Applying Earned Value Management to Design-Bid-Build Projects to Assess Productivity Disruption:

A System Dynamics Approach

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Sarah. She introduced me to the Vensim software and helped me create the model in the program. Thank you, Sarah.

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Dedication

This is dedicated to my parents, Virginia L. and the late Patrick E. Warhoe, from whom I obtained the drive and desire to not let anything stop me from finishing what I want to accomplish, including this paper. Thank you, Mom and Dad.

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Abstract

Based on over 30 years of experience working in the construction and manufacturing industries as a project manager or in other positions related to project management, it is easy to conclude that performing as a project manager is not an exact science. One of the typical jobs of a project manager is to be able to manage a project's budget and schedule. These tasks can easily be very difficult to accomplish on projects that are complex, especially since project success relies heavily on people who are expected to perform their roles individually and as a team. One of the most difficult aspects of managing projects is estimating how fast and effectively humans will perform a task; that is, determining how productive workers collectively will be each day, each week, or within any time period during the life of a project. Because projects are unique and are typically one-off endeavors, there is usually little previous empirical data to rely upon for the project manager to forecast productivity before or during the project's execution. The crux of the problem lies with adequately identifying not only the labor work flow process, but also the influences that affect the work flow process.

When scope changes are introduced into the work flow of a project, the types and number of influences and their cause and effect relationships can significantly increase in numbers. This phenomenon often turns complicated projects into extremely complex ones and the final outcome can be greater than the sum of the individual inputs. For project managers who are unable to get their arms around this very real situation, forecasting the outcome of a project often becomes out of control; especially projects that are large and heavily labor intensive.

This study takes a post-positivist approach to design and build a system dynamic model with which construction projects that are delivered using the design-bid-build methodology can be simulated to show generically how the influences that affect construction projects can affect worker productivity. No other studies are known to exist that design or build such a model for construction projects that use the design-bid-build delivery method.

The model that was designed in the study is based on the works of several academics' works as well as the input of several experts in the construction field, including this study's author. As opposed to attempting to create a simulation model based on the uniqueness of a single project, a "mosaic" approach was used in creating the model in that elements of the model were identified and taken from studies found through the literature review as well as interviews with construction industry experts. The stock and flow structure of the study's model is intended to be a composite of many construction projects and can be used for any project delivered using the design-bid-build methodology.

From the research, the model was created and tested using good modeling practice in that the model testing phase followed the process created by one of the pre-eminent system dynamic modelers in the world. (Refer to Sterman, 2000). The result of which is a model that simulates the work flow of labor hours in a design-bid-build construction project which can be affected by an immeasurable number of influences that can and do occur on construction projects.

Keywords: system dynamics, project management, construction, productivity, disruption.

Applying Earned Value Management to Design-Bid-Build Projects to Assess Productivity Disruption – A System Dynamics Approach

1.0 Chapter 1 - Introduction

The primary purpose of this study is to create a system dynamics model that can be applied to construction projects to simulate the cause-and-effect relationships between the experience of having many scope changes and the resulting productivity loss, also known as productivity disruption. The influences that can affect productivity, hard and soft alike, are numerous and can easily vary from project to project, but there is usually a short-list of a few influences that result in the most impact. What is true on most construction projects, especially those delivered using the design-bid-build method, is that changes do take place and they seldom involve significant rework. The proposed model, which has gone through several iterations in its development, demonstrates the flow of work-hours for work performed on original scope and the work resulting from scope changes. The model shows that work resulting from changes can be new work and/or rework of previously completed work. The system dynamics model maps the general cause-and-effect relationships on construction projects, from the point when scope changes are introduced to the resulting productivity impacts.

Several researchers have focused on how scope changes exclusively create rework in the construction field that results in productivity disruption. The projects that are most susceptible to rework-related productivity loss are those delivered using the design-build delivery method, because the design is not complete before construction gets under way; leaving a higher risk of design changes that affect construction work previously completed. This phenomenon appears to be why most of the previously published system research on the effects of scope changes has focused on design-build projects. No

published research has been found that uses system dynamics modeling to simulate how scope changes create productivity loss on construction projects, yet is not related to rework.

