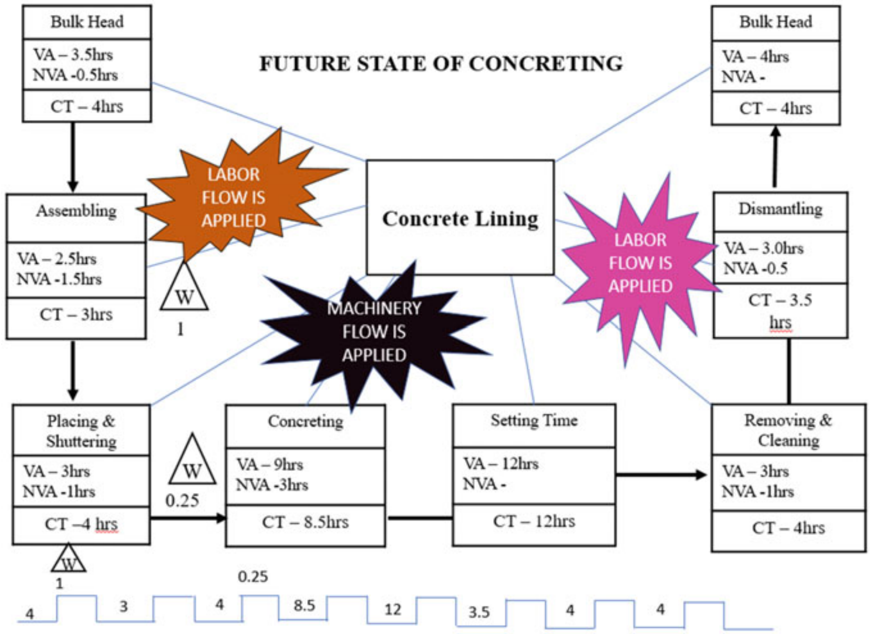


Fig. 4 Future state of concrete lining

concrete lining work in a tunnel project. Interventions were introduced for non-value adding activities identified from these three flow maps. These interventions that accounted for four months of schedule crashing would not have materialized without a flow-based perspective. The optimal duration of schedule crash from these interventions and impact on earned value/schedule will be a part of conference presentation.

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A Study on the Behavioural Aspects Contributing to Lean Transformation in Indian Construction Industry

V. Pramadha, K. V. Prasad, and Venkatesan Renganaidu

Abstract The waste generated in the construction sites not only contaminates the soil, water, and air but also impacts the efficiency of the construction projects coupled with the ill effects on its profitability. Though there are numerous studies, which have tried to identify the causative factors of construction waste, very few of them emphasized upon the human and behavioural elements contributing to it. The objective of this study is to investigate the impact of behavioural aspects with regard to their influence the successful implementation of lean systems in construction organizations. Through literature review, three key behavioural attribute groups such as 'organizational factors', 'group factors' and 'individual factors' were identified and classified. The purpose of the current study is to investigate the organizational, group, and individual factors by collecting the data from the construction stakeholders' through the questionnaire survey method. Data for the research were collected through a survey of the Indian construction industry professionals and was analysed using the SPSS software. The study identified that a great deal of change in behaviour and cultural practices from both participants and management is the need of the hour to reap the benefits of lean construction practices.

Keywords Lean construction · Lean thinking · Human behaviour · Lean culture · India

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1 Introduction

Construction industry in India is growing at an enormous pace. Research studies state that Indian Construction industry is likely to scale greater heights in the coming decade. If the estimates are to be believed, the year 2030 will witness Indian construction market as third largest globally [15] and the growth would be on an average of 7.1% each year [25]. Rising population is calling for incessant urbanization resulting in impending development of infrastructure projects. The flourishing Indian construction industry is the second largest employer next only agriculture [11].

The industry provides employment to over 60 million people presently, and this is expected to grow to 75 million both in organised and unorganized sector and contributing nearly 15% to India's GDP [15].

Owing to the progressive programmes inviting public private partnership and with advent partnership with foreign companies, this sector will be the future hub for foreign investments. Despite all the enormous requirement, research findings say that the cost of wastes (depicted in Fig. 1) in total construction cost is ranging between 20 and 25% resulting in a net profit of only 8–15% per project Indian construction industry has been highly competitive, and there is a pressing need for transformation in project execution strategy. The varied approach to project value creation will enhance the growth of industry in terms of cost, time, and quality. The biggest roadblock on the way to this progress has been the approach and methodology adopted in construction industry. Though world construction industry is progressing by adopting latest technology and techniques, Indian construction industry is still mostly working on conventional methods and among those countries that add to 23% of the global construction output and employing 74% of the global workforce [16].

The construction industry is hostile towards the environment, by contributing pollutants and disturbing the ecological balance. The sector's contribution to increasing construction waste is the result of its swift growth. Though many methods and techniques have been tried and tested through years to improve the efficiencies and minimize waste, construction practitioners have finally started finding their solution through lean practices. Lean concepts, when applied augment the ability to minimize time and cost overrun by eliminating the non-value added activities [20]. Lean construction method basically involves the continuous improvement process

Fig. 1 Common categories of waste in construction projects

using effective procedures and competent people. Lean construction delivery process focuses on the final outcomes engaging the value-based procurement, training and developing the manpower, establishing and meeting the quality standards and so on. Recent years have witnessed a steady growth in the application of lean principles both locally and globally in various industries. Research has proved that application of lean construction techniques have substantially improved the construction methods and led to considerable enhancement of performance with regard to the firms adopting it [5]. Unfortunately, the universal applications of lean concepts could not do much foray into the Indian construction industry, citing multiple reasons. While construction industry is one of the first non-manufacturing industries to take on the lean principles [28] despite some criticisms, which found Lean principles not very adaptable in construction sector [10].

2 Review of Literature

In the path of advancement, construction industry is facing chronic issues such as time and cost overrun, low productivity, inferior working conditions, and insufficient quality. These are associated with waste generated at construction site. To minimize the cost of construction or increase the profit, construction industry has started to look into waste reduction and process improvement issues through concepts like lean construction. Lean is a continual improvement philosophy to reduce waste. There are numerous studies carried out and are available with regard to implementation of lean concepts in construction industry. Lean thinking promotes reliable flows of the resources, such as material, equipment, labour, information, etc., and they led to better performance. Many lean failures have reinstated the importance of work force and insisted better labour management practices, along with other resources [27]. The systematic literature review conducted by Albalkhy and Sweis [2] provides greater understanding pertaining to novel concepts of lean construction and is instrumental in identification of the strategies for successful implementation of lean practices. A study on construction site waste management promotes waste avoidance and minimisation before treatment and disposal. This study highlights on the aspects of educating and motivating the construction crew members. The managers/ contractors should conduct a waste training program to create awareness among the members to work towards waste avoidance [17]. Another study [24] emphasizes to understand and quantify the amount of waste actually generated in the Indian construction industry. This study was conducted on six on-going projects to identify material waste, and resource waste such as waste related to labour and equipment. It was found that cost inefficiency of labour and equipment put together was very high when compared with material waste. The average percentage time spent by labour and equipment in non-value adding activities was found to be 57% and 61% respectively. This emphasizes on the need to reduce the share of non-value added activities to increase overall project performance. Formoso et al. [9] stressed the need to consider a broader view of waste that includes not only material waste, but also waste related to resources such as labour and equipment. Researchers accentuate that majority of the waste can be shunned by working on economical precautionary measures that are typically managerial in nature, hence bringing in improvements related to administrative and operative issues. In a study conducted by Kolaventi and Prasad [12] regarding improving waste management performance of construction projects, manpower was identified as one of the most influential factor. People are instrumental in either reducing or increasing construction waste. A similar study was conducted in Jordon to understand the key factors of construction waste by Al-Rifai and Amoudi [1]. This study also revealed similar results where the top factors leading to construction waste are human elements and reiterated the need to work on cultural and behavioural patterns to improve the situation. Study by Koskela [14] in the work on application of the new production philosophy in construction emphasizes on improving the competitiveness of firms. This can be achieved by eliminating the waste or non-value adding activities and increasing the value adding activities, thus minimizes the cost and effort and resulting in increased value to all stakeholders. Bajjou et al. [4] differentiated between the traditional construction practices and lean construction practices. Implementing lean construction tools and techniques like Last planner system, Value Stream Mapping, Just-in-time, 5S and Visual management improves the performances at work have been discussed in detail in comparison with traditional construction methods. This work finally provided analysis on how lean construction practices differ and improve the performance comparing to traditional construction practices. The former chairman of Toyota motors, Ohno [19] in his book on 'Toyota Production system' has suggested a simple yet brilliant way of continuous improvement. According to Ohno, it is important to focus on timeline of production and reduce the non-value activities. Ohno, the genius is the creator of the Toyota's just-in-time production system, besides many methods used at Toyota, later became as the Lean culture. But, what is more interesting is that these methods were not developed overnight, they progressed through a lot of improvements with time to evolve as what they are today. Dahlgaard and Dahlgaard-Park [6] in findings of their study related to Lean production, six sigma quality and Total Quality Management (TQM), state that both lean production as well as six sigma have their roots in Japanese TQM concepts. The research concludes on a note that though there has been enough focus on people training yet, there is little attention on understanding the human element to build the right lean culture in the organisation. According to Pramadha and Venkatesan [22] the Lean philosophy is always a mechanistic approach consists of lean tools and techniques that help in identifying and eliminating the wastage in the construction process and about the impact of cognitive aspects within the lean culture. According to this study, though technical and managerial issues play a major role in lean transformation, results established the importance of cognitive issues on implementation of lean culture. Raghavan et al. [23] as a part of the study conducted on nine on-going projects for implementing the lean concepts, undertook monitoring the sites with timely visits and periodic reviews to observe the various inhibiting factors that hinder the execution of lean implementation. The study categorized these hindering factors as poor inclusive culture, strong inclination towards conventional methods, lack of well-established planning and control systems. This research suggested instilling strong empowerment factors such as commitment from top management, knowledge of site management and changes in culture and value system of the organisation, which help in overcoming the hindering factors. A study by Marhani et al. [18] urged to move away from the traditional mode of construction practices, to benefit the stakeholders for a better valued construction projects. Bitter experiences in many projects, either due to lack of awareness or for the sake of tortuous application process are resulting in failure. Such organizations utmost probably distance themselves with future implementation of lean practices [3]. A research analysis conducted in Iran [13] to identify and understand the obstacles of lean implementation, poor knowledge and lack of awareness were prominent factors. The study suggests focusing upon the organisational and project management factors, to turn around the fate of lean implementation even in unfavourable circumstances. Erthal and Marques [8] in their study, tried to understand the dilemmas and paradoxes impacting the lean implementation. Their study derived conclusions, which recommended the managers to deal with in built cultural clashes rooting from the age-old practices. Lean implementation can be successful and overcoming the teething troubles can be easy, if the issues are identified and analysed in the early stage, the projects then can be executed in an efficient manner [26]. Pekuri et al. [21] carried out a study to identify the cornerstones for successful execution of lean principles in construction industry. The cornerstones identified in this study are: selecting right people, building trust, motivating people, developing skills, competence enhancement, and providing effective leadership. The researchers emphasise that in a rush to apply lean concepts, managements are ignoring a vital aspect to transform the organisational culture. An effective transformation, which is imbibed throughout the value chain, requires understanding of the multi layered concepts of principles and practices.

