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Sensitivity Analysis of Construction Schedule Performance Due to Increased Change Orders and Decreased Labor Productivity

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ABSTRACT: In the initial steps of construction projects, contractors plan the construction processes and timetables as accurately as possible; however, a number of change orders are inevitable. It is important for owners and contractors to know which variables more critically violate the project's process and timing. In this study, a sensitivity analysis was performed to analyze the levels of impact of the variables that affect project performance and duration. The analysis was performed for a typical project plan, to understand how the plan changed with deviations in the variables. The results showed that project duration was the most sensitive variable to project schedule performance. This effect, however, was only seen after a certain reduction in the project deadline. The results of this study can be used by project planners to avoid unnecessary change orders in a construction project.

1 INTRODUCTION

A systematic approach is required for exploring the response of a model to varying inputs, to achieve reliable insight into the behavior of the model (Hamby, 1994; Hicks et al., 2015). A sensitivity analysis studies the qualitative or quantitative changes in the output of a model that are due to fluctuations in the variables (Saltelli et al., 2004; Borgonovo and Plischke, 2016; Kermanshachi et al. 2017). For a valuable modeling practice, the sensitivity analysis has been extensively preferred (Zhang et al., 2012). Complexity of engineering and management models and the increasing use of models with dynamic behaviors have motivated the researchers for improving these models (Pan, 2018). Sensitivity analysis could be considered the inverse of uncertainty analysis. While uncertainty analysis is the measurement of uncertainties in the inputs of a model (Hall, 2006; Ferchichi, 2018), sensitivity analysis involves identifying the influence that input factors of a model have on variations in the outputs of the model. Accordingly, it is useful to implement a sensitivity analysis to diagnose which input variables in a model or system have greater and/or less impact on its performance. The productivity of the labor is a significant parameter for evaluating a construction project's success (Hwang et al., 2009; Kermanshachi, 2016). Several researchers assessed various features of the factors impacting the labor productivity, such as change orders. Since change orders' influence on productivity depends on several factors, it becomes very complicated to accurately evaluate their impacts on labor productivity (Saltelli et al., 2004; Habibi and Kermanshachi, 2018).

Factors or variables that lead to change orders in a project are called change orders factors. The sensitivity analysis of the impact of change orders on labor productivity has been rarely studied. The goal of this paper was to determine which change orders factors most affect labor productivity, and consequently schedule performance, in a construction project. To achieve the outlined goal: (1) the change orders variables influencing labor productivity were identified; (2) a quantitative dynamic model, including the relationships among different change orders variables, was developed; and (3) a sensitivity analysis was conducted to determine the impact of each of the change orders factors on labor productivity. This study answers the following questions:

Q1: What are the key change orders factors that contribute to the variability of labor productivity?
Q2: How intensively do the change orders factors affect the labor productivity?

The output of this research will assist project managers identify the key change factors that cause flaws in labor productivity, and will help them develop sufficient policies for controlling these adverse impacts.

2 LITERATURE REVIEW

The measurement of productivity is an important variable for cost and schedule estimation in a construction project (Habibi et al, 2019; Pan, 2018). In the construction industry, labor productivity is defined as the man hours required to complete a given unit of work (Dai et al., 2009). Several variables with complex interactions impact labor productivity (Kisi et al., 2018), and change orders are one of the major causes of inefficient labor productivity (Pan, 2018; Kermanshachi et al., 2018; Safapour et al. 2019).

Change orders are legal documents that adapt to “any additional work in a contract that was not included in the original contract” (Anastaopoulos, 2010; Komurlu and Arditi, 2017; Safapour and Kermanshachi, 2019). They usually lead to disagreements between the owner and contractor, or contractor and subcontractor, about the consequential effects of the change (Eden et al., 2000; Sawik, 2017). In a construction project, unexpected changes complicate the construction process and cause some reworks (Eden et al., 2000; Safapour and Kermanshachi, 2019). Change orders issued by the owner and design errors lead to change orders (Hanna et al., 2002), but their impacts are difficult to measure, since the change orders are issued for different reasons (Hsieh et al., 2004). In addition, change orders is a crucial element that causes time overruns (Safapour and Kermanshachi, 2019; Hwang et al., 2009).

