Understanding the Effects of Rework and Change of Scope on Productivity and Project Performance Using Systems Thinking

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Introduction

Identifying the effects of change in construction has been a topic of discussion and debate for several years, especially those changes that delay contractors and disrupt productivity.

Managing projects consists of a complex and integrated array of decisions, actions, and communications necessary to complete projects successfully. A project is a system requiring fully functioning processes and procedures, tools and resources, and when any of these aspects are not working efficiently, resulting from unanticipated changes, a cascade of problems can and does occur. Samual Johnson once noted many years ago that '*Change is not made without inconvenience, even from worse to better*' (Pickavance, 2005, page 409, citing the Dictionary of the English Language, edited by Richard Hooker, quoting Samuel Johnson, from the year 1755). This feeling regarding change remains the same in today's world; especially in the construction industry. When changes are introduced prior, during or after construction work has been executed, the synergistic effects of these changes can dramatically affect project performance. Identifying and quantifying the cause and effect relationships between changes in order to mitigate or avoid their impact is vitally important to the construction industry.

Keywords: *productivity, construction, change, system dynamics, disruption*

Problem Statement

Over the past five years, tens of millions of dollars have been lost in the United States due to disputes related to construction projects (AAA 2008). Additionally, millions of dollars have been spent trying to prove or disprove a contractor's entitlement to damages resulting from disputed changes to the work being undertaken (Fullerton 2005). The money and valuable time spent to fight for what a contractor or owner believes he or she is entitled to represents lost opportunities to pursue more productive and profitable endeavours.

With respect to jurisprudence in the United States, it is the plaintiff who must successfully demonstrate that they are entitled to damages suffered as the result of actions or inactions on the part of the defendant. In contract disputes in the field of construction, the contractor is most often found to be the plaintiff; and the customer or owner, the defendant. For the purposes of this discussion, it is assumed that the plaintiff is the contractor and the defendant is the owner from whom the contractor is seeking compensation or performance of some compensatory action.

The challenge for construction contractors with respect to changed work is to convincingly demonstrate to an owner or the court that: a) a change to the original contract occurred and why; b) the plaintiff/contractor had no responsibility for the change, nor could it have foreseen the change; and c) the requested damages and their calculation are reasonable. The other challenge for the contractor is to demonstrate and substantiate the claim, while at the same time, avoiding a costly dispute, or worse, litigation.

Oftentimes, the issues surrounding a construction contract dispute are convoluted, integrating the hard quantitative effects as well as the softer 'human' effects (Howick 2003, 222), making it difficult for the contractor to convincingly argue its case. Through the use of systems thinking and system dynamics (SD) modeling, the causes of construction disputes can be identified in ways that prove liability and allow for the equitable apportionment of damages to the contractor who has experienced productivity losses. Because an SD model has the ability to capture not only the quantitative effects of changes, but the softer human effects, as Howick (2003, 222) notes, the result of the model outlined here is to remove the complexity associated with most construction contract disputes.

Discussion

Lyneis & Ford (2007, 158), in their paper documenting the evolution of the use of systems thinking in project management, note projects modeled using a system dynamics modelling techniques can be classified into four groups: 1. project features, 2. rework cycle, 3. project control, and 4. ripple and knock-on effects. Current systems thinking uses all four of these groups, along with controlling feedback loops. In Figure 1 from Lyneis and Ford (2007), Lyneis and Ford's stock flow diagram is used as a basis.