3 Research Objectives

The objective of the present chapter is:

To identify the various key factors impacting the successful implementation of lean practices in Indian construction projects.
To assess the degree of importance of the identified key factors for the implementation.

4 Scope of the Study

Relevant key organizational, group and individual factors were identified from literature review, and the same were incorporated in the questionnaire survey. Questionnaire was circulated among the respondents, among the professionals of Indian construction industry. The job details of the respondents were also considered, such as whether the respondent is an engineer, client, contractor, consultant, or subcontractor and also the respondents experience with regard to the construction industry is also included. The respondents were asked to rate the importance and impact of the variables on a scale of 1–5, where each number denoted the following:

5—Strongly Agree,
4—Agree,
3—Neutral,
2—Disagree and
1—Strongly Disagree.

Statistical analysis was done on the data collected from 125 respondents and the mean of these sample mean is calculated. The variables included in the questionnaire are generic in nature and are applicable to most of the construction projects. Waste generating variables were grouped into three categories namely Organizational, Group, and Individual. A questionnaire was developed for gathering perceptions about human elements contributing to lean implementation/transformation. The questionnaire consisted of two sections. The details regarding the respondents, projects and company profile were collected in the first section. The second section comprised questions relating to the level of effect or impact of factors that contribute to lean transformation in the construction projects. In addition, ANOVA test was conducted to test the difference in perceptions among the different group of industry professionals—owners, contractors and clients, on the various factors. Accordingly, the following hypothesis was formulated.

H0: The mean responses of all the group of respondents are same
H1: The mean responses of all the group of respondents are not same.

5 Data Analysis and Interpretation

A questionnaire survey was conducted to identify the factors, which are hampering the implementation of lean principles and practices. The inhibiting factors in lean implementation, which are enlisted in the questionnaire, are given below. These factors are grouped into three major categories and further two subcategories in each of major category. These questionnaires are then devised into Google forms and circulated among experienced stake holders from construction industry. The descriptive study was done with respect to 5 scale rating, which is commonly used in this type of analysis. The various aspects considered here under different criteria are:

Organizational Factors

- Organizational culture
- Organization management practices

Group Factors

- Team work
- Leadership

Individual Factors:

- Attitudes
- Perception

6 Results and Discussion

Responses of all the respondents are analysed using SPSS software, and the factors were rated to understand, based on their impact on hindrance in implementing the lean culture. Table 1, below portrays the analysis, where the data collected from questionnaire were analysed to derive the mean value to interpret the most significant behavioural factors that lead to waste generation.

From Table 1, it is validated that organizational factors among the various behavioral aspects are highest contributors to waste generation; these factors are followed by group and individual factors. For further analysis, individual factors were sub-categorized into two different sub groups as Attitudes and Perceptions. To formulate the strong level of agreement among all sub classification mean value is interpreted for the set of sub factors are as shown in Table 2.

Table 2 authenticates that perception factors of a person has more weightage than the attitude factors at the workplace. The second set of factors comprising group elements are further subcategorized into teamwork and leadership. To formulate the strong level of agreement among these sub classifications, mean value is interpreted for both the factors are as shown in Table 3.

Table 3 endorses the fact that, at work place, leadership plays a bigger role when compared to the team work element. Leader especially the project manager plays

Table 1 Descriptive statistics test for comparison of organization, group and individual factors

Factor groups	*N*	Minimum	Maximum	Mean	Std. deviation
Organization factors	125	1.00	5.00	**4.102**	0.790
Group factors	125	1.00	5.00	**4.041**	0.831
Individual factors	125	1.00	5.00	**3.912**	0.886
Valid *N* (list wise)	125				

Table 2 Descriptive statistics for individual factors

Factor groups	*N*	Minimum	Maximum	Mean	Std. deviation
Attitudes	125	1.00	5.00	**3.850**	0.901
Perception	125	1.00	5.00	**3.973**	0.867
Valid *N* (list-wise)	125				

Table 3 Descriptive statistics test for group factors

Factor groups	*N*	Minimum	Maximum	Mean	Std. deviation
Team work	125	2.00	5.00	**3.962**	0.787
Leadership	125	1.00	5.00	**4.120**	0.844
Valid *N* (list-wise)	125				

Table 4 Descriptive statistics test for organization factors

Factor groups	*N*	Minimum	Maximum	Mean	Std. deviation
Organization culture	125	1.00	5.00	**4.096**	0.815
Management practices	125	1.00	5.00	**4.112**	0.752
Valid *N* (list-wise)	125				

a critical role at work place and influences the success as well as the failure of the project. Hence leadership will play a very crucial role in lean implementation also. The third set of factors related to Organization are further split into two subcategories, namely, Organization culture and Management Practices. To analyse these factors better and also to formulate the strong level of agreement among the sub categories, mean value is interpreted for both the factors as shown in Table 4.

Table 5 demonstrates that management practices has slightly more impactful than the organization culture for lean transformation in Indian construction industry.

From the results of the ANOVA, it may be observed that except for three factors (one each under organizational culture, organizational management polies and team work), the ANOVA test result (at a confidence level of 95%) didn't show any significant difference among the vast experienced groups and failed to reject the null hypothesis.

7 Discussions

The study provided insights to understand the various perspectives related to lean transformation, such as individual, group and organizational factors. The results shown in Table 1 certify that amongst all these factors the most significant one is the organizational factor with a maximum mean value of 4.102. Within the category of organizational factors, one of the highly rated key factor under the sub category of organization management practices 'deficiency in number of employees training and development program' requires attention [3, 17]. The organizations have to seriously allow their key stakeholders to take part in many lean implementation programs to realize the full benefits of lean construction methodologies. However, among all these factors 'leadership' under Group factors, has the highest mean value of 4.120. This is in support with the findings of Pekuri et al. [21] that effective leadership' [7] is one of the main cornerstone for successful execution of lean principles in

Table 5 Test results of ANOVA

Group	Factors	Significance*
Organizational factors		
Organizational culture	Building relationships with top management and employees increase the loyalty at work culture	0.663
	Management policies and principles help in having clear goals in employees	0.015*
	Providing basic social amenities for employees relieve employee from some external concerns	0.670
Organizational management practices	Conducting training and development programmes improve the employee skills	0.002*
	Recurring layoff increases the employee turnover	0.390
Group factors		
Team work	Social loafing in employees reduces group cohesiveness	0.915
	Blame culture among team will lead to unclear explanations	0.108
	Communication and transparency among team will develop team work	0.226
	Trust in working relationship will avoid conflicts in team	0.010*
	Team spirit will avoid destructive politics	0.192
Leadership	Leader with optimistic and positive will enhances team work	0.073
Attitudes	Fear of taking risk will result in lack of commitment in work culture	0.743
	Ego driven decision signs attitude of ignorance	0.298
	Working with self-esteem will provide recognition at work place	0.828
Perceptions	Individual perception of their personal needs motivates employees at work place	0.233
	Lack of opportunity to perform at work place, demotivates employees	0.282
	Stress and work life imbalance will affect work performance	0.369

*Denotes having significant differences in the perception of the group of respondents construction sector. The present study confirms, that to comprehend the increase in complexity of projects which implement lean technology, there is a need to understand and analyse human related detrimental factors, which often lead to failure of the lean implementation. Executing the lean principles and practices and eventually to transform into a lean organization requires an exemplar change in the thinking as well as behavioural patterns. A great deal of change in behaviour and cultural practices from both participants and management is the need of the hour.

In addition, the results from the ANOVA test revealed that the various groups of the industry i.e., the clients, contractors and consultants largely agree on the aspects. However, it can be seen that the attributes of management policies, employee training and trust in working relationship had differences among the respondent groups. This can be attributed to the fact that the stakeholders of construction organizations in India are not in alignment due to conflict of interests. Educating, training of the employees is still seen as a cost rather than an investment, especially by the contractors. This confirms the observations of earlier study that employee training and development is an area that needs attention [3, 17]. It is also documented that the construction industry still continues to work under individual silos and this lack of trust is a barrier for the implementation of integrated and collaborative approach which lean philosophy advocates.

8 Conclusions

This chapter was a detailed observation of the various factors that are mainly hindering the application of lean principles and practices. The various behavioural factors, which formed a part of this study, have been categorized into individual, group, and organizational factors. Among the factors selected in this study, organizational factors have proven to have the highest significance in transforming a conventional organization into a lean organization. Successful transformation requires implementation of peoples' practices at workplace; respecting the work culture, analysing the factors causing motivation at work place; providing a stress-free working environment among others. Organizations, which are working diligently on people's practices, have succeeded in implementing lean in organization. It's imperative to know that employee always enjoys being part of structured planning and decision-making process. This can be achieved by promoting behavioural aspects at all the levels of organization.

