

Dynamic modeling of labor productivity in construction projects



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Abstract

The presence of labor with high productivity at each stage of a project's development plays a significant role in project success. This research presents a system dynamics (SD)-based approach to model labor productivity. The complex inter-related structure of different factors affecting labor productivity is modeled using system dynamics approach. The qualitative model of labor productivity is constructed using governing cause and effect feedback loops. Then, the relationships that existed between different factors are determined and the quantitative model of the labor productivity is built. Using the proposed SD model, the labor productivity is simulated considering the effects of all the influencing factors. The effect of labor productivity on different project performance measures is also assessed in terms of time and cost. Using the proposed model, the project manager may find the root causes of a decrease in productivity. Therefore, the labor productivity may be improved by implementation of proper solutions.

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1. Introduction

The presence of labor with high productivity at each stage of a project's development plays a significant role in project success. Management decisions affecting labor productivity can influence the success of a construction project because a major portion of construction budget is allocated to labor expenses (Hanna et al., 2005; Sonmez, 2007). Productivity estimate is an essential element to estimate duration and cost of a construction operation (Hwang and Liu, 2010). Site workers account for up to 40% of the direct capital cost of large construction projects and there is a need to maximize the productivity of labor resources (Ng et al., 2004). Improving construction productivity can go some way toward eliminating time and cost overruns (Kaming et al., 1998).

Economists and accountants define productivity as the ratio between total input of resources and total output of product (Hanna et al., 2005). In construction, productivity is measured at different levels of detail for different purposes (Song and AbouRizk, 2008).

Project managers and construction professionals define productivity as a ratio between earned work hours and expended work hours, or work hours used (Hanna et al., 2005). For the current research, labor productivity is defined as the ratio between completed work and expended work hours to execute the project.

A better understanding of the factors influencing labor productivity can enable site management teams to more effectively allocate their limited resources, provide craft workers with better support, increase craft workers' motivation, and enhance craft workers' commitment to productivity improvement. It is important to know what craft workers need and what affects their performance in order to accomplish productivity improvement (Dai et al., 2009a; Oglesby et al., 1989).

The loss of construction productivity is usually attributed to various factors, rather than a single one. In addition, factors affecting construction labor productivity are rarely independent of the others, some factors may be the result of the same cause, or one factor may trigger the occurrence of others (Dai et al., 2009b). There are several studies that attempted to assess the impact of some of the influencing factors on productivity. However, the complex inter-related structure of different factors

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affecting the labor productivity was not accounted by the previous works. The previous researches had studied the effects of one of the affecting factors on the labor productivity and they cannot account for the effect of all the influencing factors which have complicated interactions with each other.

Moselhi et al. (2005) explored the impact of change orders on construction productivity and proposed a new neural network model for quantifying this impact. Pan (2005) presented a fuzzy based model by which the impact of rainfall on project productivity and completion time is assessed. Hanna et al. (2005) presented an analysis of the impact of overtime on construction labor productivity. Ibbs et al. (2007) illustrated causal linkages to capture the interactions of changes, disruptions, productivity losses, and the responsible parties. Hanna et al. (2008) assessed how shift work affects labor productivity. Westover et al. (2010) conducted a research to explore key work domains that impact worker job satisfaction and organizational commitment, which in turn impact long-term worker productivity. Zhai et al. (2009) presented an analysis of data to show that labor productivity is positively related to the level of IT implementation and integration. Goodrum et al. (2009) conducted a study through analysis of variance (ANOVA) and regression analyses, and found that activities experiencing significant changes in material technology have also experienced substantially greater long-term improvements in both their labor and partial factor productivity. Watkins et al. (2009) showed that congestion on construction sites often leads to a lower labor productivity using agent-based modeling.

Although several researches have been conducted to determine the effects of different factors on labor productivity, they are faced with some major defects. The previous studies had investigated the effects of one of the influencing factors on the labor productivity and they are not able to account for the effect of all the influencing factors. The labor productivity is influenced by several factors which have complex interactions with each other. None of the previous works, however, took into account the complex inter-related structure of different factors affecting the labor productivity. Furthermore, in the previous researches, the effect of workforce productivity on the project performance criteria in terms of time, cost and quality was not investigated.

This research presents a system dynamics (SD)-based approach to model labor productivity. System dynamics (SD) introduced by Forrester, is an objective-oriented simulation methodology enabling us to model complex systems considering all the influencing factors. The complex inter-related structure of different factors affecting labor productivity is modeled using system dynamics approach. The qualitative model of labor productivity is constructed using governing cause and effect feedback loops. Then, the relationships that existed between different factors are determined and the quantitative model of the labor productivity is built. Using the proposed SD model, the labor productivity is simulated considering the effects of all the influencing factors. The effect of labor productivity on different project performance measures is also assessed in terms of time and cost. Using the proposed model, the project manager may identify the root causes of a decrease in productivity. Therefore, the labor productivity may be improved by implementation of proper

solutions. To evaluate the performance of the proposed method, it has been employed in a housing project.

2. Research methodology

2.1. System dynamics approach

System dynamics (SD) introduced by Forrester (1961), is an objective-oriented simulation methodology enabling us to model complex systems considering all the influencing factors (Khanzadi et al., 2012). System dynamics approach provides a rigorous method for description, exploration and analysis of complex systems (Rodrigues, 1994). A dynamic system is a system in which the variables interact to simulate changes over time (Mawdesley and Al-Jibouri, 2010). SD modeling is useful for managing and simulation of processes with two major characteristics: (1) they involve changes overtime and (2) they allow feedback — the transmission and receipt of information (Richardson and Pugh, 1981). Much of the art of SD modeling is to discover and represent the feedback process which along with stock and flow structures, time delays and nonlinearities, determine the dynamics of system (Sterman, 2000). Several diagramming tools are used in system dynamics to capture the structure of systems, including causal loop diagrams and stock and flows. Each causal link is assigned a polarity, either positive or negative to indicate how the dependent variable changes when the independent variable changes. The important loops are highlighted by a loop identifier which shows whether the loop is a positive (reinforcing) or negative (balancing) feedback (Sterman, 2000).

3. Model structure

A flowchart representing different stages of the labor productivity simulation by the proposed SD approach is shown in Fig. 1. As it can be seen in this figure, the proposed SD approach can simulate labor productivity considering all the influencing factors. For this purpose, first all the factors affecting labor productivity are identified. The qualitative model of labor productivity is constructed using cause and effect feedback loops. Then the inter-relationships that existed between different factors are defined by mathematical equations and the quantitative model of labor productivity is built. Dynamic simulation of labor productivity is performed using developed quantitative model and labor productivity is determined. Sensitivity analysis is conducted to assess the impact of different factors on labor productivity.

Using the developed SD model, the impact of alternative solutions to improve labor productivity could be assessed.

4. Dynamic simulation of labor productivity: proposed system dynamics approach

The following section will consider how different stages of labor productivity simulation are performed by the proposed SD-based approach.

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