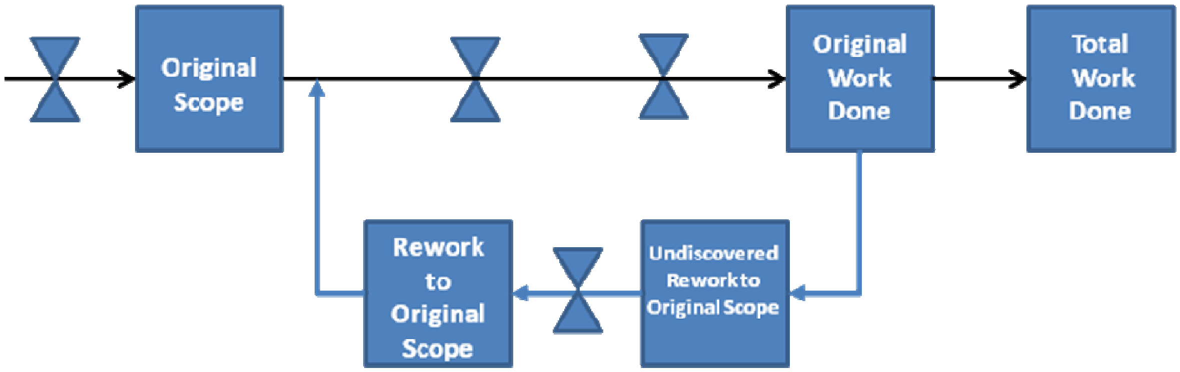

Figure 1 Stock Flow Diagram for Rework (Lyneis and Ford 2007, 161)

Change is one of the few constants within a project that a project manager can be confident will take place. According to AACE International[1], a change is defined as an alteration or variation to a scope of work and/or the schedule for completing the work (AACEI 2007, 15). On most construction projects, in addition to the reworking of the original scope, other changes invariably take place.

Changes, which are singularly or collectively administratively documented in the form of change orders, occur for many reasons on construction projects. On the surface, each change to a construction contract is unique when compared to all other changes on the same project. However, most all changes share some common characteristics and can be classified in common categories. In construction, primarily on design-bid-build projects, the causes of changes have been classified into five categories. According to two US federal government studies (National Research Council 1986), one by the US Army Corps of Engineers and the other by the US Navy, the categories into which the primary causes for changes fall are:

- design deficiencies
- criteria changes
- unforeseen conditions, including differing site conditions
- changes in scope directed by the owner
- other categories

The following is further description of each of the change causing categories:

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[1] AACE International, also known as the Association for the Advancement of Cost Engineering, has been the leading-edge professional society for cost estimators, cost engineers, schedulers, project managers, and project control specialists. With over 7,000 members worldwide, AACE International is the largest organization serving the entire spectrum of cost [engineering] professionals. AACE International is industry independent, and has members in 80 countries. (AACE International Website 2009)
According to the AACE International website, Cost Engineering is defined as the area of engineering practice where engineering judgment and experience are used in the application of scientific principles and techniques to problems of cost estimating, cost control, business planning and management science, profitability analysis, project management, and planning and scheduling. (AACE International Website 2009)

Design deficiencies – Also known as designer errors and omissions; these changes relate to plans that are incomplete or contain errors that aren't found until the construction contractor finds them well after the construction phase of the project has started. With most US construction contracts, in which the contractor bids on designs that are completed prior to contract award, the owner is liable for the designer's errors and omissions.

Designer deficiencies are changes that are the result of faulty or confusing aspects of construction designs and specifications, attributable to the designer, which are not discovered until the contractor begins working towards building what is shown on paper. As opposed to the other types of change, design deficiencies are often the result of ineffective quality control in the design process, and are controllable. Designer errors may go beyond the development of the project designs and specifications. In addition to defective designs, according to Bramble and Callahan (2000), the owner is also liable for the contractor's costs due to other designer errors, such as unreasonable delays in reviewing shop drawings, failure to provide drawings or design information in a timely fashion, failure to proved timely inspections and other delays due to the designer's contract administration problems (Bramble & Callahan 2000, 3-16).

There are a few theories on why this type of change is most common among construction projects. The most prevalent theory posits that the financial pressures owners are under to complete projects as soon as possible are transferred to the designer, who is asked to complete the design within an unreasonable timeframe that encourages error through haste.

According to the studies by the US Army Corps of Engineers and US Navy, design deficiencies account for nearly 40% of all construction changes on a design-bid-build project, more than any other category of change.

Criteria changes – For most projects, government owners will refer to a specific version of their design or construction standards. It happens sometimes, however, that government owners who have well established written standards for design and construction, choose to revise those standards after the construction has been awarded based on a previous version. Criteria changes can also be found on projects with private owners who also have well established design and construction standards, or private owners whose projects are subject to government design and construction standard changes.