9 Scope for Further Study

Many of the organizations perceive that lean is more of implementation of a set of tools and techniques. However, the organizations need to realize that the long-term success is realized by a more "human/people centric approach" focusing on the process rather than merely the tools. There is a great scope to study about the further aspects related to lean construction transformations, which have to be more focused on people, enabled by the technology. People oriented practices would be more effective for lean implementation in construction projects. Formalizing the construction management and engineering practices with regard to lean principles and lean behaviour, as a whole, should be long-term research goal. This line of research would bring in striking results and shed light on factors that maximize the efficiency of construction industry performance with respect to cost, time and quality and most importantly deliver value to the customer.

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Prefabrication Methods for Lean Delivery of Construction Projects

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Abstract The construction industry has been receiving severe criticism over its inability to improve productivity associated with project delivery as compared to the manufacturing industries. The construction projects continue to struggle with the problems of delay, cost overruns, and litigations. Lean construction philosophy evolved from Toyota's Production Systems (TPS) has gathered significant attention in recent years and has been proven to be successful in minimizing the inefficiencies and wastages at projects and improving the project delivery. The prefabricated method of construction has been found to fasten the delivery of projects and achieve the principles of pull production, Just in Time (JIT) and minimize wastages. The development of prefabricated structures in the construction industry has shown the potential to drastically improve the construction environment, productivity and quality. The present paper discusses a part of the work carried out to investigate the cost–benefit analysis of the prefabrication methodology for the construction of residential projects using the prefabrication method over traditional projects. The study aims to introduce the methods and techniques of prefabrication for building projects and how it contributes to sustainable lean delivery of building construction projects.

Keywords Lean construction · Prefabrication · Buildings · Case study · Productivity

1 Introduction

Prefabrication is the construction practice of building a structure from components made from a fabrication yard or factory and then transporting them to the site where the structure is planned to be assembled. By incorporating the prefabrication technique over conventional construction techniques, we can control construction costs by economizing time through a faster construction rate, wages through the reduction

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in labour requirement, and materials through the reduction in wastage. Wall panels, staircases, lintel beams, roof slabs, beam section of any size and bridge decks come under prefabricated units. In the case of the prefabricated construction method, we could achieve structures with high complications without any flaws in quality since it is a factory-controlled manufacturing process. Usually, the process comprises two stages, manufacturing of the components in the factories and then the assembly location where the erection or placing of those components take place. By adopting prefabrication techniques, there is no chance of interruption due to any bad weather conditions and ensures speedy completion of the project.

The prefabrication technique allows producing custom-specific products to be produced exactly to the requirement with shorter lead times and higher reliability [1]. Prefabrication offers to reduces uncertainty, cuts down the wastage of labour and materials and can enhance the quality significantly [3]. Prefabrication integrates the manufacturing approach to construction projects [2]. Prefabrication offers an innovative process of mass production in a controlled environment, organized logistics, combined with systematic planning and management [8].

The state of prefabricated buildings in India is still at the blooming stage owing to limited exposure and expertise in the field of conventional construction techniques. With an expected requirement rate of 50 million homes and approximately 90 smart cities being planned in India, there is a huge potential for those companies which are developing prefabricated structures. Currently, precast structures are commonly used for the construction of infrastructure projects like bridges and tunnels, to meet the government proposal "Housing for All" as part of the Pradhan Mantri Awash Yojana scheme, the incorporation of precast technology will play an upper hand in shortening the execution time with improved quality in mass housing construction. Our project focuses on the aspects of cost, labour, time and environmental impacts of adopting the prefabrication method over the conventional method.

2 Literature Review

Various articles and journals related to various topics such as cost–benefit analysis of prefabrication technology, case studies on labour productivity and the impact of time and environment are studied. These journals helped us to gain knowledge on the functioning of prefabricated industry, hindrances in implementing prefabricated structures, methods of estimating the labour productivity analysis and ways of estimating the environmental impact. The literature studies that we have done are discussed below.

In this literature review, various articles and journals related to various topics like cost–benefit analysis of prefabrication technology, case studies on labour productivity and the impact of time and environment are studied. This study helped us to gain knowledge on the functioning of prefabricated industry, hindrances in implementing prefabricated structures, how to identify the labour productivity analysis and how to weigh up the environmental impact. The following section summarizes the work as documented by a few pieces of literature.

The author [5] studied the impact on the labour structure market resulting from the extensive application of prefabrication in the construction industry of Hong Kong. He identified that the construction industry had found difficulties in recruiting manpower in the past. The author has conducted interviews with eight interviewees all of them in directorial positions in different organizations. The existing labour consumption data was collected from the contractor using standard information sheets and compared between the traditional method of construction and prefabricated construction where more than 70% of the elements were prefabricated and the total difference per unit was identified. The author found that labour resources can be reduced by 40% from the existing labour force. The author also studied the impact of HB/NCB and SPC on truck drivers' consumption and found that a difference per unit of 0.82 driver days was found.

The study [6] conducted a study investigating the benefits of prefabrication technology mainly implemented in four private building projects in Hong Kong with mixed projects such as hotel, residential, and two commercial projects. In the projects, prefabrication structures included staircases, beam sections, column sections and lintels. These are cast on-site to improve the speed of construction, in site grouted joints minimized and reduced water leakage in the prefabrication building plastering, tiling and scaffolding work are reduced, 2 mm thin layer of the skim coat is done instead of plastering. The study reported 1–2 mm skim coat was only required in lieu of plastering of 15–20 mm, reduction in timber formwork in the range of 74–86%, concrete wastage reduction in the range of 51–60%, reduction in steel wastage in the range of 35–55%. This case study concludes that prefabrication is one of the ways to reduce material wastage, reduce construction duration, increase quality and improve site safety, reducing the overall cost of the project.

The authors [4] through their case study intended to explain the environmental impacts of prefabricated construction by the emission of CO_2 gas in comparison between precast and in-situ concrete. The thesis explains the minimal impact of CO_2 emission on the environment through concrete, steel, transportation, machinery, equipment and tools while practicing precast techniques over conventional construction techniques. The author also gives detailed insight through case study data on CO_2 emissions about the loss of material, transportation distance, vehicle capacity, fabrication and installation of precast components (or) structures. The findings and recommendations state that CO_2 emission is more due to loss of materials, and it can be considerably reduced during the production and construction stages, and it can be achieved through prefabrication techniques rather than undergoing conventional techniques. The best way suggested is by adopting eco-friendly materials rather than conventional materials. The thesis though has some restraints since the conclusion is arrived at based on only one case study, and the results might change on various conditions and complexities of the project.

In the work by Tumminia et al. [7], the authors conducted a study on the life cycle energy performance of prefabricated structures and the environmental impacts of prefabricated structures by taking a case of a building located in Messina, Italy. The authors used an approach that combines both "non-steady state building simulation" and "life cycle assessment" methodology. The authors identified the average monthly solar radiation from the building to quantify the solar energy produced. The authors also identified the life cycle inventory for each stage of the project such as the material production stage, construction stage, usage stage and end-of-life stage and benefits. The authors identified the material manufacturing stage in factories as having the most impact. The author concludes that the incorporation of a life cycle assessment methodology to design choice is the most important thing to be implemented.

3 Methodology

A case study approach has been adopted in the present work. The paper is based on the field visit conducted and the analysis of data collected from visiting the precast factory yard in Chennai. The data is planned to be collected in three stages for the prefabricated structures, for the four major fields—cost, time, labour and environmental impact aspects—(1) prefabrication yard data collection for initial cost invested and productivity of each component, (2) prefabricated structures installation site for calculating the productivity, labour consumption and time consumption for erection, (3) analysing the environmental impact from prevalent carbon emission data. The data to analyse the cost for conventional is done by a cost estimation of the similar plan which has been used to estimate the cost and environmental impact data. After the data collection, the estimated data from both approaches is compared, and the cost–benefit analysis will be achieved. The final cost per square foot for the prefabricated industry and minimum square foot required for adaptation of prefabricated structure is to be established. The paper, however, presents the initial data from the precast factory on the time cycles and crew gang composition for various components produced for a real estate project.

4 Case Study

In the precast industry, the factory setup with desired equipment, machinery and state-of-the-art production technology is the first and foremost aspect to be looked into to sustain in the market over other competitors. The key to producing and delivering quality precast concrete products is by having the right equipment based on the nature of the job. All the precast components are cast on moulds or forms which are then treated in a controlled environment and moved to the storage yard for curing using lifting equipment. From batching to placing concrete, there are many types of machinery required to carry out and deliver a quality end product.

For the present study, a precast site in the city of Chennai has been taken up. There are a series of machinery used for the production, installation and transportation of precast elements in the precast fabrication yard, and let us discuss them in detail. The batching plant production capacity is 1.5 m^3 and is supported by three silos, one each for fly ash, cement and GGBS, and the coarse aggregates of size 10 and 20 mm, and m-sand are transferred to the mixing unit using an automated hopper that weighs the required quantity of aggregates and transferred through a belt conveyor. The production of concrete through batching plant will take around 2–3 min. Then, the batched concrete is transferred to the concrete distributor using fly buckets in a short time without compromising the quality of the batched concrete. These fly buckets travel on a separate rail positioned high in such a way that it does not interfere with other equipment in the plant. The fly buckets combined with the concrete distributor function completely on automatic operation from the batching plant, and there is no need for any operator intervention. An overhead concrete distributor that travels on overhead rails mounted on the columns of the factory helps in placing the concrete by lowering and rising the equipment without any spillage. Then, after placing of concrete in the moulds, the compaction is done manually by means of needle vibrators.

The factory is equipped with all kinds of moulds such as beam moulds, column moulds, wall moulds, footing moulds and tilting table moulds. The tilting mould is exactly similar to the flat mould with one additional feature where the entire mould table can be tilted 90° using hydraulic jacks. These types of moulds are convenient for providing windows and door openings, and also for casting sandwich wall panels. The layout of the factory is shown in Fig. 1.