A common challenge in estimating the impact of change orders on labor productivity is the quantification of the impact of the change orders factors and the identification of the most influential of these factors (Serag et al., 2010; Sacks et al., 2017; Safapour et al. 2018). Sensitivity analysis is commonly implemented to analyze the values of any of the parameters and observe the behavior of the model. Sensitivity analysis helps in understanding how input sources can affect the output of a model (Saltelli et al. 2004). The approaches to this technique are classified as either local or global. The local approach considers one variable of a model at a time, while the remaining variables of the model are kept fixed to a value within their applicable range (Saltelli et al. 2004). Lee et al. (2010) generated a simulation system, Construction Operation and Project Scheduling (COPS), which implemented sensitivity analysis with various combinations of resources, to achieve the optimal resource combination.

The motivation of this study was the gap of knowledge created by the lack of a sensitivity analysis of change orders parameters that affect the labor productivity of a construction project. The goal of performing a sensitivity analysis in this research was to reach the best variable combination to attain the maximum productivity of a system by altering the values of the variables and identifying the critical factors that affect the labor productivity.

3 RESEARCH METHODOLOGY

A five-step research approach was developed to achieve the objectives of this study (Figure 1). First, a thorough literature review was performed, focusing on change orders, labor productivity, and sensitivity analysis. Second, the change orders variables were identified from the literature review and based on construction industry expectations. Third, a system dynamics model was developed that was capable of modeling the effect of change orders on labor productivity, and consequently the schedule performance of a project. Fourth, a sensitivity analysis was performed to evaluate the change orders factors and impact of each on labor productivity. Finally, the change orders factors with the most impact on labor productivity were identified. In the following, the methods for performing the sensitivity analysis and project productivity and schedule performance evaluation are presented.

3.1 Sensitivity Analysis Method

A sensitivity analysis is a common approach to evaluating the impacts of resources on a system’s performance. One of the most practical methods for performing the analysis technique is to change one factor at a time (OAT), to see how it causes changes in the output. This method involves: (1) changing one of the input variables, while keeping the others at a nominal value; and 2) repeating the process for all of the other inputs analogously. The sensitivity is determined by monitoring the changes in the output of the system, which is an adequately logical method since any observed change in the output would unquestionably be due to the changes of the moving variable. This practical approach has been widely preferred by modelers in different areas of interest. In addition, in the case of model failure, OAT immediately reveals which of the inputs is responsible for the failure.

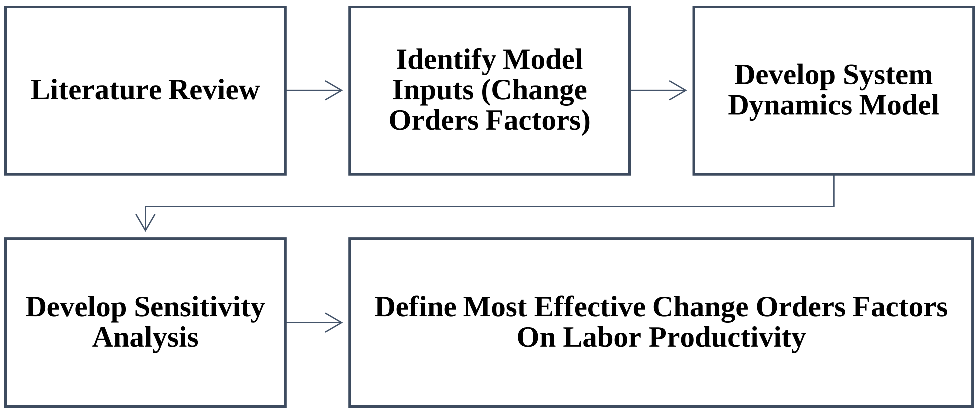

Figure 1. Research methodology figure.

