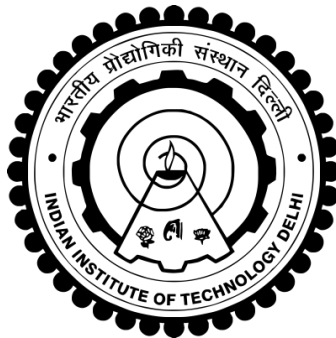


**LEAN SCHEDULING IN CONSTRUCTION PROJECTS:
REALISTIC MILESTONE PLANNING**

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**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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REALISTIC MILESTONE PLANNING**

by

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DEPARTMENT OF CIVIL ENGINEERING

Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

JUNE 2019

I dedicate this effort

To My Family

CERTIFICATE

This is to certify that the thesis titled “**Lean Scheduling in Construction Projects: Realistic Milestone Planning**” being submitted by **Col Pawan Pandey** to the Indian Institute of Technology Delhi, India for the award of the degree of ‘**Doctor of Philosophy**’, is a bonafide record of the research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for submission of this thesis, which to the best of my knowledge has reached the requisite standard. The results contained in this thesis have not been submitted either in full or in parts to any other University or Institute for the award of any degree or diploma.



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Date: 12 June 2019

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Pawan Pandey

ABSTRACT

The efficient construction industry is essential for socio-economic development. The delay in the desired infrastructure not only leads to cost escalation but severely affect the outcome of the dependent socio-economic ventures. To avoid the delay, construction projects are conventionally modelled as a network of conversion processes or work packages (WPs) and scheduling techniques are used for their coordinated execution. These techniques are top-down passive approaches because what happens inside a WP and their linkages are abstracted. The resources and directions are ‘pushed’ downwards without considering execution capability. Due to these unrealistic assumptions, the initial schedule becomes obsolete soon after the commencement of work. The reactive system of project control creates further confusion, leading to time cost overrun.

Lean Construction is a bottom-up approach based on ‘TFV Theory’ of production. It enhances value for the customer through optimization and/or elimination of flow activities in addition to optimization of conversion activities. Last Planner is an established ‘pull’ based ‘lean production system and control’ which attempts to reduce inflow variations through commitment-based execution plan and enhances efficiency through continuous improvement. The Last Planner primarily uses two key inputs; 1) Milestones from the master schedule to prepare the phase schedule by planning backwards and; 2) Feedback from the workers for the weekly plan. Since the master schedule is generally based on unrealistic assumptions and there exist several uncertainties associated with workers’ (in terms of availability and capability), the implementation of lean in construction becomes questionable. Experts opined that true benefits can accrue only if the master schedule is realistic and adequate number of

workers with requisite skills are available. Thus, main objective of the present study is to develop a robust proactive ‘Lean Scheduling Framework’ which reduces project duration, ensures optimum workers utilization and provides realistic master schedule to enhance the performance of ‘Last Planner’.

The proposed solution involves realistic modelling of the construction project using combination of ‘network of main conversion activities’ and ‘feeding processes’ followed by realistic scheduling. The scheduling process involves series of schedule iterations using project specific data to progressively enhance schedule reliability, synchronization of the activity execution rate by modifying workers employment (i.e. using multiple crews, crew multitasking, crew resizing, etc.) for continuous flow, etc. The final schedule obtained after iterations has been termed as ‘Lean Schedule’ because scheduling framework is based on ‘Lean’ concept and provides ‘reliable schedule’ to augment the LPS (Last Planner System).

Initially, the components of proposed lean scheduling framework were derived from the literature and integrated using logical reasoning followed by testing of these components were tested using pilot case studies. The findings from the case studies were utilized to progressively improve the framework. Finally, entire framework is tested using data from an ongoing mass housing project. The pilot studies and verification cases revealed that the framework is too generic and can be applied to most of the construction project. It was observed that the accuracy of the lean schedule largely depends on the quality of data utilized, and capability of expert involved in modelling and imitation of project conditions.