The hollow-core slabs are cast in a 147 m long bed using an extruder machine. The extruder machines are designed for the production of a wide range of prestressed concrete hollow-core slabs both for floors and walls on long production beds. With the help of an extruder machine, one can cast hollow-core slabs ranging from 150 mm thickness to 500 mm thickness in a single phase using the extrusion method without the need for vibration, thus keeping the noise of the mission to a minimum. The width of the hollow-core slab produced by the extruder machine is 1.2 m, and the length is 140 m. It delivers high concrete compaction and excellent top surface flatness, and thus, one can walk above it immediately after the casting of the hollow-core slab. The hollow-core mould in the extruder can be replaced based on the desired thickness of the slab, and the process to complete the 147 m long slab will be around 2–2.5 h. After attaining their initial strength, the prestressed tendons are cut down, and then, as per the length requirement as per the design, slabs will be cut down and will be shifted to the curing yard by means of a lifting beam with clamps hooked to an overhead crane. These lifting beams are available in standard lengths of 7, 9 and 12 m. EOT or bridge cranes are the most common type of overhead cranes used in any precast yard, which consist of parallel runways with a travelling bridge spanning the gap. The EOT crane used in the precast yard is of two variations—15 and 20 T used to lift the moulds, reinforcements, lifting beams, and concrete distributors. The EOT crane works by means of electricity, and it can be operated with the help of

Table 1 Hollow-core slab productivity

Concrete qty: For 12 m = 3.168 m^3					
Dimension of slab		Manpower		Equipment	Production data
Width	1.2 m	Batching plant	1	1. Fly bucket	**Cycle 1**
Thickness	0.4 m	QC	1	2. Concrete distributor	For 15 m^3 = 212 s
Length	12 m	Helper	3	3. Extruder machine	**Total time = 212 s**
		Extruder operator	1		**Cycle 2**
					Conveyor belt = 90 s
					Concrete mixing = 38 s
					EOT transfer = 30 s
					Transfer to spreader = 30 s
					Horizontal movement of spreader = 40 s
					Total time = 228 s

(Cycle 2 determines the productivity time)
Ideal productivity for 12 m hollow-core slab = ((12 * 1.2 * 0.4 * 0.55)/1.5) * 228 * (45/60)) + 228 = 589 s
Figures 2 and 3 present the hollow-core slab casting extruder machine and the cast hollow-core slab sections

either the driver or by remote control. The details of the cycle time observed for various components are given in Tables 1, 2, 3 and 4 (Fig. 1).

5 Results and Discussion

After conducting the initial phase of the study, the productivity and manpower usage for various components of the prefabricated structure was estimated. The productivity has been estimated by noting down the actual time taken for casting each of the sections and calculating the effective time of operation per hour. All the above-estimated time does not include the bar-bending time and MEP fixtures time which goes on separately and is assembled over the mould. The productivity is estimated by taking two cycles—(1) cycle time for casting, (2) cycle time for batching plant mixing into consideration and identifying which cycle determines the productivity and considering that time into consideration.

Table 2 Wall panel productivity

Concrete qty: For one panel = 1.125 m^3					
Dimension of panel		Manpower		Equipment	Production data
Width	2.5 m	Batching plant	1	1. Fly bucket	**Cycle 1**
Thickness	0.2 mm	QC	1	2. Concrete distributor	For pouring = 80 s
Length	3 m	Barbender	2	3. Needle vibrator	For compaction = 67 s
Window opening	1.25 m × 1.5 m	Barbender helper	2	4. Mould	**Total time = 147 s**
		Helper	3		**Cycle 2**
					Conveyor belt = 90 s
					Concrete mixing = 38 s
					EOT transfer = 30 s
					Transfer to spreader = 30 s
					Horizontal movement of spreader = 40 s
					Total time = 228 s

(Cycle 2 determines the productivity time)
Cycle time for one wall panel = ((1.125/1.5) * 228 * (50/60)) + 228 = 371 s

For the productivity analysis of the hollow-core slab of M 40 concrete, the machines and plants used were batching plant, fly bucket, concrete distributor and extruder machine. The manpower used were batching plant operator (1), QC engineer (1), helper (3) and extruder operator (1). The data has been collected for 12 m long at the casting yard and since the batching plant is of 1.5 cum capacity, the data collected for the hollow-core panel has been converted to the same 1.5 cum and cycle time is estimated for both cycles. For the run of 12 m of hollow-core slab of 0.4 m thickness, the cycle time observed is 589 s.

For the analysis of the wall panel cycle time of M 40 concrete, the machines and plants used were batching plant, fly bucket, concrete distributor, needle vibrator and mould. The manpower used were batching plant operator (1), QC engineer (1), bar bender (2), bar bender helper (2) and helper (3). The data has been collected for a wall panel of 2.5 m × 3 m × 0.2 m with a window opening of 1.25 m × 1.5 m at the casting yard, and since the batching plant is of 1.5 cum, the data collected for the wall panel has been converted to same 1.5 cum and cycle time is estimated for both

Table 3 Beam productivity

Concrete qty: For 15 m = 1.5 m^3					
Dimension of beam		Manpower		Equipment	Production data
Width	0.25 m	Batching plant	1	1. Fly bucket	**Cycle 1**
Thickness	0.4 m	QC	1	2. Concrete distributor	For pouring = 240 s
Length	15 m	Barbender	3	3. Needle vibrator	For compaction = 80 s
		Barbender helper	2	4. Mould	**Total time = 320 s**
		Helper	2		**Cycle 2**
					Conveyor belt = 90 s
					Concrete mixing = 38 s
					EOT transfer = 30 s
					Transfer to spreader = 30 s
					Horizontal movement of spreader = 40 s
					Total time = 228 s

(Cycle 1 determines the productivity time)
Cycle time for 15 m beam = ((1.5/1.5) * 320 * (50/60)) + 228 = 495 s

the cycle. For the above-mentioned wall panel for the volume of 1.5 cum, the cycle time estimated is 371 s.

For the cycle time analysis of beam section of M 40 concrete, the machines and plants used were batching plant, fly bucket, concrete distributor, needle vibrator and mould. The manpower used were batching plant operator (1), QC engineer (1), bar bender (2), bar bender helper (2) and helper (3). The data has been collected for the beam section of 0.25 m × 0.4 m × 15 m at the casting yard, and since the batching plant is of 1.5 cum, the data collected for the hollow-core panel has been converted to the same 1.5 cum and cycle time is estimated for both the cycle. For the above-mentioned beam section, the cycle time for a volume of 1.5 cum is estimated to be 495 s.

For the cycle time analysis of column section of M 40 concrete, the machines and plants used were batching plant, fly bucket, concrete distributor, surface vibrator and mould. The manpower used were batching plant operator (1), QC engineer (1), bar bender (2), bar bender helper (2) and helper (3). The data has been collected for the column section of 0.3 m × 0.3 m × 3 m at the casting yard, and since the batching plant is of 1.5 cum, the data collected for the hollow-core panel has been

Table 4 Column productivity

Concrete qty = 0.27m^3					
Dimension of column		Manpower		Equipment	Product data
Width	0.3 m	Batching plant	1	1. Fly bucket	**Cycle 1**
Thickness	0.3 m	QC	1	2. Concrete distributor	For pouring = 333 s
Length	3 m	Barbender	2	3. Needle vibrator	For compaction = 166 s
		Barbender helper	2	4. Mould	**Total time = 499 s**
		Helper	3		**Cycle 2**
					Conveyor belt = 90 s
					Concrete mixing = 38 s
					EOT transfer = 30 s
					Transfer to spreader = 30 s
					Horizontal movement of spreader = 40 s
					Total time = 228 s

(Cycle 1 determines the productivity time)
Cycle time for one column member = ((1.5/1.5) * 499 * (50/60)) + 228 = 644 s

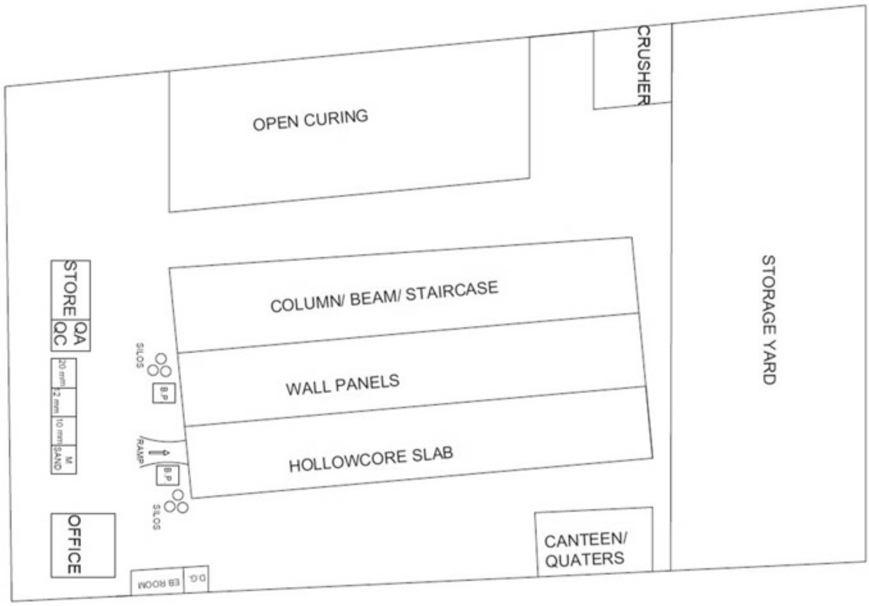

Fig. 1 Factory layout

Fig. 2 Hollow-core slab extruder machine

Fig. 3 Hollow-core slabs

converted to the same 1.5 cum and cycle time is estimated for both the cycle. For the above-mentioned column section for the volume of 1.5 cum, the cycle time estimated is 644 s.

6 Conclusion

Adaptation of precast and prefabricated structures in the construction industry would result in improvement in productivity because the maximum amount labour-intensive work is done in the precast yard itself. The team observed the ease with which the components are cast with minimum involvement of labour. In future, the team intends to visit the prefabricated site and collect the required data such as the usage of machinery like a crane, the requirement of the area and other parameters and quantify it for the residential project and compare the same with a similar conventional means of construction and site execution, thereby obtaining the cost–benefit and estimating the environmental impact for the adaptation of prefabrication and by minimizing the wastes generated.

