Discovering the Impact of Late Change Orders and Rework on Labor Productivity: A Water Treatment Case Study Analysis Using System Dynamics Modeling

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ABSTRACT

Most complex projects can expect some level of rework and minor changes that can be conceptually predicted and estimated during the bidding process. However, existing literature and practitioners’ experience indicate that the true impact of late change orders and rework on labor productivity behavior is often greater than expected, and the unintended side effects are very difficult to measure. This lack of knowledge and understanding leads to inaccurate calculations of the true impact of project changes and creates an incorrect ground for future decisions. Therefore, this research aims to develop a system dynamics model to understand and analyze the fluctuations in the field labor productivity rate and behavior in response to changes in the scope of the project. The other objective of this study is to formulate and discuss management policies that limit these undesirable side effects and their implications. Based on a large-scale design-bid-build water treatment project, this research conducts a case study to monitor the behavior of changes in productivity rate due to different scale change orders. The simulation results show that if a project falls behind schedule due to a change and the project deadline remains fixed, schedule pressure leads to an initial increase in productivity up to a certain level, but eventually may lead to major employee frustration. This frustration has the potential of increasing the project duration further and makes a bad situation even worse. Schedule pressure further exacerbates the problem by typically increasing the rework fraction or the errors on the built work packages. The outcome of this study helps practitioners to utilize the developed model to monitor and track labor productivity rate changes in each individual construction project and manage institutional overtime policies accordingly.

INTRODUCTION

Change orders in construction projects result from a change in scope of work from the originally agreed upon work between the Owner and the Contractor. A change order is “a written order to the contractor signed by the owner and architect, issued after execution of the contract, authorizing a change in the work or an adjustment in the contract sum or the contract Time” (American Institute of Architects, 1977). Change orders may result from a number of reasons such as a discrepancy in the design documents, change order directives given by the owner, and unforeseen/differential site conditions. Change orders have a significant impact on project performance in terms of delay in project schedule, increase in cost through rework and decrease in labor productivity.
Managing change orders is a challenge for contractors and owners alike (Habibi et al., 2017). Unresolved conflicts with respect to change orders may result in a costly claim resolution process. The domain of this research is to study the impact of change orders on labor productivity with an objective to formulate policies that mitigate this negative impact on ultimate project performance. While it is apparent that change orders have a direct impact on project performance (Safapour et al., 2018), it is often difficult to understand the indirect effects (Kermanshachi, 2016). The project manager may estimate the time and cost to complete the change order, but often these estimates are mainly based on uncertain information and do not consider the indirect effects caused by the change (Kermanshachi, 2017). Specifically, studies have shown that change orders have a negative effect on labor productivity (Moselhi et al. 2005; Hanna et al. 1999). This effect may vary due to several reasons: intensity (number/frequency), timing in relation to project duration, work type, type of impact, and on-site management (Moselhi 2005). The issue for this research is that often these side effects of the change order process are unclear or are difficult to predict.

The fundamental problem is that despite common knowledge that change orders cause negative effects on project performance measures, practitioners often inaccurately estimate these effects. Specifically, change orders have unintended side effects that are difficult to predict. This study builds on past research to consider the effect of change orders on labor productivity. The expectation is that change orders tend to result in an increase in productivity initially, but as time goes on, labor productivity decreases at an increasing rate. Change orders probably have some maximum effect on labor productivity as well, and labor productivity eventually reaches a maximum effect and levels out. The intent of this research is to explain how this behavior might occur.