Keywords: Delayed Projects, Workers Deficiency, Lean Construction, Last Planner, Realistic Master Schedule, Lean Scheduling.

सार

सामाजिक और आर्थिक विकास के लिए कुशल निर्माण उद्योग आवश्यक है। वांछित अवसंरचना में देरी से न केवल लागत में वृद्धि होती है, बल्कि यह निर्भर सामाजिक और आर्थिक उपक्रमों के परिणामों को गंभीर रूप से प्रभावित करती है। विलंब से बचने के लिए, निर्माण परियोजनाओं को पारंपरिक रूप से रूपांतरण प्रक्रियाओं या कर्म संकुल के संजाल के रूप में तैयार किया जाता है और सारणी तकनीकों का उपयोग उनके समन्वित निष्पादन के लिए किया जाता है। ये तकनीकें 'ऊपर से नीचे' दृष्टिकोण हैं। आम तौर पर एक कर्म संकुल के अंदर होने वाला कार्यकलाप ज्ञात नहीं होता है। सामान्यतः निष्पादन क्षमता पर विचार किए बिना संसाधनों और निर्देशों को जारी किया जाता है। इन अवास्तविक मान्यताओं के कारण, काम शुरू होने के तुरंत बाद प्रारंभिक अनुसूची कालविसृद्ध हो जाती है। परियोजना नियंत्रण की विद्यमान प्रणाली आगे भ्रम पैदा करती है, जिससे समय और लागत लगातार अधिक होती रहती है।

लीन निर्माण TFF सिद्धांत पर आधारित एक उपरगामी दृष्टिकोण है। यह रूपांतरण गतिविधियों के अनुकूलन के अलावा प्रवाह गतिविधियों के उन्मूलन के माध्यम से ग्राहक का हितलाभ बढ़ाती है। लास्ट प्लानर एक स्थापित सिद्धांत है, जो प्रतिबद्धता-आधारित निष्पादन योजना के माध्यम से अंतर्वाह विविधताओं को कम करने का प्रयास करता है और निरंतर सुधार के माध्यम से दक्षता बढ़ाता है। लास्ट प्लानर मुख्य रूप से दो प्रमुख निविष्ट पर आधारित है; 1) पीछे से आगे की योजना तैयार करने के लिए मुख्य पड़ाव से सारणी बनाना ; 2) साप्ताहिक योजना के लिए कार्यकर्ताओं की प्रतिपुष्टि पर निर्भरता। चूंकि मुख्य सारणी आम तौर पर अवास्तविक मान्यताओं पर आधारित होती है और इसमें श्रमिकों के साथ जुड़ी कई अनिश्चितताएँ मौजूद होती हैं जिससे निर्माण प्रक्रिया संदिग्ध हो जाती है। विशेषज्ञों ने कहा है कि परम लाभ तभी प्राप्त हो सकते हैं जब मुख्य सारणी यथार्थवादी हो और अपेक्षित कौशल वाले श्रमिक पर्याप्त संख्या में उपलब्ध हों।

इस प्रकार, वर्तमान अध्ययन का मुख्य उद्देश्य एक मजबूत सक्रिय सारणी तंत्र विकसित करना है, जो परियोजना की अवधि को कम करे, इष्टतम श्रमिकों का उपयोग सुनिश्चित करे और लास्ट प्लानर के प्रदर्शन को बढ़ाने के लिए यथार्थवादी मुख्य सारणी प्रदान करे। प्रस्तावित समाधान में 'मुख्य रूपांतरण गतिविधियों के संजाल और निर्माण भरण प्रक्रियाओं के संयोजन का उपयोग करके निर्माण परियोजना की यथार्थवादी प्रतिरूप प्रक्रिया शामिल है जिससे यथार्थवादी