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A Study on BIM Implementation a Residential Construction Project in India

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Abstract The construction industry has been growing despite the complexities and risks involved throughout the life cycle of project delivery. To continue this growth path and to fulfil the increasing demands, the industry has started adopting various new trends and technologies such as building information modelling, lean technology, precast-prefabricated and pre-engineered structures. Research and study of BIM use in many countries has proved various benefits of BIM in the construction industry such as improvement in productivity and collaboration, reduced risk of cost and time overrun and rework. However, BIM implementation in India is lagging behind most of the other countries despite its vast range of benefits. There are factors like lack of information, training, awareness, apprehensions regarding the technology and lack of comprehensive analysis documenting the advantages. The present paper intends to explain the benefits of BIM implementation in a residential project in the Indian city of Pune. The paper intends to demonstrate the process of BIM implementation and promulgate the benefits, so that it encourages practitioners in India to adopt BIM on a larger scale.

Keywords Lean construction · Prefabrication · Buildings · Case study · Productivity

1 Introduction

Similar to the global construction industry, architecture, engineering and construction (AEC) in India is growing rapidly which is the second-largest industry after the agricultural sector. Indian architecture, engineering, construction and operation (AECO) industry employs more than 35.5 million people and has the second-highest direct investment after the services sector, and the contribution of the AECO industry to India's GDP is 11.2%. According to the Economic Survey of India, it is predicted by 2045, Indian construction industry will require an investment of

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approximately $4.6 trillion for sustainable economic growth. The data obtained from the Ministry of Statistics and Program Implementation (MOSPI) indicate that the government has suffered INR 3.89 lakh crore in cost overrun. Also, the Ministry stated that approximately 553 projects in India experienced a notable overrun in time of completion.

In the past few years, construction industry is changing from employing conventional methods and routine work to using more advanced technologies to enhance the efficiency and productivity of men and machinery, quality of infrastructure and sustainability to reduce overall project cost, lead and idle time, design clashes and rework with the help of effective collaboration and communication among the different project teams. To achieve the above-mentioned goals and targets, construction industry is adopting various modern trends and technologies like IoT, building information modelling, 3D printing, digital construction and collaborative information management systems.

Specifically, building information modelling (BIM) has opened up many possibilities. Building information modelling (BIM) has been considered an enabler for other modern technologies and thus increased output in the construction industry. Building information modelling has the capabilities to reduce time and cost overruns, increase the safety, quality and performance of 3Ms of the construction industry (i.e. men, materials and machines) and check the design mistakes to avoid future clashes during actual construction. Though BIM has been in use for the past 15–20 years, only in the last few years companies, governments and professionals are understanding and accepting the benefits and capabilities of BIM to address the various problems that the construction industry is facing today which is evident from the increase in the adoption of BIM in developing countries.

Some of the issues that are preventing BIM from getting adopted in developing countries like India include:

- Shortage of trained BIM professionals and the absence of government initiatives such as nationwide BIM implementation and awareness programs.
- Lack of detailed research considering the micro-level of factors and knowledge required for a quantitative assessment of the advantages of BIM.
- Lack of convincing proof of the advantages of BIM in terms of detailed cost–benefit analysis.

The objective of the present study was to thoroughly understand the process of BIM implementation in an ongoing project and explore the advantages it brings to the project management process, evaluate and analyse the cost–benefit of BIM implementation. This shall help encourage practitioners to adopt BIM increasingly on Indian projects.

2 Literature Review

Since the objective of the study was to comprehensively study the cost–benefit associated with BIM implementation, the authors identified the literature related to surveys conducted on BIM, application of BIM, implementation of BIM, advantages of BIM and various stages of BIM from various journals/articles are collected and distributed amongst each of the group members. The process of literature review helped the team understand the various aspects of BIM implementation, and methodologies adopted by earlier studies and paved the way for setting up a methodology that is appropriate for the present study.

The authors [3] conducted a study to investigate the use of BIM for cost control in a real estate project. The authors adopted a case study approach by selecting a 12 floors residential building with a built-up area of 15,000 m^2. The study investigated the benefits by constructing architectural and structural models, integrating the BIM model with the Autodesk Revit software and carrying out 5D modelling on the project. The authors concluded that although the process of BIM model development is time consuming, the results for cost control are significantly improved with a BIM model and simulation allows real-time project time and cost monitoring.

The study conducted by Baldauf et al. [1] investigated the use of BIM for capturing and modelling client requirements in a low-income social housing project. The authors proposed a system to model the requirements with standardization of the design process, facilitate early information availability, control the development process and assist the visualization during the development of the model. The authors reported the use of BIM for requirements modelling can help generate value and improve the delivery process.

A study by Soliman Junior et al. [6] conducted a study to model the design requirements using BIM for a healthcare facility. The study designed the model to systematically capture the design requirements—such as emergency exit requirements and healthcare facility regulation requirements in the model design. The authors captured 177 requirements under 13 categories and 32 subcategories. These requirements were integrated with the design of the healthcare facility model. The study reported significant benefits with limited automated requirement processing.

In the study [7], it was discovered that from the unification of BIM with facility management at intervals in the first stages of a project life cycle, qualification objectives were discovered. A close strategy coupled with effective style and operations at regular intervals leads to less quantity of time spent and improved collaborations amongst the professionals and provides fruitful results. The study reported significant challenges faced due to the lack of knowledge and skills in the field of facility management which can act as a framework for the benefits of integrated BIM projects. The authors of this study also reported that to get the maximum output from building information modelling, it can be said that the application should be used beyond designing and construction management.

The authors [5] review the stages and trends of BIM plan development presenting the case studies of four projects. The authors investigated the various aspects of BIM implementation such as the benefits realized by the projects with the BIM implementation, obstacles faced during the process of BIM implementation and the problems associated with the implementation of BIM in these projects. The study reported a saving of 0.5% of the value of the entire project through BIM, realistic quantity estimation resulted in accurate payments to the contractors, and minimized disputes. The study reported that ensuring adequate and effective collaboration between the various participants of the project was a challenge. In addition, lack of awareness of the various BIM tools and standards was also identified to be a challenge.

In the study by Chahrour et al. [2], a model is developed to conduct a cost-profit analysis of BIM-enabled clash detection. Then case study is conducted to visualize the results and validity of this model that found that there is concerning two hundredth saving in price by mistreatment BIM-enabled clash detection. The schema developed for determining cost–benefit analysis in this paper is more generic and applicable mainly for clash detection. The framework developed during this paper is changed and applied to additional complicated comes. Also, this schema is extended to use for different BIM uses like 4D and 5D**.**

A study was conducted by Koseoglu et al. [4] investigating the BIM and lean synergies in an airport project in Istanbul. The BIM implementation on the project consisted of 4D, 5D and construction supervision processes as well. The authors conducted a detailed clash detection process, and 600,000 clashes were identified during the construction of this mega airport project. The study reported a saving of 16,442 man-days and a total of €835,389,260 from the implementation of BIM models at all stages of the project.

3 Research Methodology

In this study, a quantitative methodology is used to ascertain the total amount of costs and benefits involved in the implementation of BIM in a construction project in India. To collect the data required, a case study was conducted on an ongoing project where the project group members worked during a summer internship as a part of the course curriculum. Many previous research papers [8–10] related to cost–benefit analysis of BIM implementation have used case study methods. Figure 1 details the different steps followed to identify, resolve and quantify the cost implications of BIM implementation in a construction project:

4 Data Collection

In this project, the data we collected is from a live project located in Pune, Maharashtra. The project is a commercial building. The project consists of three towers. The total built-up area of the project is 10, 21,154 (Sq. Ft). And the planned duration of the project is 562 days. The model was developed in June 2022, and the

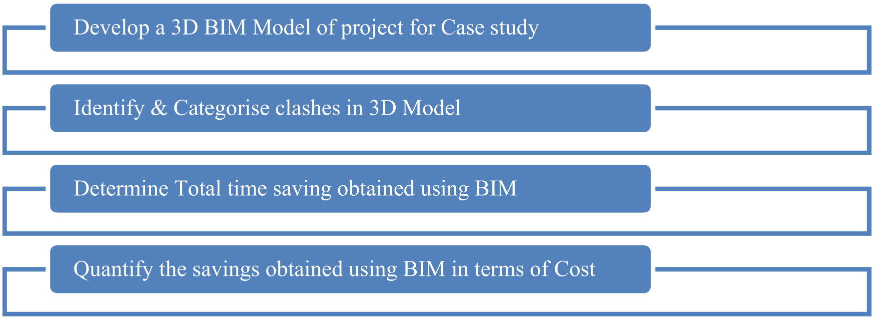


Fig. 1 Research methodology adopted for the study

clash detection report was generated. During the process of clash detection, several clashes were identified. From these clashes, a quantitative cost–benefit analysis has been carried out.

5 3D Modelling

First, the CAD drawings of the model were developed. Following this, the 3D Revit models are developed which are then revised according to the changes made in the building.

6 4D Scheduling and Clash Detection

The schedule is developed by the planning department in Microsoft Project and is imported into Navisworks Manage. Then, each element is attached to its respective activity. The process is shown in Fig. 2.

7 Clash Detection Process

Firstly, the selection of two different aspects of the model is done. 'RCC' and 'FF' are selected in section A and section B, respectively, by keeping the clash type as hard and tolerance at 0.050 m. And various other clash detection tests were run on different aspects of a building (e.g. Arch vs Elect, Arch vs MEP, RCC VS Arch). After running the test, the number of clashes and type of materials are identified. The results are shown in Fig. 3.