3.2 Productivity Evaluation

In this study, project duration was selected as the dependent variable for labor productivity and project performance because of its importance and because it is highly influenced by change orders. In fact, when a project faces change orders, the pressure of anticipated changes to the schedule causes a decrease in labor productivity, as well as causing additional change orders. Although at the beginning of applying schedule pressure, when the deadline is fixed, the productivity increases, after a while it causes the project to be lengthier than the baseline (Figure 2). As shown in Figure 2, applying schedule pressure leads to labor frustration and consecutively decrease of labor productivity, which causes increase of change orders. Therefore, even though schedule pressure is a solution for change orders management, it can cause further change orders by affecting the labor productivity.

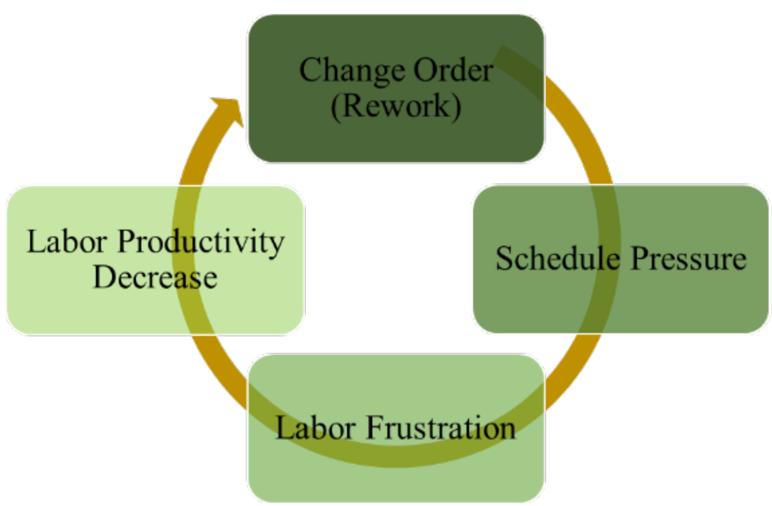

Figure 2. Effect of change orders & schedule pressure on a project.

4 MODEL DEVELOPMENT

4.1 Model Inputs

The change orders variables were identified from the literature and modeled systems, and eight of the most effective ones were selected for sensitivity analysis. Table 1 shows the list of these variables and the literature from which they were extracted. These variables' interactions and their relationships with labor productivity were identified and implemented in the model. The development of the model is described in the next section.

Table 1. List of Sensitivity Analysis Variables

Variables	Support from Literature
Percent of effectiveness of planners	Alsehaimi (2014)
Percent of change orders approved	Hanna (2002)
Percent of work packages that require changes	Eden (2000)
Percent of work packages that require rework	Riley et al. (2005)
Average approval duration	Karim (1999)
Planned project duration	Sambasivan & Soon (2007)
Effectiveness of inspection	Sterman (2000)
Project deadline	Taylor and Ford (2006, 2008)

4.2 System Dynamics Model Development

Changes over time and the interaction among variables in a system can be modeled with a system dynamics model (Ibbs et al. 2012) (Figure 3). System dynamics is capable of providing analytic solutions for complex and systems that are nonlinear (Javed et al., 2018). It has been broadly utilized in construction projects to assess the impact of rework on performance (Love et al., 2000), change orders management (Abotaleb & El-adway, 2018), risk analysis (Javed et al., 2018), labor productivity (Ibbs et al., 2012), etc.