समय- निर्धारित होता है। लीन शेड्यूलिंग परियोजना में सम्बद्ध तथ्यों का उपयोग करते हुए कई बार सारणी की पुनरावृत्ति के साथ श्रमिकों के रोजगार को संशोधित करके गतिविधि निष्पादन दर को समक्रमिक बना देता है जिसमें कई कर्मिदलों को एक काम पर, एक कर्मिदल को कई काम, और कर्मिदल का आकार बदलना, आदि शामिल है। पुनरावृत्तियों के बाद प्राप्त अंतिम अनुसूची को 'लीन शेड्यूल' कहा जाता है क्योंकि सारणी संतंत्र 'लीन' अवधारणा पर आधारित है और लास्ट प्लानर सिस्टम को सुदृष्ट बनाती है।

प्रारंभ में, प्रस्तावित लीन शेड्यूलिंग ढांचे के घटकों को साहित्यिक अन्वेषण से प्राप्त किया गया उसके बाद प्रारंभिक मार्ग-दर्शन अध्ययन से इन घटकों के परीक्षण के बाद तार्किक तर्क का उपयोग करके एकीकृत किया गया। तत्पश्चात व्यष्टि अध्ययन के निष्कर्षों का उपयोग उत्तरोत्तर रूपरेखा में सुधार के लिए किया गया। अंत में, एक सामूहिक आवास परियोजना के तथ्यों का उपयोग करके पूरे ढांचे का परीक्षण किया गया। प्रारंभिक मार्ग-दर्शन अध्ययन और सत्यापन के मामलों से पता चला कि ढांचा बहुत व्यापक है और इसे अधिकांश निर्माण परियोजना में लागू किया जा सकता है। यह देखा गया कि लीन शेड्यूल की परिशुद्धता काफी हद तक उपयोग किए गए तथ्यों की गुणवत्ता और प्रतिरूपण में शामिल विशेषज्ञ की क्षमता और परियोजना प्रतिनिधित्व पर निर्भर करती है।

सूचक शब्द: विलंबित परियोजनाएं, श्रमिक की कमी, लीन निर्माण, अंतिम नियोजक, यथार्थवादी मास्टर अनुसूची, लीन शेड्यूल

TABLE OF CONTENTS

Description	Page
Certificate	i
Acknowledgment	ii
Abstract	iv
List of Figures	xii
List of Tables	xiv
List of Abbreviations	xvi
Chapter 1 INTRODUCTION	
1.1 General	1
1.2 Rationale for the Study	3
1.3 Motivation	5
1.4 Problem Statement	6
1.5 Research Aim and Methodology	7
1.6 Objectives and Scope	8
1.7 Organization of Thesis	9
Chapter 2 LITERATURE REVIEW	
2.1 Introduction	11
2.2 Construction Projects	12
2.3 Measuring Project Success	13
2.4 Construction Workers	15
2.4.1 Availability Issues	17
2.4.2 Capability Issues	19
2.4.3 Mitigation Measures	21
2.4.4 Challenges in Managing Construction Workers	24
2.5 Scientific Management in Construction	24
2.5.1 Work Study	26
2.5.2 Productivity	27
2.5.3 Project Management	31
2.5.4 Project Control and Dynamic Scheduling	37

2.6	Lean Construction	39
2.6.1	Limitations of Project Management	40
2.6.2	Contemporary Approaches to Improve Project Efficiency	42
2.6.3	Defining Lean Construction	44
2.6.4	Lean Project Delivery System (LPDS)	47
2.6.5	Critical Chain	51
2.7	Gaps in the Literature	53
Chapter 3	RESEARCH METHODOLOGY	
3.1	Introduction	57
3.2	Research Strategies	57
3.3	Research Design	58
3.3.1	Research Questions	58
3.3.2	Proposition and Assumptions	61
3.3.3	Research Process	65
3.4	Research Method	65
3.2.1	Data Collection	65
3.2.2	Data Analysis and Inferences	66
Chapter 4	DEVELOPMENT OF SOLUTION FRAMEWORK	
4.1	Introduction	69
4.2	Proposed Lean Construction Model	69
4.3	Solution Framework	72
4.4	Part 1: Application of Work Study in Construction Projects	74
4.4.1	Simplified WS Flow Diagram	75
4.4.2	Crew Optimization using WS	76
4.4.3	Results and Inferences	79
4.5	Part 2: Dynamic Scheduling	82
4.5.1	Schedule Optimization using WS	82
4.5.2	Project Schedule with Multi-Skilled Workers	84
4.5.3	Improving Schedule by Synchronized Execution Rate	88
4.5.4	Findings and Discussion	90