LITERATURE REVIEW

Construction management is a complex process that is rendered more complicated by change orders. Typically, two types of change orders exist. Owner generated change directives involve an adjustment to the project scope, design, or detailing as requested by the owner. Field generated change orders result from problems in the field that require changes in the design (Riley et al. 2005). Although there is a possibility for scope reduction that leads to a decrease in project cost as well as duration, most studies have focused on the additional work added to the project scope during the actual construction phase (Schumacher 1995; Eden et al. 2000; Moselhi et al. 2005; Lee et al. 2006; Taylor et al. 2006; Taylor et al. 2008; Serag et al. 2010; Wambeke et al. 2011; Kermanshachi et al. 2017). This attention is warranted since the increase in cost and time lead to unexpected claims and conflicts, which could harm both owner/architect and contractor (Schumacher 1995; Williams et al. 1995). As a result, project managers must learn how to react to such change orders during the project life cycle in order to manage the negative consequences effectively. Dao et al. (2017) claimed that most complex projects have some expected level of rework and minor changes which are roughly estimated during the bidding process (Eden et al., 2000). In this regard, Dao et al. (2016a and 2016b) tried to quantify complexity dimensions of the project and developed a tool to manage project complexity to avoid the occurrence of potential changes. Kermanshachi et al. (2016a and 2016b) found that if complexity is not managed properly, it would cause increase amount of change orders and therefore, it will impose significant cost escalation to the project. Initial estimates typically consider such events by adding contingency to the base estimate. However, there are often additional unexpected changes to a project that negatively affect project performance and lead to higher delays, duration and eventually cost.
These change orders result from several problems such as: (1) level of client knowledge, (2) lack of a plan for unforeseen external events, (3) ambiguous contractual structure and (4) lack of communication between project staff.

As past research indicates, change orders may affect the project negatively due to several reasons. One of these reasons is the inability to accurately estimate the cost and time that a change order forces on the project. Another common problem is when several change orders occur at the same time, and it is difficult to manage the sequence of change orders (Eden et al. 2000). Sometimes evidence suggests that the total cost of a series of change orders is greater than the sum of the individual change orders (Williams et al. 1995). This behavior is known as the “portfolio effect”. Further still, sometimes project controls used to get the project back on budget or schedule have an unintended effect of reinforcing the problem (Williams et al. 1995). Williams et al. (1995) claims these “vicious circles” normally center around two issues: the rework cycle and productivity issues.

As rework increases, all else being equal, productivity decreases (Eden et al. 2000). Excessive rework causes fatigue, which can cause more rework. Taylor and Ford (2008) showed that projects are least robust to the rework fraction. Moreover, project controls methods used to increase the rate of progress often have long-term negative consequences (Lyneis et al. 2007). For example, excessive rework may cause the project manager to turn on the overtime clock, which initially causes the rate of progress to increase. However, after a while, fatigue sets in causing the rate of progress to decrease. Fatigue may cause additional mistakes, which leads to more rework and an even lower rate of progress. These actions are meant to close the performance gap between actual performance and the target, but have unintended side effects or “policy resistance” (Lyneis et al. 2005).

Another indirect effect of change orders is the apparent decline in labor productivity. As recent research indicates (Moselhi 1998; Hanna et al. 1999), major and consistent change orders significantly lower labor productivity. Since construction is a sequential process, change orders may affect the remaining tasks even if they do not involve the changed task directly. Such behavior is commonly referred to as a “ripple effect” (Lee et al. 2004).

Hanna et al. (1999) claimed that to predict labor efficiency, the amount of change, the type of change, and the timing of the change are significant predictors. Moselhi et al. (2005) claimed that the timing, intensity, and type of the change order and type of impact are significant predictors of labor productivity. As required performance increases, the difference between actual and required performance, or the performance shortfall, increases. This performance shortfall causes schedule pressure that in turn motivates employees to work faster. This faster work rate increases the actual performance and reduces the performance shortfall. However, a performance shortfall too big simply causes frustration because the performance gap appears to be too big to close. This frustration lowers employee motivation and, in turn, actual performance (Sterman 2000; Cooper and Reichelt 2004; Lyneis and Ford 2007). As schedule pressure increases, motivation begins to increase at an increasing rate. Schedule pressure has some maximum effect on motivation, however, after which employees are not additionally motivated to work faster. Li (2008) also claims that the concurrence relationship between frustration and a motivation effect is something like the following figure. Frustration has a small effect on motivation at first, but as frustration increases, motivation decreases at an increasing rate. Similar to schedule pressure, frustration has some maximum effect on motivation, after which the employee’s motivation does not decrease.
MODEL DEVELOPMENT

The model structure captures the effect of change directives and design discrepancies on project schedule performance for a traditional design-bid-build project delivery method. The model was developed to address the problem description and was expanded incrementally from the conceptual model to a more formal model.

The conceptual model addresses the problem description and is shown in Figure 1. The conceptual model captures the effect of change orders on staff productivity due to factors such as motivation and frustration.