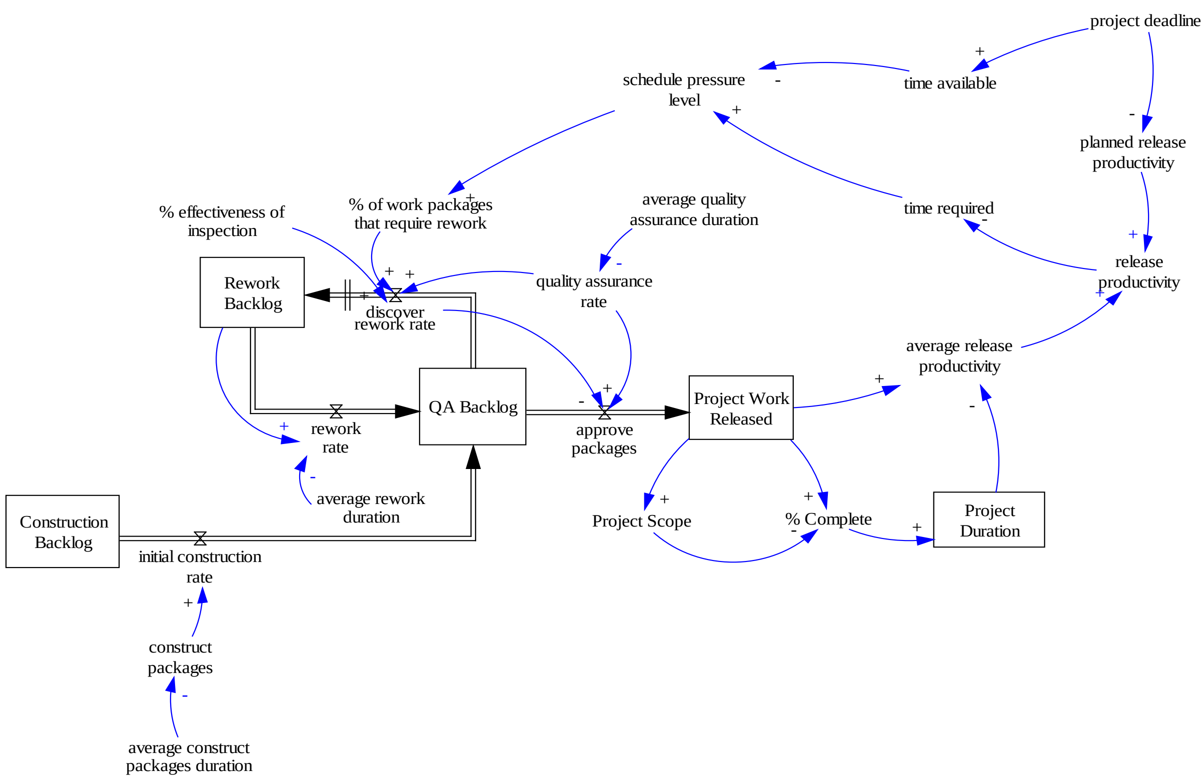

Figure 3. Base model.

A system dynamics model capable of capturing the influence of change orders on labor productivity was developed in this study. The model was based on one developed and validated by the Ford and Taylor (2006, 2008), that was implemented for a single project. Their model consisted of three major sectors, including a workflow sector, a resource allocation sector, and a schedule pressure sector. The workflow sector was based on a simple loop for feedback of rework. The resource allocation sector was designed to allocate resources to three activities: construction, quality assurance, and rework, after an information delay. The purpose of the schedule pressure sector was to describe the indirect impact of schedule pressure on the rework. In addition, two loops, including employee frustration and stretch objective, were added to the model to identify the impact of change orders, due to frustration and motivation, on staff productivity. This model was named the conceptual model and is shown in Figure 4.