4.6	Part 3: Realistic Initial Schedule	91
4.6.1	Baseline Productivity (BP) and Factor Analysis	92
4.6.2	Realistic Scheduling with Modified BP	95
4.6.3	Deductions from the Study	96
4.7	Part 4: Flow Process Design (FPD)	97
4.7.1	Framework for FPD	98
4.7.2	FPD for Reinforcement Work	98
4.7.3	Findings of the Study	106
4.8	Summary of Pilot Studies	107
4.9	Prerequisites of Lean Scheduling	108
4.9.1	Detailed Project Information	108
4.9.2	Workers Skill Database (WSD)	109
4.9.3	Crew Productivity Matrix	112
4.10	Lean Scheduling Framework	114
4.10.1	Schedule Iterations	114
4.10.2	Simulation of Absenteeism	117
4.10.3	Feeding Process Design	118
4.11	Summary	118
Chapter 5	MAIN CASE STUDY AND RESULTS	
5.1	Project Description	120
5.2	Data Collection	122
5.3	Lean Scheduling	127
5.4	Discussion and Analysis of Results	149
Chapter 6	DISCUSSION AND IMPLEMENTAION	
6.1	Salient Features of Lean Scheduling	152
6.2	Industry Implementation	153
6.3	Prototype Tool Development	156
6.4	Discussion	
6.4.1	Pondering	157
6.4.2	Significance	162
6.4.3	Limitations	163

Chapter 7 SUMMARY AND CONCLUSIONS

7.1	Summary	
7.1.1	The Problem	165
7.1.2	The Proposed Solution Framework	165
7.1.4	Summary of the Main Case Study	167
7.2	Conclusions	169
7.3	Contributions	169
7.4	Scope for Future Research	170
REFERENCES		171
LIST OF PUBLICATIONS		189
APPENDIX A	CALCULATION OF BP USING K MEAN CLUSTERING	190
APPENDIX B	CASE STUDY: OPTIMIZING FLOW PROCESS THROUGH SYNCHRONISATION OF CYCLE TIME	195
APPENDIX C	CURRICULUM VITAE OF THE AUTHOR	206

LIST OF FIGURES

Figure No.	Figure Caption	Page
Figure 1.1	Planning stages in a construction project	5
Figure 1.2	Overall research methodology	7
Figure 1.3	Flowchart indicating organization of the thesis	9
Figure 2.1	Open conversation model of construction (Drewin 1982)	30
Figure 2.2	Transformation and flow view of production (Koskela, 1992)	41
Figure 2.3	LPS focusing on system component (Ballard & Howell, 1994)	50
Figure 3.1	Research methodology	64
Figure 3.2	Methodology for data collection	66
Figure 4.1	Proposed lean construction model	70
Figure 4.2	Flow diagram for realistic scheduling	71
Figure 4.3	Solution framework	73
Figure 4.4	Simplified Work Study flow diagram	75
Figure 4.5	Outline Process Chart for Reinforcement Work	77
Figure 4.6	Synchronizing execution rate of activities to reduces project duration	90
Figure 4.7	Framework for flow process design	99
Figure 4.8	Project site details	100
Figure 4.9	FPC for Manpower	105
Figure 4.10	Creation of workers skill database (WSD)	111
Figure 4.11	Flow diagram for Lean Scheduling	115
Figure 5.1	Site layout of a mass housing project	121
Figure 5.2	Plan view of one dwelling unit	121
Figure 5.3	Data collection for main case study	123
Figure 5.4	Initial Schedule	128
Figure 5.5	Hypothetical as-planned schedule after reducing activity duration	130
Figure 5.6	Execution schedule due to as-planned schedule	131
Figure 5.7	Improved schedule using work study	135
Figure 5.8	Schedule after synchronizing execution rate of selected key activities	138
Figure 5.9	Schedule after synchronizing execution rate of fresh activities	139