Differing Site or Unforeseen conditions – A differing site or unforeseen condition occurs when latent site conditions of a construction project are uncovered after the contract between the contractor and the owner has been executed, and was not previously anticipated or included in the design documents. Differing site conditions are worth making note of only if the contractor experiences an increased cost and/or delay. Common examples of differing site conditions occur when a contractor performs earth excavation and uncovers objects or soil types that were previously unforeseen, and require extraordinary measures to accommodate. These extraordinary measures can easily cost the contractor additional money and/or time above that for which they were originally contracted.

Changes in scope directed by the owner – Although changes in scope directed by the owner are not the most frequent changes, they are the most controllable on the part of the owner. These changes represent those in which the customer, the owner, chooses to make changes to the final product after the design has been completed and the contractor has been hired. According to Bramble & Callahan (2000), 'most construction contracts give the owner the right to make changes within the general scope of the contract without breaching or invalidating the contract' (Bramble and Callahan 2000, 3-22, footnote 100). The American Institute of Architects (AIA) has in fact developed a set of contract documents that are frequently used in US-based general construction. According to the AIA's *General Conditions of the Contractor for Construction*, the owner is given the right to make changes…'after execution of the Contract, and without invalidating the Contract, by Change Order, Construction Change Directive or for a minor change in the Work…' (AIA 1997, Article 7).

Other changes – There are many changes that do not easily fit into any of the four categories already mentioned. US military studies include the following types of changes in their 'Other' category:

- Contract Options
- Administrative
- Deficiency in Gov't furnished property
- New laws, regulations, codes
- Suspension of work
- Value engineering
- Accounting
- Unresolved claims
- Currency reevaluation
- Other

Other, more contemporaneous, studies exist that try to determine what types of construction changes are most common and why, but they apparently don't delve into the set of categories that the US Army Corps and US Navy studies use. According to Ibbs (1997), there has been much research on project change, most of it qualitative due to the difficulties in obtaining accurate and consistent quantitative data (Ibbs 1997, 308). Ibbs goes further to note in the same paper that other researchers such as Diekmann & Nelson (1985) have been able to categorize by percentage all changes into errors & omissions (65%), design changes (30%), and unforeseen conditions (5%).

Not only does rework impact the performance and outcome of a project, so do scope changes. Changes, just like rework, create causal and feedback loops that influence the project outcome for the owner, the designer, the contractor, as well as other stakeholders. Changes can occur before or after the rework process has been completed; and can even occur during the rework process. Changes can take place before the contractor has even started work, and they can continue well after the work is considered substantially complete. Changed work, just like original scope work, can lead to rework as well. In this current discussion, only changes that occur before and after a rework cycle has been completed are considered since it is assumed that seldom will a change in scope occur during a period in which rework of the original scope takes place when the change is implemented.

For most projects, the rework process should not be ignored; therefore, in the proposed system dynamics model the rework process is assumed from the beginning to be part of the overall project management work execution model. In Figure 2, a proposed approach that integrates the rework and change processes is presented in a stock flow diagram. This proposed stock flow diagram adds work scope changes to the Lyneis and Ford (2007) rework process.