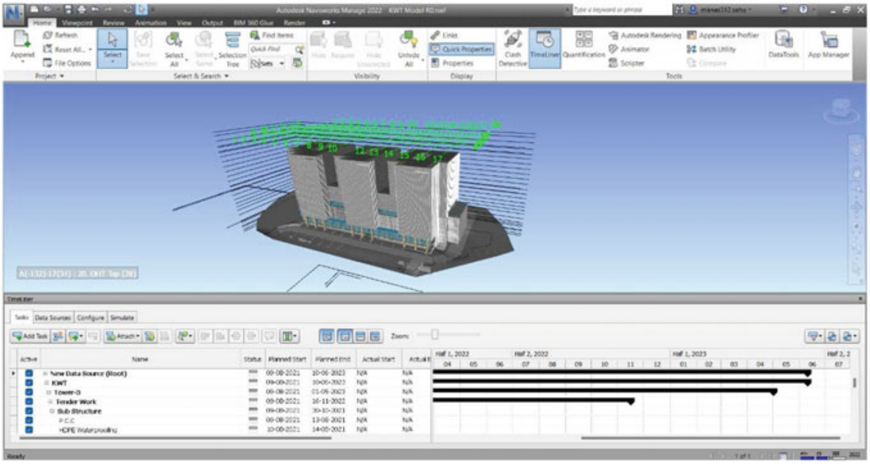


Fig. 2 4D Navisworks with MSP schedule

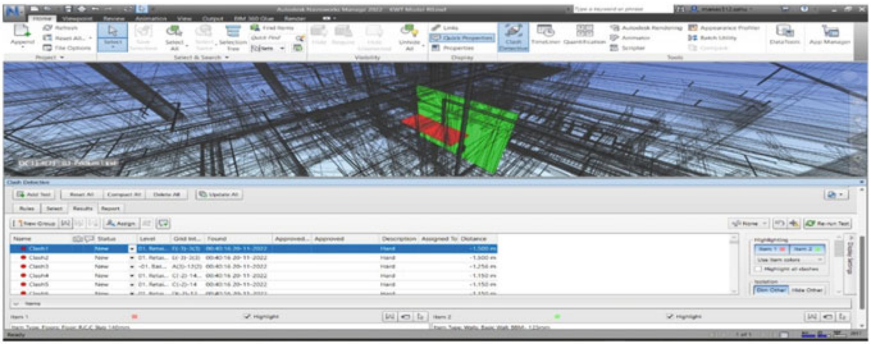
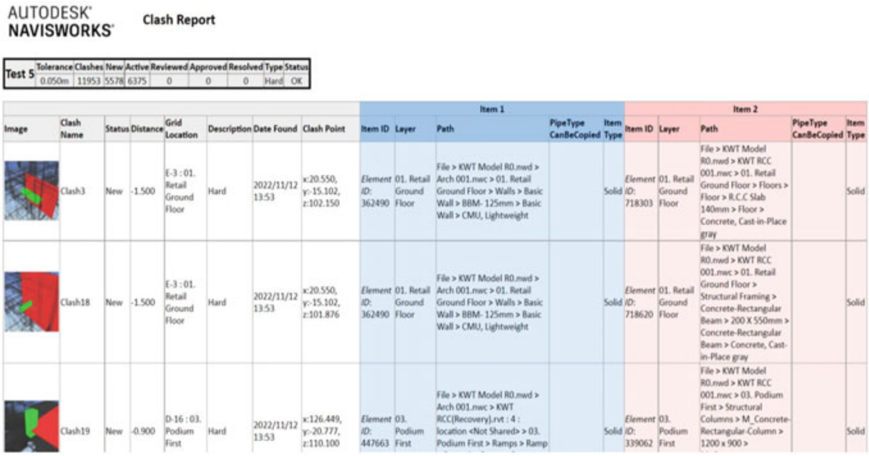


Fig. 3 Clash detection process

Once the clashes were detected, the automated export of the clashes is made. The spreadsheet allows further detailed analysis of the nature and types of the clashes, the number of clashes and the type of components in clash, and this allows the project team to consult, collaborate and evaluate options to find strategies to resolve the clashes and redevelop the model that allows unhindered construction on site. The details are as shown in Fig. 4. The summary of the clashes are as below.

- Architectural components versus Electrical components
  - Major clashes—11
  - Minor clashes—14
- Architectural components versus RCC components



AUTODESK NAVISWORKS Clash Report

Test 5	Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Type	Status
	0.050m	11953	5578	6375	0	0	0	Hard	OK

								Item 1					Item 2				
Image	Clash Name	Status	Distance	Grid Location	Description	Date Found	Clash Point	Item ID	Layer	Path	PipeType CanBeCopied	Item Type	Item ID	Layer	Path	PipeType CanBeCopied	Item Type
	Clash3	New	-1.500	E-3 : 01. Retail Ground Floor	Hard	2022/11/12 13:53	x:20.550, y:-15.102, z:102.150	Element ID: 362490	01. Retail Ground Floor	File > KWT Model R0.nwd > Arch 001.nwc > 01. Retail Ground Floor > Walls > Basic Wall > BBM- 125mm > Basic Wall > CMU, Lightweight		Solid	Element ID: 718303	01. Retail Ground Floor	File > KWT Model R0.nwd > KWT RCC 001.nwc > 01. Retail Ground Floor > Floors > Floor > R.C.C Slab 140mm > Floor > Concrete, Cast-in-Place gray		Solid
	Clash18	New	-1.500	E-3 : 01. Retail Ground Floor	Hard	2022/11/12 13:53	x:20.550, y:-15.102, z:101.876	Element ID: 362490	01. Retail Ground Floor	File > KWT Model R0.nwd > Arch 001.nwc > 01. Retail Ground Floor > Walls > Basic Wall > BBM- 125mm > Basic Wall > CMU, Lightweight		Solid	Element ID: 718620	01. Retail Ground Floor	File > KWT Model R0.nwd > KWT RCC 001.nwc > 01. Retail Ground Floor > Structural Framing > Concrete-Rectangular Beam > 200 X 550mm > Concrete-Rectangular Beam > Concrete, Cast-in-Place gray		Solid
	Clash19	New	-0.900	D-16 : 03. Podium First	Hard	2022/11/12 13:53	x:126.449, y:-20.777, z:110.100	Element ID: 447663	03. Podium First	File > KWT Model R0.nwd > Arch 001.nwc > KWT RCC(Recovery).rvt : 4 : location <Not Shared> > 03. Podium First > Ramps > Ramp		Solid	Element ID: 339062	03. Podium First	File > KWT Model R0.nwd > KWT RCC 001.nwc > 03. Podium First > Structural Columns > M_Concrete-Rectangular-Column > 1200 x 900 >		Solid

Fig. 4 Clash detection in HTML format

  - Major clashes—36
  - Minor clashes—14

- RCC components versus Firefighting components

  - Major clashes—36
  - Minor clashes—39

8 Analysis of Data

1. **Identifying and Categorizing Clashes**
   It involves identifying clashes using Navisworks Manage in an already prepared 3D model of the given project consisting of three towers of 19 floors each. These clashes are further categorized into two categories, i.e. (1) major clashes and (2) minor clashes based on the level of effort required for the resolution of these clashes. The total no. of major and minor clashes detected in the 3D Revit models of the building are as follows:

   (i) Major clashes—83
   (ii) Minor clashes—67

2. **Determining Clash Resolution Time/Total Time saving by using BIM**
   In this step, total time required for the complete resolution of the clashes is determined. This includes the time required for different activities such as:

   (i) Redesign of the structure,

(ii) Demolish the existing wrongly built structure,

(iii) Rebuild as per rectified design.

To calculate the total time required for resolving all the clashes, average time for each category of clashes is determined and this average time is then multiplied by the total no. of clashes in each category.

(i) Average time required for resolving major clash—1 day (Istambul Airport Research Paper)

(ii) Average time required for resolving minor clash—0.5 days,

(iii) Total required for resolving all the clashes in the project,

= (Total no. of major clashes) × (Average time required for resolving major clash) + (Total no. of minor clashes) × (Average time required for resolving minor clash)

= 116 days

3. **Determining the total construction cost of the Project using Conventional Construction Method**

In this step, total construction cost of the project is calculated, which includes the cost of RCC framework construction, non-load bearing elements and finishes as well. This is calculated using the following formula:

Total construction cost (Rs.) = Construction cost (Rs./sq. ft) × Total built-up area (sq. ft)

= 2780 × 1,021,154 (Ref—Project details)

Total construction cost (Rs.) = Rs. 2,838,808,120 = 283.88 Cr

4. **Determining Total Project Duration**

This is directly taken from the schedule prepared using MSP by planning engineer working on the project.

Total project duration = 562 days (Ref—MSP project schedule)

5. **Calculating the Total Indirect Cost of the Project**

The indirect cost of the project is calculated by considering the coefficient which is practically taken by the company cost engineers at the time of estimation of cost. This coefficient gives the percentage of indirect cost in total construction cost.

Total indirect cost of project = (Indirect cost coefficient) × (Total construction cost)

= 0.075 × 2,838,808,120 (Ref—Project team inputs)

Total indirect cost of project = Rs. 212,910,609 = Rs. 21.29 Cr

6. **Calculate the Total Indirect cost savings that can be obtained by use of BIM**

The total amount of indirect cost saved (Rs.) = Total time saved × (Total indirect cost/Total construction time)

= 116 × (212,910,609/562)

= Rs. 4.39 Cr

7. **Determine Cost of Installing BIM Software's**

Cost of BIM software installation for 3 years (Rs.) = Rs. 872,256.

No. of projects on which BIM software's are being used = 2.

Cost of BIM software for given project = (Cost of BIM software installation for 3 years × Project duration/Software license validity period (3 year))/No. of projects us

= (872,256 × 562/(3X365))/2

Cost of BIM software for given project = Rs. 223,839 = Rs. 22.38 lakh

8. **Cost of Employing BIM Team**

   The total no. of employees working on BIM is as follows:

   (i) CAD + Revit modeller (Salary—Rs. 20,000/month)
   (ii) BIM manager (salary—Rs. 45,000/month)

   Cost of employing BIM team per day = (20 + 45)/30 = Rs 2000/day

   Total cost of employing BIM team = (Cost of employing BIM team per day) × (Total project duration) = 2000 × 562

   Total cost of employing BIM team = Rs. 1,124,000 = Rs. 11.24 lakh.

9 Results and Conclusion

The present study through the approach of BIM implementation in a real estate project that early BIM implementation with proper implementation strategy yields significant benefits. The benefits also outweigh the costs incurred significantly. Thus, from the research and case study on BIM implementation on a residential project in Pune, it was found that by adopting proper strategies and planning, BIM implementation on construction projects in developing countries like India leads to several benefits such as reduced rework, saving in time and cost involved in wastage incurred due to rework and improved collaboration among various stakeholders of the project. The benefits reported in the study are limited. With the implementation of BIM, apart from the reduction in construction time, efforts to take out quantities, designing–redesigning, progress monitoring and real-time updates also shall be substantially reduced. These benefits are planned to be assessed in the future course of the research work.