Figure No.	Figure Caption	Page
Figure 5.10	Rebar demand based on schedule-4	142
Figure 5.11	Modification in the duration of selected activities to reduce fluctuation	144
Figure 5.12	Snapshot of schedule after rebar demand optimization	144
Figure 5.13	Rebar demand schedule to feed all reinforcement related activities	145
Figure 5.14	Crew flow diagram for reinforcement work	147
Figure 6.1	Planning stages in construction project	158

LIST OF TABLES

Table No.	Table Caption	Page
Table 2.1	Summary of literature: Impact of absence on construction productivity	18
Table 2.2	Summary of approaches to improve project performance	38
Table 2.3	Contemporary Approaches to improve project performance	43
Table 2.4	Principles governing Lean Management (Liker 2003)	45
Table 2.5	Integrated TFV view on production (Koskela and Howell 2002)	46
Table 2.6	Comparison between conventional and lean approach (Koskela and Howell 2002)	47
Table 2.7	Project length and appropriate method of management (Adapted from Bartelsen et al. 2006)	54
Table 4.1	Initial flow process chart for reinforcement work	78
Table 4.2	Revised FPC for reinforcement work	80
Table 4.3	Project schedule before using Work Study	85
Table 4.4	Project schedule after using Work Study	86
Table 4.5	Impact of multiskilling on workers employment	87
Table 4.6	Project schedule after synchronizing rate of execution of the selected key activities	89
Table 4.7	Activities associated with civil trade and corresponding crew productivity	93
Table 4.8	Summary of productivity loss due to various factors	95
Table 4.9	Comparison of project deadline with different productivity norms	96
Table 4.10	Flow process chart (FPC) for 1 Truckload (3.75 MT) of steel	101
Table 4.11	Revised FPC for 1 Truckload (3.75 MT) of steel	102
Table 4.12	FPD for reinforcement work	104
Table 4.13	Summary of pilot studies	107
Table 4.14	Productivity matrix	113
Table 5.1	List of activities involved in the construction of one block	126
Table 5.2	Initial schedule for main case study	129
Table 5.3	Hypothetical as-planned schedule	132
Table 5.4	Assessment of project duration if execution is based on the hypothetical schedule	133

Table No.	Table Caption	Page
Table 5.5	Application of WS on reinforcement work in slab	134
Table 5.6	Schedule optimization using WS	136
Table 5.7	Improved schedule after synchronising execution rate of selected key activities	137
Table 5.8	Additional improvement in schedule after synchronising fresh key activities	140
Table 5.9	Modified schedule after FPD	143
Table 5.10	FPD for reinforcement work	146
Table 5.11	Summary of main case study	148
Table 7.1	Lean schedule for main case study	168

LIST OF ABBREVIATIONS

BP	Baseline productivity
CPM	Critical path method
CFP	Continuous flow process
CC	Critical Chain
DU	Dwelling units
ENVA	Essential but non-value adding activities
FPC	Flow process chart
FPD	Flow process design
HS	Highly skilled worker
LPS	Last planner system of production control
LPDS	Lean project delivery system
LS	Lean Scheduling
LWS	Lean work structuring
MRCPSP	Multimode resource constrained project scheduling problem
MSPSP	Multi-skilled project scheduling problem
MS	Multi-skilled worker
NVA	Non value adding activities
PPC	Planned percent complete
RCA	Root cause analysis
RCC	Reinforced cement concrete
RCPSP	Resource constrained project scheduling problem
SK	Skilled worker
SS	Semiskilled worker
TFV	Transformation flow and value
US	Unskilled worker
VA	Value adding activities
WSD	Workers skill database
WBS	Work breakdown structure
WS	Work study