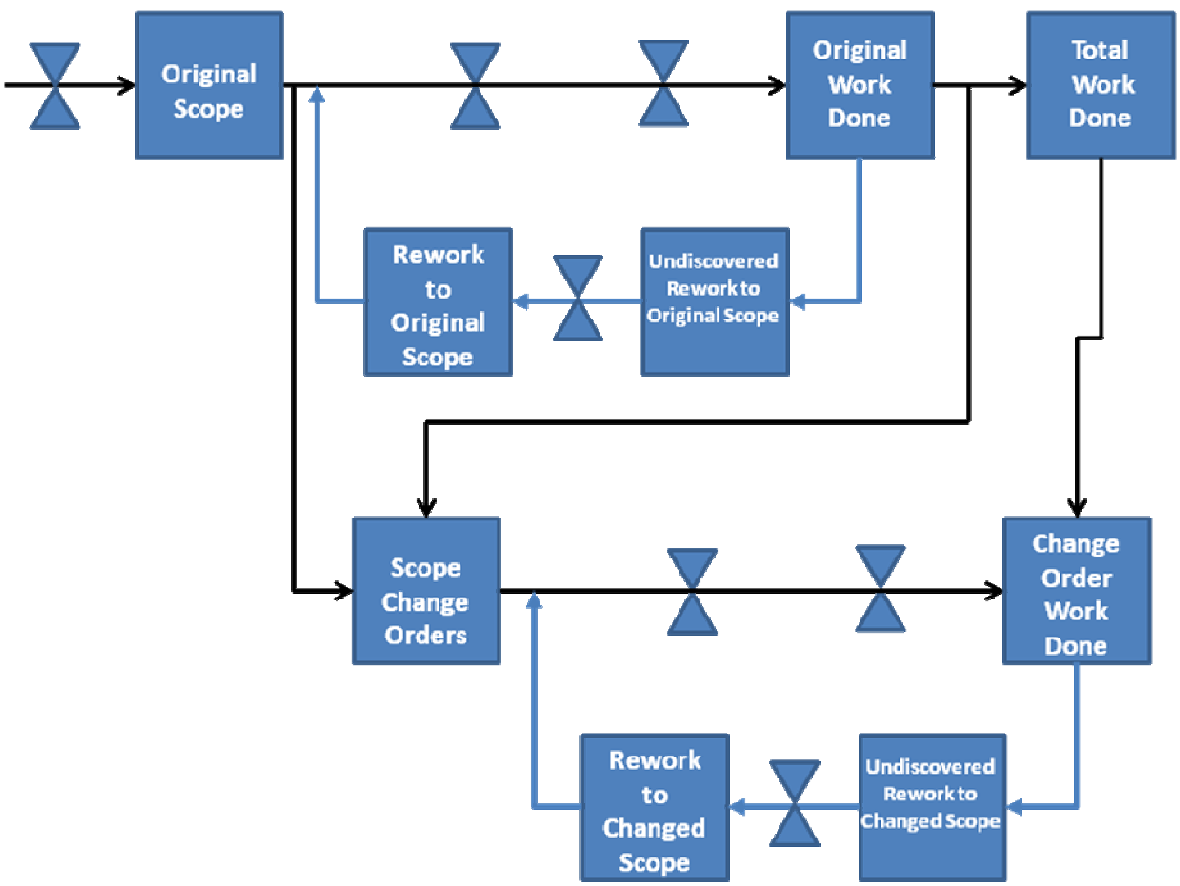

Figure 2. Stock flow diagram for Rework and Changed Work

Regarding changes that take place after the work has been completed, the above stock flow diagram expands on one developed by Pugh-Roberts Associates in which Sterman (2000, 59) notes that changes in customer specifications make some work previously done correctly obsolete. Even work that is changed work sometimes must be redone. Therefore, in our stock flow diagram, we borrow from the Lyneis & Ford (2007) model of stock flow for reworking the original scope, and use the same stock boxes illustrating undiscovered rework and rework to be done on work changed previously. Usually the changes have some degree of impact on labor productivity; sometimes, a highly disputed area of compensation.

Labor productivity is in some way directly or indirectly affected by changes in construction. In the past, many disputes have occurred as the result of contractors and owners disagreeing on the amount of impact that changes do have on labor productivity. Many of the same causal and feedback loops that Lyneis and Ford (2007) use in describing the dynamics of the rework process are applicable with the change process. This is confirmed by Sterman (Sterman 2000),who notes that the effects of changes are similar to the discovery of errors (59). In Figure 3, Lyneis and Ford (2007) demonstrate the causal and feedback loops relating to the rework process that influence project structures, including project features, project control, and ripple and knock on effects.