10 Limitations

The authors would like to inform that the benefits reported in the study is from the study conducted within a small observation period of the project. Further validation studies need to be carried out to revalidate the findings reported in the study. The authors intend to conduct further validation with the company and confirm the findings.

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Application of IOT in Construction Industry

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Abstract Construction is a continuous process that not only acts as a foundation for urbanization but also as a source of jobs and new complexes and structures. The need to construct new and creative structures is something that everyone understands and accepts. The phrase IoT in construction was recently introduced as an application. It refers to employing technological equipment, such as the IoT and the latest internet software, in the construction process to enhance project efficiency. The construction business is constantly striving to provide better services to its customers. Simultaneously, they are attempting to make building procedures more efficient and, as a result, profitable. In order to make these activities more effective in successful execution of construction projects, IoT-based intervention in the construction ecosystem should persist. There exist several studies concentrated on one or more domains for IoT implementation. However, holistic IoT application from the conceptual to hand-over phase is under-researched area. To this end, there exists limited studies concentrated on exploration of IoT-grounded applications from the lens of project management body of knowledge domains. Thus, the current study attempts to address the lacuna through the development of conceptual framework for IoT applications in construction projects through mixed methods approach.

Keywords IOT · Project management · Construction · Knowledge domains · Conceptual framework · Mixed methods research

1 Introduction

The Internet of Things, or IoT, refers to the multitude of physical items around us that are combined with specialized software and devices such as sensing devices, monitors, storage, and other devices to exchange, generate, and operate data thus

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collected and provided. IoT is widely used in a wide range of sectors, depending on the demands and requirements of each.

The primary purpose of the IoT in the construction industry is to use technologically matured devices for optimizing the resource management. This can be accomplished through the use of sound engineering practices and management of expenses minimally with low risk. It can be characterized as a guarantee of good use. As the construction sector expands and grows with people to meet their needs, it introduces new strategies and technologies to increase productivity and address the current challenges and problems facing the construction sector. Applying the Internet of Things (IoT) establishes a site where devices, materials, and personnel are connected to central servers. Their actions are monitored in real time to ensure compliance and safety with applicable regulations. In today's construction industry, different equipment is manufactured and processed for different purposes.

The construction industry is involved in developing the needs of the growing population and leading to urbanization by adopting new techniques, strategies, and modern technologies to increase the efficiency and competency of construction business concerns and challenges. IoT provides a Web where devices and employee hardware are synchronized with a central server that monitors activities in real time, ensures compliance with applicable policies, and keeps them safe. In today's construction industry, many devices are created and maintained for various reasons.

The construction industry well understands the demands and potential of digital technology. A KPMG poll found that 95% of construction businesses anticipate that new technologies like IoT would fundamentally alter their sector. Another 72% of respondents claim that implementing new technologies, including IoT, is critical to their overall strategy or strategic vision. PwC reports that 98% of industrial firms anticipate efficiency gains of up to 12% from digital solutions like IoT-enabled predictive maintenance or augmented reality. The building is prepared for digital transformation, and unadaptable businesses face the danger of falling behind.

2 Benefits of IOT in Construction

One of the most basic and undeveloped concerns on a building site is the workers' safety from numerous hazards, even though various safety measures and regulated behavior patterns have failed in multiple instances. Accidents can be reduced with the use of IoT alignment. For instance, if any working personnel is wearing a real-time location monitoring device and heavy machinery with a real-time motion detection chip used at the same construction site, whose movements can be easily tracked from a control center. This will ensure their performance and allow them to anticipate and avoid potentially dangerous situations. Staying within budget is the most challenging problem for any construction company. Available resources are frequently not treated according to their actual value, people are left idle, and the total value of rented equipment needs to be appropriately valued. IoT can assist real-time business management in tracking but also create a clear budget proposal sequentially, implementing the most broadly utilized and effective ways to cut project costs by ensuring proper delivery of products, machines, and other resources. It also helps with planning by keeping track of resources available and maximizing their worth while avoiding squandering any.

Construction garbage gets the same amount of attention as construction itself. This negatively influences the ecology and destroys the ecosystem, but it also generates a waste and debris disposal problem that must be dealt with on-site. The used IoT might help them design a sustainable plan for using recycled materials and using zero-waste terminology, as well as educate workers on the construction's sustainable concept. This design of a workable throwaway strategy has to be implemented to decrease waste and understand its importance.

IoT seems to also provide daily remote control of employees, with site evaluations that are as exact and clear as the workers in real time to the person seeing them. The project manager or owner may track real-time movement and obtain a complete snapshot of the project's state and daily work analysis from anywhere they choose (if it is Internet based). Drones, for example, might be used to undertake on-site safety evaluations before a dispute ever breaks out. Such remote devices can be beneficial when constructing is taking place in areas inaccessible to people, unclean, or dangerous to be in, so that the workplace environment can be made utilization of human force friendly following post-machine analysis. As a result, these are the different ways in which IoT's impact on the construction sector is essential and evident.

3 Problem Identification

There are many studies conducted on the usage of IoT in manufacturing, automotive, IT/ITES, and other industries; however, there are few types of research conducted on IoT-related projects. Numerous aspects, including productivity, agility, creativity, consumer experience, quality, cost, and revenue have improved due to digitalization. Although there have been substantial improvements in construction technology, materials, site automation, scheduling collaboration procedures, and platforms like BIM, concerns have been raised regarding the potential for resistance to using such technologies in the construction industry. Applications for IoT are prevalent everywhere. The construction sector is behind other industries in adopting the IoT ecosystem, although doing so in its everyday operations.

A recent Burger research finds numerous areas of construction project applicability, such as remote operation, supply supplies, tools, and construction equipment monitoring, managing and repairing equipment; utilizing it for remote surveillance, augmented reality (AR), and building maintenance. Additionally, use of IoT is found with respect to Building Information Management, predictive maintenance, progress monitoring, safety and quality monitoring aspects [1].

To boost construction efficiency, IoTs are being used to monitor resources such as people, materials, and equipment and all knowledge areas of construction project

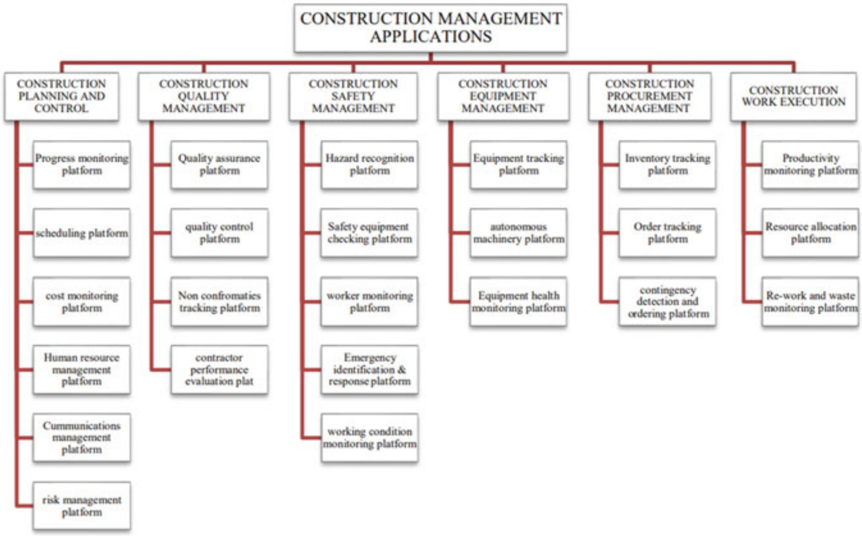

Fig. 1 Few IoT applications to be inculcated in the construction phases of the project

management. This is a widely regarded PMI PMBOK framework for project management for offering an overarching structure. The PMBOK framework was created with the help of numerous project management specialists and comprises all of the necessary procedures for building in the six categories listed below.

1. Construction planning and control,
2. Construction quality management,
3. Site safety management,
4. Construction equipment management,
5. Construction bidding management,
6. The IoT applications are vividly illustrated in the (Fig. 1).

3.1 Gartner's Hype Cycle

The lifetime of technology, from conception through maturity and widespread acceptance, is represented graphically by the hype cycle. The research and consulting company Gartner, which specializes in information technology (IT), developed the hype cycle as a branding tool. However, marketing and technology publications frequently utilize the phases of the hype cycle as a point of reference. Businesses may utilize the hype cycle to inform their technological selections based on their comfort level with risk. The cycle's several phases each have their unique hazards and possibilities as shown in Fig. 2.

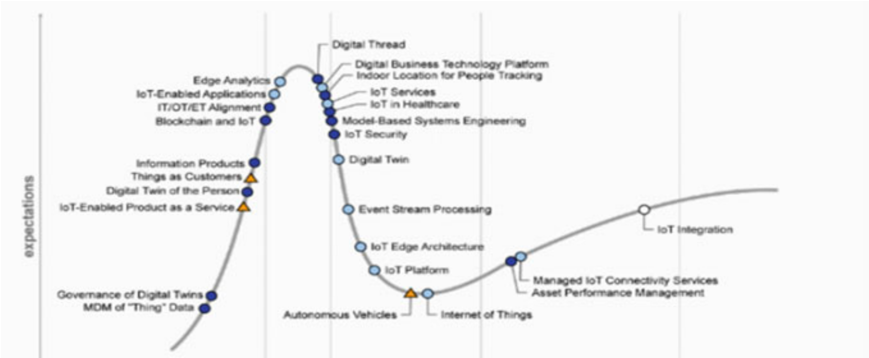

Fig. 2 Five key phases of a technology's life cycle

3.2 Innovation Trigger

Everything begins with a possible technical advance. Early proof-of-concept accounts and media attention significantly increased public activation. Frequently, no beneficial items are available, and economic feasibility is not proven.

3.3 Peak of Inflated Expectations

Early public disclosure results in some success, frequently accompanied by several failures. Many individuals and some businesses are in action.

3.4 Trough of Disillusionment

As testing and deployments fail, interest wanes. Manufacturers of technology fall or fail. Only the other suppliers that make improvements to their goods in order to win over early adopters will continue investment. IoT and its key components are typically considered to have occurred at this period.