Although the stock and flow structure portion of the model is meant to work in all circumstances for projects that are delivered using the design-bid-build method, the model in its entirety is not meant to be a standard with which the circumstances for all construction projects can be simulated. One of the valuable benefits to using system dynamics modeling is that the influences that affect productivity the most can be modified with few limits to best represent nearly any construction project.

A post-positivist approach is used as the methodology of this research and will be discussed in more detail later in the paper. The model is developed using the tacit knowledge of the author as well as the research of other experts and academicians in the field of construction. Quantitatively, the model includes a mosaic approach to acquiring the necessary algorithms for the simulation model and will be validated using empirical data when practical.

1.1 Dissertation Topic Determination

Because the previous system-thinking research found relative to productivity loss resulting from changes was oriented towards design-build projects and how change-caused rework affects productivity, the question was asked why there was so much focus on this type of delivery method when most of the construction projects executed around the world are delivered using the design-bid-build method (FMI and CMAA 2010). Based on the research that was performed on this dissertation topic and the researcher's nearly 30 years in the construction industry working DBB and DB projects varying in

size up to well over US$4 billion, the topic was identified as: by using a post-positivist paradigm, to develop a system dynamics model that simulates how construction labor productivity is impacted as the result of introducing an increasing amount of scope change labor hours into the project during the life of the project. The purpose of the research described in this paper is to further academic knowledge with respect to better understanding the dynamic relationships that exist on large and complex construction projects. This understanding is a factor in describing the influential cause and effect relationships that impact construction worker productivity especially when scope changes and quality problems arise during a project; an important factor in resolving productivity loss disputes between construction contractors and owners.

The objective of the research is to develop a theoretical system dynamic model that simulates the general work flows of worker hours on a design-bid-build construction project. This model will also analyze how the work flow is affected when scope changes and quality issues arise during the life of the project. A model of this type will be valuable in helping to understand how and why productivity impacts to worker hours occur on construction projects. A simulation model of this description has not been previously published, but is valuable to and necessary for the construction industry. The simulation model that is developed will be based on the use of a mosaic approach in which a combination of sources will be used.

The output of the system dynamic model will integrate earned value analysis techniques to show the outcome of planned, actual and earned labor hours after the modeled project is subjected to a myriad of input combinations. Also, through the use of earned value analysis techniques, we will be able to see the magnitude of impacts and at which point

during the life of a project impacts to productivity were experienced. Understanding the timing and magnitude of impacts will help contractors and owners better understand the relationships between what were previously indescribable or quantifiable influences that affected overall project labor productivity.

Through comprehensive research, interviews with experts in the construction industry, and the author's tacit knowledge of the construction industry, a system dynamic model structure was developed that represents the flow of worker hours on a project using the design-bid-build methodology. The model was validated and stood up in most cases to accepted system dynamic testing techniques. Where the model did not meet expectations after testing, explanations are provided that describe why.

1.2 Inspiration for taking on the Topic

The seed that generated this research came from the PhD candidate's project controls and disputes resolution experience working on and observing change management processes and dispute resolutions processes on large-scale construction projects. Over the past 25 years, the researcher has either led or participated in project controls teams on several mega construction projects as large as US$4.2 billion. During this same period, he also has led or participated on teams hired by either the contractor or the owner to develop or defend against construction claims and disputes. From his experience working as a cost engineer, claims analyst, and manager of each discipline, the researcher identified types of disputes that were difficult to prove; a couple of primary examples are productivity disruption and cumulative impact disputes. Having this tacit knowledge built up over the past 25 years in the areas of construction project controls and disputes resolution has set the framework for the inductive reasoning portion of the research cycle.

After discussions with Professor Christophe Bredillet and Dr. Paul Giammalvo about the subject area the researcher was interested in, they both recommended considering the use of simulation techniques to resolve productivity disruption, delay, and cumulative impact on construction projects. Professor Bredillet suggested the use of system thinking and modeling with system dynamics. To understand and use the theory behind system dynamics, the prominent books and papers included Williams (2002), Sterman (2000), Forrester (1991), Ford and Lyneis (2007), Randers (1980), Richardson (1981), and many others.