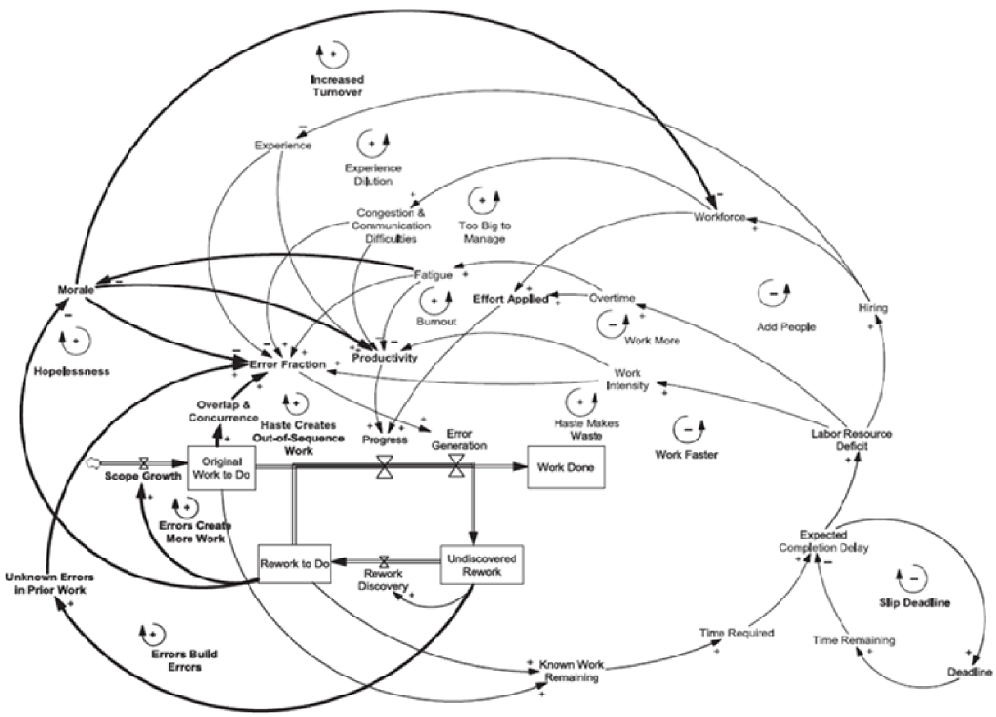

Figure 3. The Rework Process Model (Lyneis and Ford 2007, 165)

Issues resulting in rework, such as the requirement for overtime or other means of acceleration to help ensure the project meets contractual or other deadlines, are causal to other impacts in the change process. According to Horner and Talhouni (1995), accelerating productivity in construction can lead to labor productivity that is negatively affected by overtime, causing problems such as fatigue, reduced safety, increased absenteeism, and low morale.

By simply replacing the stock boxes from the original work found in Lyneis & Ford's (2007) rework stock flow model with our proposed changed work stock boxes, we obtain what is found in Figure 4. Causal and feedback loops remain the same for both models. The model in Figure 4 shows how changed work, with its rework process, might be represented.