3.5 Slope of Enlightenment

More and more instances of how technology might help organizations are starting to come into focus and become clearer. Technology providers are starting to release second- and third-generation products. Pilot programs are being funded by many businesses, although conservative businesses are still hesitant.

3.6 Plateau of Productivity

The effects of widespread adoption have begun to be felt. More precise criteria are used to assess the viability of suppliers. It is obvious that the technology has benefited from its application and market relevance.

The Internet of Things, as part of a digital business strategy, merges the physical and digital worlds, revolutionizing how everyone live and work. This Hype cycle will assist businesses in determining the maturity and hype surrounding crucial IoT building pieces.

4 Literature Review

Although the construction industry is embracing new technologies and communication tactics, it should be noted that this is still a slow process. Many builders and contractors need to be aware of the need for such devices and are willing to invest in them. However, if used effectively and prudently, these technologies have the potential to play a vital role in establishing a location in which everything is coordinated and documented. Companies like Trimble, Pillars Technologies, ES Tracks, and others are producing and introducing IoT solutions in the construction industry, urging construction firm owners to consider this option and experience the tremendous potential of this technology [2].

It is easy to see how IoT is used by practically every business and industrial field. It also provides them with several opportunities. As a result, the Internet of Things (IoT) has emerged as the dominant technology that will define the future of numerous industries and create a significant shift in everyday life [3]. Also, allied technology-based processes such as building information modeling (BIM) and blockchain interfaces in water projects [4] and productivity improvement as well as building trust in the AEC IoT and blockchain principles were studied [5]. Integration of artificial intelligence, blockchain, and IoT have been linked in the construction safety domain for communication and information dissemination [6].

Managers and executives can receive real-time data from IoT in construction, allowing them to respond quickly to urgent day-to-day circumstances. On a more significant, strategic level, IoT data may assist construction companies in analyzing and improving their operational operations to improve efficiency, quality, and, as a result, profitability. Given how the Internet of Things is affecting firms in other industries, there is little doubt that the Internet of Things will revolutionize construction companies and the industry. To achieve the early-adopter edge, construction businesses must find possibilities to incorporate IoT in their operations and engage in test projects [7].

The major equipment manufacturers in the construction sector are all heavily involved in the following principles. In the stage of technical development, most applications still focus on the low-hanging fruit, such as machine hours, GPS tracking, fuel usage, and idle hours' time. Equipment owners may use this information to plan preventative maintenance, define optimistic operating procedures, prevent misuse and theft, and more. Engine speed, liquid pressure and temperature, and other operating parameters in construction equipment are measured and tracked by more sophisticated systems. Depending on the program, varied levels of analysis assist in making decisions based on the data. Greater data analytics may contribute to less downtime by enabling more preventive modeling, such as replacing oil only when its outward appearance has deteriorated. Planned maintenance allows the consumer to do repairs only when necessary [8].

Ignoring emerging technology is one thing to avoid the installation of the app or visiting the manufacturer's webpage to learn more about the equipment and staff. The excavator may send a message that it needs a new pressure control valve, and an autonomous repair truck will arrive and use a portable 3D printer to build the part. One thing is sure, IoT will be an emerging topic for years to come.

5 IOT Application Framework in Construction

For presenting a broad foundation for construction.

This PMI PMBOK framework for project management is extensively used. The PMBOK framework, which was created with the help of several project management experts, covers all the critical steps required to construct the following six categories.

1. Construction planning and control,
2. Construction quality management,
3. Site safety management,
4. Construction equipment management,
5. Construction bidding management,
6. Construction work execution.

Figure 1 shows some applications where IoT can be used to inculcate these areas during the construction phase of the project. There are many applications on the characteristics of project [9–12].

6 Methodology

This study uses a five-step research design to accomplish its goals. First, based on a prepared literature research and expert comments, a preliminary identification of enablers that may have an impact on the integration of IoT technique in the construction sector was made. The major enablers that specifically influence the integration of IoT technique were then determined by conducting a questionnaire survey with industry practitioners. This will make it easier to determine the pairwise contextual relationships between these enablers.

In the current study, the methodology comprises of two phases, one is a quantitative research strategy in which data collection is done through responses gathered from the floated questionnaire survey. Subsequently, the questionnaire survey is framed in a way having questions for various departments in the organization like execution, safety, planning, and others.

And the second phase is an interview-based research strategy, wherein physical interaction of the construction industry professional experts and go on with interviewing them to collect abundant data for data analysis process. The interviews are conducted till the saturation of responses is attained.

Based on the data collection, from both phases of the methodology, triangulation study is arrived on integration with the of data analysis stage.

7 Data Collection

This study adopts questionnaire survey followed by qualitative interviews for data collection. It happens through recording responses to closed-end questions, closed-ended questions when they have different responses from the respondents. They are helpful in the well-defined variable like respondent's level of agreement with some statements, perceptions of risk, etc. Moreover, the difficulty involved in this method is that we have to frame an appropriate set of response options. Nevertheless, they are comparatively quick and easier for respondents to complete. This technique is easier for us since it allows us to record the responses in numbers and enter them into the spreadsheet.

The responses are generally categorical or quantitative. In categorical variables, like the gender of the respondent, they choose what they belong to. In addition, in quantitative variables, a rating scale is generally provided. The rating scale is defined as the ordered set of responses that the respondents should choose. Five-point scales are generally best for unipolar scales. In our research project, we use five-point scales.

The research methodology used in this study can be depicted using a research framework as shown below, in the Figs. 3 and 4.

8 Conclusions

IoT applications gained significant uptake in the construction space owing to the increased thrust on decision-making capabilities from the empirical evidence from data-capturing sensors mounted on construction resources on further transforming the data into meaningful insights. Also, managing construction projects with empirical supported decisions deemed to be more effective rather than heuristic judgment that might lead on adversarial consequences. The current study attempts to develop a conceptual framework for the feasibility of IoT-based applications for the PMBOK knowledge domains. The study has limitation such as Indian-based construction

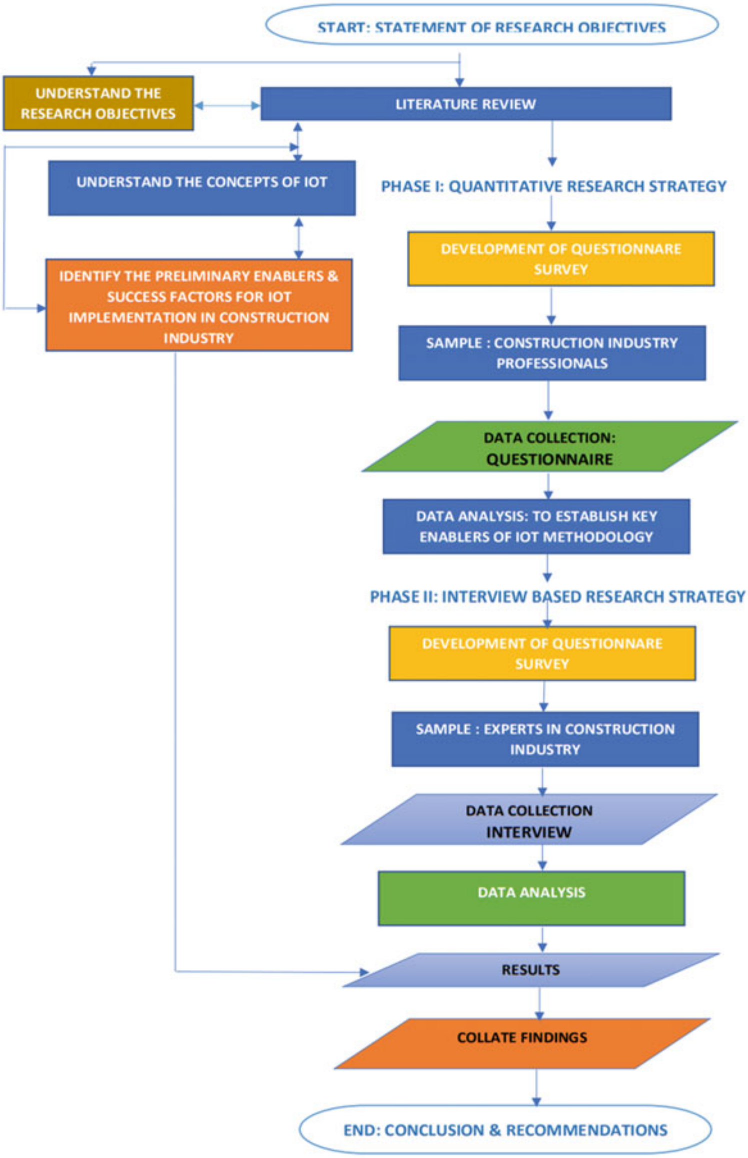

Fig. 3 Research design and methodology

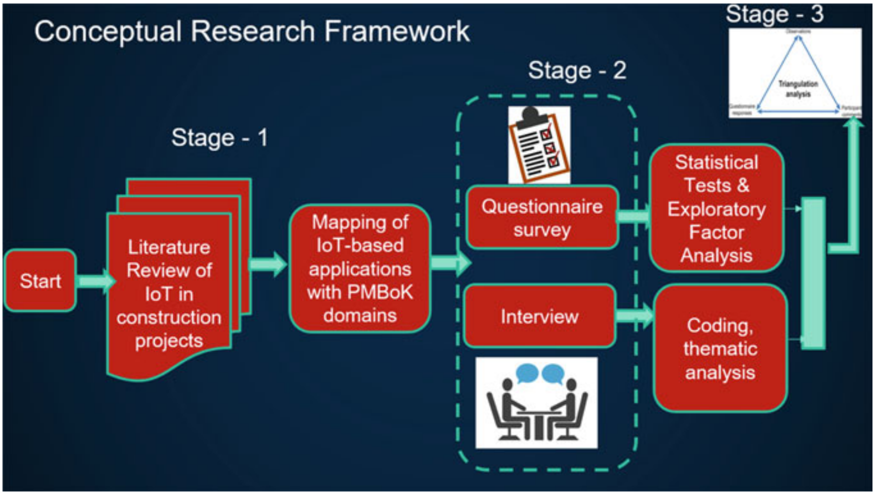

Fig. 4 Conceptual research framework

firms adopting IoT-based applications are chosen as the sample which is of lesser populace.

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