LEAN SCHEDULING IN CONSTRUCTION PROJECTS: REALISTIC MILESTONE PLANNING

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by

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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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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 तकनीक 'ऊपर से नीचें' दृष्टिकोण हैं । आम तौर पर एक कर्म संकुल के अंदर होने वाला कार्यकलाप ज्ञात नही 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 कालविस्र्द्ध हो जाती है। परियोजना नियंत्रण की विद्यमान प्रणाली आगे भ्रम पैदा करती है, जिससे समय और लागत लगातार अधिक होती रहती है।

लीन निर्माण TFV 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 जिसमे कई कर्मीदलों को एक काम पर, एक कर्मीदल को कई काम, और कर्मीदल 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 सुदृण 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

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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