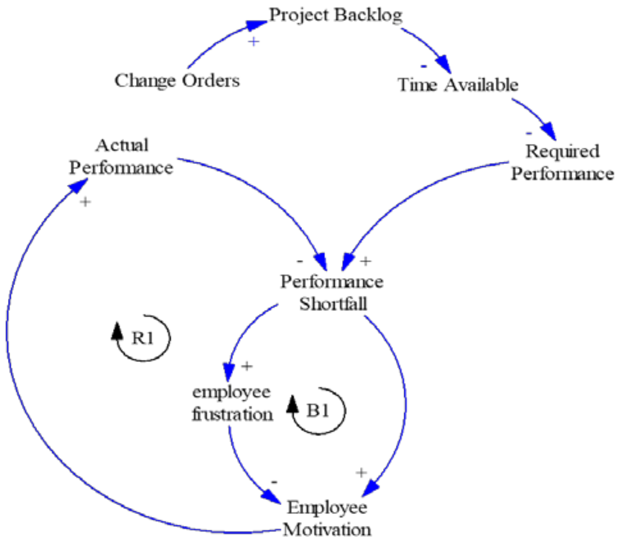

Figure 4. Conceptual model. B1 is balancing loop and withdraws work from the rework loop. R1 is reinforcing loop and adds to the required work.

The model was then expanded in three steps. First, flows and stocks were added to the model in order to reflect the dynamics of the real system. Next, the schedule pressure sector was expanded to include both the positive and negative influences of schedule pressure on labor productivity. Finally, an information delay was added to the model structure that could delay the frustration of the project staff caused by schedule pressure. The model was calibrated to represent the behavior of a typical construction project plan. Figure 5 shows the behavior of the model for project duration and percent complete. This project was implemented for the sensitivity analysis performed and presented in the next section.

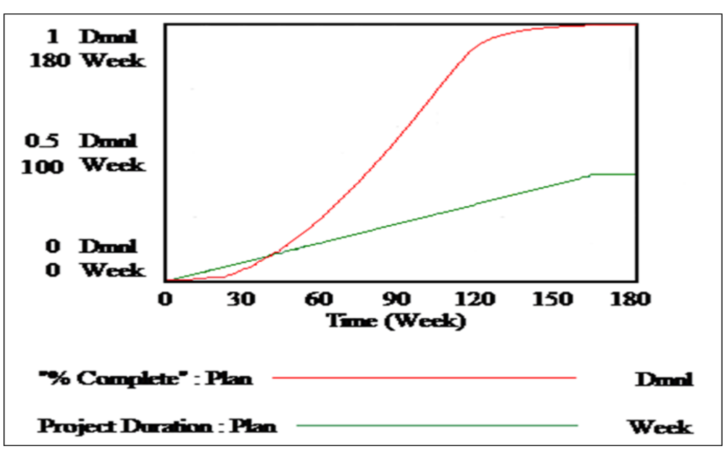

Figure 5. Model percent complete and duration.

5 RESULTS AND DISCUSSION

A sensitivity analysis was performed to identify the nature of the response of the performance measure, project duration, to control variables. The analysis was performed for a typical plan to better understand how the plan might go wrong. Simulations were run for all exogenous variables across reasonable ranges from the base case conditions. A 100% reduction and a 100% increase in the most important exogenous variables are shown in Figure 6.