**Legend of Loops**

**B1-Stretch Objectives Loop:** This balancing loop assumes that an increase in change orders increases the project backlog required to complete. As the project backlog increases, the time available to accomplish these tasks decreases (provided the deadline remains constant). As the time available to finish the project decreases, schedule pressure increases which, in turn, increases the required productivity. With an increase in required productivity, the performance shortfall increases. The performance shortfall may increase staff motivation, which leads to an increase in actual staff productivity. This increase in actual staff productivity then reduces the performance shortfall.

**R1-Employee Frustration Loop:** This reinforcing loop represents the increase in the staff frustration level as the performance shortfall increases due to an increase in change orders. An increase in staff frustration reduces employee motivation, which in turn reduces actual staff productivity. A decrease in actual staff productivity increases the performance shortfall, which further increases staff frustration. An increase in staff frustration further reduces staff motivation.

The conceptual model was then expanded into the formal model by adding structure (Stocks and Flows) to reflect the dynamics of the real system. In this model, the set of stocks and flows developed to reflect scope addition (i.e. change directives) and change orders during the planning and construction phases of the project. The material unit flowing through the system is work packages. Downstream work packages are not constrained by upstream ones. This simplifying assumption is meant to model a project with few interdependencies between work packages, such as a flat project with a relatively large site.

Change orders may occur due to design errors or change directives issued by the owner. The planning department plans, estimates and logically divides the total project scope into work
packages and checks work packages for design discrepancies. The initial scope of work is the initial planning backlog. After the work is planned, the work packages are either released for construction at the “approve for construction” rate or are diverted to the owner for clarification and possible change order due to a design discrepancy at the “discover changes rate”. The “approve for construction rate” is simply “planning rate” – “discover changes rate”. The “planning rate” is the minimum of the “planning process rate” and the “planning resource rate”.

The scope increase due to change orders increases the amount of work required to complete which, in turn, increases the time required to complete. If the project deadline remains fixed, the project manager pushes his team to get the work done within the available time. By doing so, the project manager increases the required performance (e.g. required productivity) for the project staff. The project staff attempts to work harder to close this performance shortfall. Initially, workers are motivated and work harder, thereby increasing their actual performance and decreasing the performance shortfall. The project team responds positively to this performance shortfall (stretch objectives loop R1). However, if the change in scope is large enough and the project deadline is not relaxed, the required performance is perceived as too great to reach. After working sometime at this high productivity level, the staff starts to get frustrated. The employee frustration loop (B1) eventually dominates and there is a decrease in actual staff productivity. This result, in turn, increases the performance shortfall.

As shown in Figure 2, the schedule pressure sector was also expanded to include both the positive and negative effects of schedule pressure on labor productivity. As required performance increases, the difference between actual and required performance, or the performance shortfall, increases (Sterman 2000). This performance shortfall causes schedule pressure, which in turn motivates employees to work faster. This faster work rate increases the actual performance and reduces the performance shortfall. However, a performance shortfall too big simply causes frustration because the performance gap appears to be too big to close. This frustration lowers employee motivation and, in turn, actual performance.

As schedule pressure increases, motivation begins to increase at an increasing rate. Schedule pressure has some maximum effect on motivation, however, after which employees are not additionally motivated to work faster. Frustration has a small effect on motivation at first, but as frustration increases, motivation decreases at an increasing rate. Like schedule pressure, frustration has some maximum effect on motivation, after which the employee’s motivation does not decrease.

Figure 2. The Effect of Change Orders on Labor Productivity
CASE STUDY

The effect of change orders on project performance may be observed from the available data for a $188 Million, design-bid-build water treatment project, which at the time of this study was under construction in California. At this time, the project manager estimated that the project was about one month behind schedule. Table 1 illustrates the first 10 period project cumulative planned and earned values.

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The project data is available from a period when the project was 75% complete. An excerpt from the project progress report is as follows:

“To date, the project has received 99 change directives and 11 Notice of Change are in dispute. The monetary value of billable Extra Work Orders (EWO) is close to $1.7 Million. No time extension has been given by the owner in spite of several Time Impact Assessment (TIA) submittals. These changes to the original work have also played a major role in delaying the schedule. Since the change directives follow no time extension, the labor force has been moved around to complete these EWO. This has made the recovery on critical path for the contractual schedule very difficult.