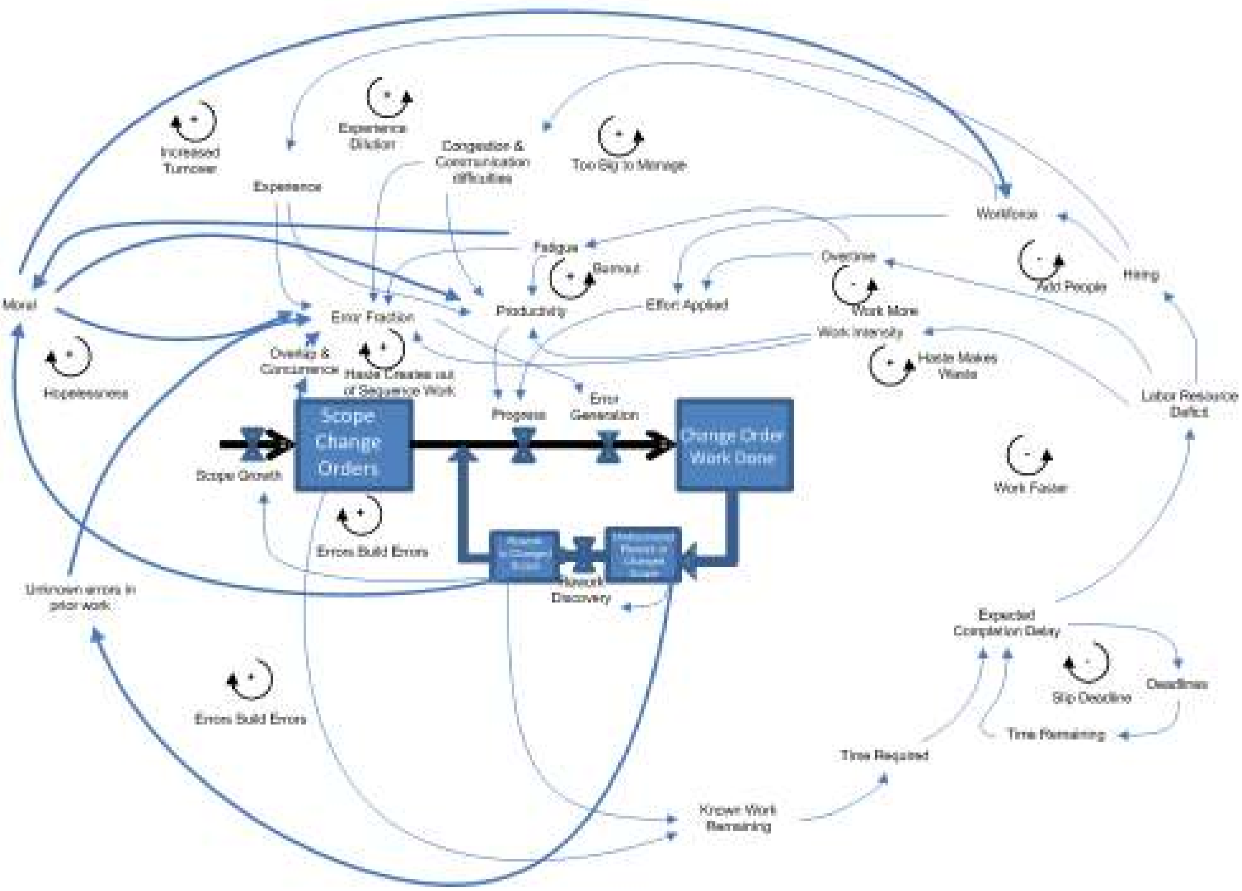

Figure 4. The Changed Work Process Model

The timing of any changes is crucial with respect to the actual execution of the work. If new work or a change to the previous scope is introduced by the customer prior to its start, the impact is likely to be less to the contractor than if the change occurs in the midst of work already underway or completed, so that significant rework is required. Accepting that change is inevitable on construction projects (Ibbs 2005), and could occur at any point from the beginning to the end of the project, it is likely that the impacts from early changes will be easier to recover from than those later in the project (Ibbs 2005, 1222). Therefore, it is important to evaluate changes to a task that might occur before the work on that task is started.

Depending on the category of change, we argue that the impact to the project outcome will vary depending on when during the life of the project the changes are introduced. For instance, errors or omissions in the project design discovered prior to the start of work may not directly or immediately affect construction productivity, but may create unforeseen circumstances of delays or productivity disruptions that will impact work planned to start later in the project. This is an import causal aspect of a phenomena known as cumulative impact or cumulative effect. By applying systems thinking to the problem of unforeseen change by understanding which categories of changes, or combination of change categories are most likely to be active, and estimating the scope of rework required were those changes to occur at various times during the project, systems thinking may lead the construction industry towards realizing how to prevent or mitigate delay and disruption impacts by anticipating when and where they are most likely to occur.

In this way, the proposed model moves construction planning and process from a reactive position to a proactive one. *Praemonitus, praemunitus*.

Future Research

The initial steps towards quantifying the effects of construction changes can be found in past systems thinking research. In the future, empirical data will be acquired to support or disprove the results of the SD model described above.

Conclusion

This paper proposes that the introduction of scope changes during or after the performance of work will result in a synergy between cause and effect that will multiply the negative impact of changes during a project. Additionally, it is hypothesized that the category of change will influence how much synergy develops and how great the negative consequences are for the project. By analyzing the system dynamics model, evaluating change types individually and simultaneously, along with rework, this hypothesis should be proven or disproven.

With a better understanding of which change categories or combination of change categories are most influential in the development of delay and disruption impacts, the construction industry will hopefully be able to better forecast and manage the impacts of change.

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