1.3 - General Problem

The problem described below is a significant one in today's world. Over a span of six years, from 2003 through 2008, an annual average of approximately US$615 billion was spent in the construction industry within the United States (Bureau of Economic Analysis 2010). Contract changes performed during the construction phase of a project play an important role in its final cost. The root of the problem arising from changes on construction projects is that sometimes the owner and contractor dispute the cause, liability, or the resulting cost of the change. From 2003 through 2008, tens of millions of dollars were disputed in the United States on construction projects (AAA 2008). These disputes can become very costly to both parties, considering the expense of hiring attorneys, experts, and consultants, as well as employee involvement and other costs. According to a recent study that determined the average value of construction disputes around the world in 2011, globally the value was just over US$32 million, and the region of the world with the highest average value for each of its disputes was the Middle East at US$112.5 million (EC Harris 2012). Millions of dollars are been spent to prove or

disprove a contractor's entitlement to damages resulting from disputed change order work (Fullerton 2005). Disputes tend to occur on construction projects that are more complex than simpler projects because that is the nature of complex projects. The construction process may be considered the most complex undertaking in any industry (Baccarini 1996, citing Bennett from *International_Construction Project Management: General Theory and Practice 1991*). As an industry that is in and of itself composed of complex processes, the construction industry has been very slow to evolve. The money and valuable time spent to fight for what a contractor or owner believes it is entitled to represents lost opportunities to pursue more productive and profitable endeavors.

With respect to jurisprudence in the United States, the United Kingdom, and other common-law countries, it is the plaintiff that must successfully demonstrate and prove that it is entitled to damages suffered or to compel performance as the result of actions or inactions taken by the defendant. As it pertains to contract disputes in the area of construction, the contractor is most often found to be the plaintiff and the customer or owner, the defendant. For this research, it was assumed that the plaintiff is the contractor and the defendant is the owner. The contractor submits a formal document called a request for change, request for equitable adjustment, or a claim to the owner requesting and substantiating its entitlement for compensation concerning a contractual change in scope. The challenge for construction contractors with respect to changed work is to convincingly demonstrate to an owner that: a) a change occurred and what caused the change, b) the plaintiff/contractor had no responsibility for the change, nor could it have foreseen the change when it submitted its bid price to the owner/defendant, and c) the requested damages and their calculation are reasonable. The other challenge for the

contractor is to demonstrate and substantiate its contract change request or claim, while at the same time, avoiding a costly dispute, or worse, litigation.

Disputes on projects do occur as a result of changes imposed by the owner or its design representative. Sometimes it is not the individual changes that cause the dispute, but rather the delay and disruption to the contractor resulting from the accumulation of changes. According to his master's thesis which took approximately eight man-years of effort to complete (Revay 1987, p.1), Charles A. Leonard notes that it is generally accepted that large, untimely, and numerous change orders can disrupt progress of the work and reduce productivity (Leonard 1988, p. 2). He goes on to note that owners often cannot make up their minds about the requirements of the final product, believing changes can be readily made in the field as construction progresses (Leonard 1988, pp. 2-3). Additionally, responses from owners concerning contractors' claims is initially one of indignant refusal, "particularly those for loss of productivity resulting from untimely and/or frequent changes, are considered by many as a means of getting compensation for either a bad bid or inefficient performance" (Leonard 1987, p. 1).

A type of productivity or efficiency impact that contractors sometimes experience as a result of an enormous amount of changes on a project is known as "cumulative effect" or "cumulative impact." This problem is exacerbated on complex projects where the cause-and-effect relationships may have consequences latent and unimagined, not known until the project has completed. In recent times, the United States federal legal system has established precedence by recognizing that the phenomenon of cumulative impact does exist. However, over the past 40-plus years since cumulative impact was first known to have been first adjudicated, the courts have not yet accepted or recognized a universal