The project deadline was not extended despite incurring about 100 change orders and despite the contractor’s request, who felt time extensions were justified. The distribution of change order categories is shown in Figure 3. The contractor claimed that to complete the work on time, available resources should have been reallocated. However, the contractor was still concerned about meeting the contractual schedule and was undoubtedly under pressure to make up this difference.

Figure 3. Change Order Category Distribution

The data available for this study include the change order log which classifies change orders by time, type (design discrepancy or owner’s change directive), and dollar amount. Other
data available include the expected initial scope, expected project staff, and project duration. The performance indicator is project duration. The other exogenous variables are estimated based on construction industry expectations.

MODEL VALIDATION

The model was tested using standard methods for system dynamics models (Sterman 2000). Basing the model on the Taylor and Ford’s (2006, 2008) framework for work flows of a single project system and the literature improves the model’s structural similarity to the real system. The model was gradually expanded to depict the problem in question.

The effect of change orders on labor productivity may be observed from the earlier described case study project. Project duration was considered as the performance indicator in this study. The other exogenous variables were estimated based on construction industry expectations. The model was calibrated to represent two conditions, a typical plan and a base (bad) case behavior. Figure 4 shows the plan and base case behavior of the model for percent complete and project duration. The planned percent complete plot presents a typical construction project plan for work released over time (i.e. logistic or s-curve behavior). The bad or base case shows the same project but with a high amount of change orders. Progress accelerates early in the project, but as change is incurred, progress slows and the project completes significantly later.

Figure 4. Project Duration and Percent Complete Behavior for Planned and Undesirable Cases

Figure 5 shows the plan and base case actual staff productivity and schedule pressure. During the early stages, the project manager perceives that the time required to complete the project by a specified deadline is more than the time available. This problem causes the project manager to push the staff to increase their productivity and there is schedule pressure to finish the project on time. The actual staff productivity increases due to the increase in schedule pressure. After a while, however, the staff begins to get frustrated, eventually dominating the positive aspect of schedule pressure, and productivity goes down. Progress slows further as an increase in schedule pressure typically results in an increase in the rework fraction.
RESULTS
This study built on past research to consider the effect of change orders on labor productivity. The expectation was that change orders tend to result in an increase in productivity initially, but as time goes on, labor productivity decreases at an increasing rate. Change orders probably have some maximum effect on labor productivity as well, and labor productivity eventually levels out as this maximum effect is reached. As the intent of this research was to explain how this behavior might occur through literature review and project data, both support the theory that change orders have unintended side effects or “policy resistance”. This study showed what causal structure explains this “policy resistance” and formalized this structure to explore what management policies might help manage this effect (Ford et al. 2005). The following analysis explains some of those management policies.

In this study, the two following separate cases besides the planned and undesirable scenarios were studied:

- Policy 1 describes the case which project manager has an internal deadline for the project. The internal deadline is relaxed when the actual staff productivity falls below the expected productivity level.
- Policy 2 defines the time when a change order occurs and project manager requests a time extension rather than putting pressure on his staff to be more productive.

Figure 6 shows labor productivity for the planned, undesirable, and policy 1&2 cases. The results of both policies are that the project finishes by the revised deadline (195 weeks). The base case project or the bad project takes more than 300 weeks to finish. As expected, the project with policy 1 and 2 and a deadline extension still finishes late but not nearly as late as it might otherwise. Because the deadline is extended, schedule pressure does not build to the point that frustration kicks in and productivity stays close to the reference productivity.

CONCLUSION
This study explored the effect of change orders on labor productivity and explained what causal structure accounts for this “policy resistance”. The results of the model analysis provide a basis for this policy or system design and testing.
It was concluded that the project duration is most sensitive to the project deadline. If the project falls behind schedule due to change, and the project deadline remains fixed, schedule pressure leads to an increase in productivity at first but eventually may lead to frustration. This frustration has the potential to increase the project duration further and makes a bad situation even worse. Schedule pressure further exacerbates the problem by typically increasing the rework fraction or the errors on the built work packages. Policies were designed to help manage these effects and the implications of these policies were discussed. This structure was formalized to explore management policies that help better manage this effect. This model may be expanded to explore additional policies as well.

REFERENCES