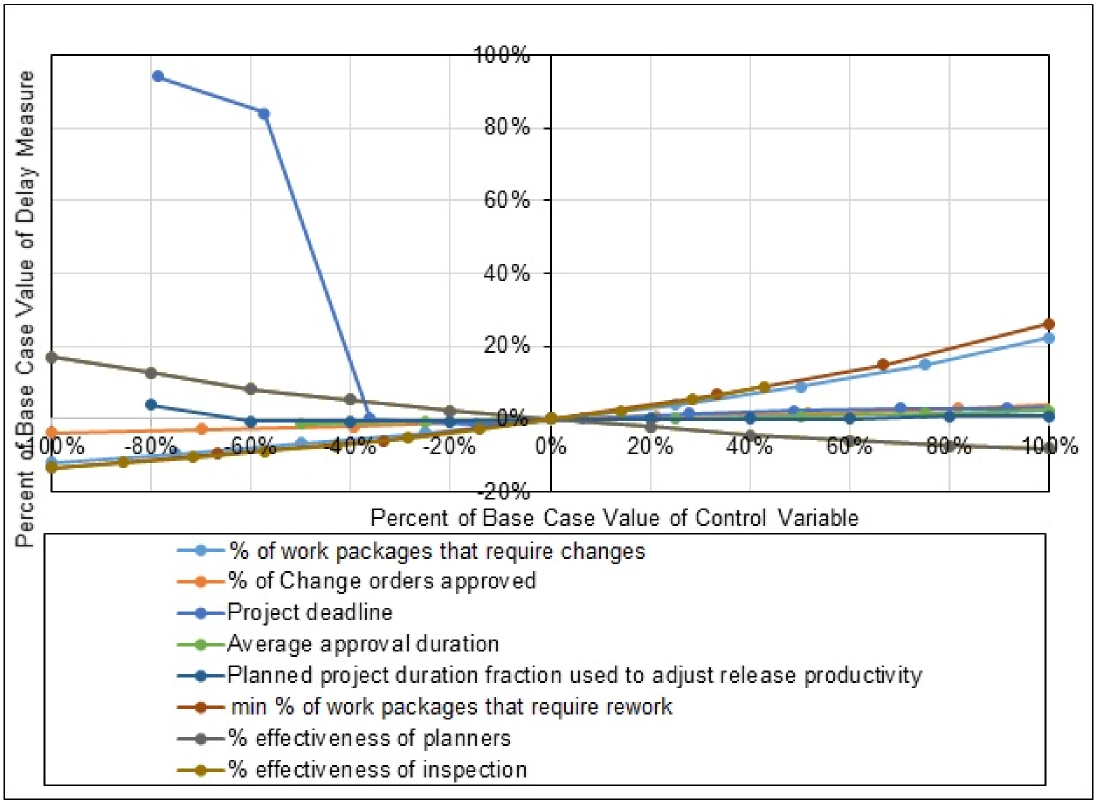

Figure 6. Sensitivity analysis results for different variables.

The variables with steeper lines have more influence on the performance measure. Project duration is most sensitive to the project deadline, and as the project deadline decreases, the project duration increases. However, this effect is only seen after a certain reduction in the project deadline. An 80% reduction in the project deadline results in an approximate 95% increase in the project duration, but an increase in the project deadline has little effect on the project duration. Such behavior is logical since an unreasonable project deadline eventually causes staff frustration, and the project duration tends to be greater. Of secondary significance are the percent of work packages that require changes, and the minimum percentage of work packages that require rework. A 100% increase in the percent of work packages that require changes, and the minimum percentage of work packages that require rework results in an increase in project duration of about 26% and 22%, respectively. A reduction in either of these two variables results in a reduction in the project duration. Such behavior is logical since reworks occur during the latter stages of the project and have a more significant negative impact on the project duration.

6 CONCLUSIONS

Sensitivity analysis is essential to assess how the input variables of a model affect the output, specifically in multidisciplinary and/or complex models. The information achieved by sensitivity analysis can be used to acquire data and make more effective management decisions by identifying the parameters that cause the greatest influence on the performance of the system. This paper was conducted to evaluate the change orders variables' influence on labor productivity by implementing local sensitivity analysis. The analysis was performed for a typical construction project to understand how the labor productivity changed with the fluctuations in the change orders variables. The results indicated that project duration was most sensitive to the project deadline, and as the project deadline decreased, the project duration increased. However, this impact was only seen after a certain reduction in the project deadline. An 80% reduction in the project deadline resulted in about a 95% increase in the project duration, but an increase in the project deadline had little effect on the project duration. The results of this study can be implemented by planners to avoid increasing change orders and reworks in their projects.

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