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Investigating the effect of construction management strategies on project greenhouse gas emissions using interactive simulation

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ABSTRACT

The challenges posed by global climate change are motivating the investigation of strategies that can reduce the life cycle greenhouse gas (GHG) emissions of products and processes. While new construction materials and technologies have received significant attention, there has been a limited emphasis on understanding how construction processes can be best managed to control GHG emissions. Unexpected disruptive events tend to adversely affect construction costs and delay project completion. They also tend to increase project GHG emissions. The objective of this paper is to investigate ways in which project GHG emissions can be controlled by appropriately managing disruptive events. First, an empirical analysis of a specific highway construction project is used to illustrate the impact of unexpected schedule delays in increasing project GHG emissions. Next, a simulation based method is introduced to assess the effectiveness of alternative project management strategies in controlling GHG emissions. It demonstrates that appropriately selected strategies can reduce project GHG emissions without increasing the contractor's financial burden or causing project schedule delays. The contribution of this paper is that it explicitly considers project emissions, in addition to cost and project duration, in developing project management strategies. Practical application of the method discussed in this paper will help construction firms reduce their project emissions through strategic project management, and without significant investment in new technology. In effect, this paper lays the foundation for best practices in construction management that will optimize project cost and duration, while minimizing GHG emissions.

1. Introduction

According to the U.S. Environmental Protection Agency (EPA), the construction sector accounts for 131 million metric tons of CO_2 equivalent (EPA, 2009). GHG emissions from construction and rehabilitation of highway infrastructure make up 13.22% of the emissions in the construction sector (EPA, 2006a). The challenges posed by global climate change are motivating the investigation of strategies that reduce the life cycle GHG emissions of products, processes, and services. While novel construction materials and technologies have received significant attention (Gambatese and Rajendran, 2005; Horvath and Hendrickson, 1998; Muga et al., 2009; Zapata and Gambatese, 2005), there has been a limited emphasis on studying the construction phase to understand if better management of construction processes can lead to reduction of project GHG emissions.

Close monitoring of a few highway construction projects shows that poor management during the construction phase results in higher project GHG emissions. A detailed case study presented in this paper illustrates the differences observed between the as-planned and the actual as-built project GHG emissions. These observations reveals that unexpected interruptions and delays increase the total project GHG emissions. Often the underlying cause is the increased material and equipment used on-site, as compared to the planned use. Guggemos and Horvath (2006) pointed out that equipment use accounts for 50% of most types of emissions and energy use of construction processes. In addition, EPA (2006b) reported that in 2005, construction equipment generated roughly 32% of all land-based non-road NO_X emissions and more than 37% of land-based Particulate Matter (PM10). In general, non-road equipment has higher emissions than heavy-duty highway vehicles and automobiles (EPA, 2006b). Ahn and Lee (2013) investigated the environment improvement by controlling equipment efficiency in construction operations. Ozcan-Deniz et al. (2012) used genetic algorithms to optimize construction operations with an objective function of project time, cost, and environmental impacts. But they did not investigate the relationship between managing project time, cost, and environmental impacts.

In light of these observations and findings, this paper aims to investigate the relationship between construction management

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strategies and increased project GHG emissions. A construction management strategy is defined as a sequence of decisions to manage the project, given the project priorities and outcomes. It is hypothesized that the success of achieving project objectives and priorities is dependent on understanding ways of developing coherent management decision sequences. Appropriately selected management strategies can better manage equipment usage. In turn, it is likely that such strategies can reduce project GHG emissions. However, as with cost and duration, there may be a trade-off between cost, duration, and GHG emissions given different management strategies.

Therefore, this paper introduces and implements a simulation based method that can be used to experimentally investigate the relationships between project cost, duration, and GHG emissions by testing different management strategies. The first part of this paper presents an empirical analysis of a highway construction project to illustrate the impacts of schedule delays on project GHG emissions. The second part of the paper uses the same project in an experimental simulation platform to analyze the impact of different management strategies on project cost, duration and emissions. Project GHG emissions for the planned project schedule (referred to as 'as-planned emissions') and each of the simulated outcomes (referred to as 'as-simulated emissions') are estimated and compared to the actual project GHG emissions (referred to as 'as-built emissions' based on observed data). All emissions are estimated based on as-planned, as-simulated and as-built material and equipment use on the project site. This paper does not describe detailed emission calculations. However, the underlying method can be found in co-authors' previous work (Cass and Mukherjee, 2011).

Traditionally, construction project planning considers trade-offs between project cost and duration. Project GHG emissions should become a third objective that needs to be explicitly considered, as well. The primary contribution of this paper is that it introduces project GHG emissions as a third leg in the time-cost trade-off problem and investigates the relationships between project duration, cost, and GHG emissions. The proposed simulation method is expected to support project planning by identifying ways to optimize cost and schedule performance, while minimizing project GHG emissions.

2. Background

State agencies are increasingly implementing regulations that encourage stakeholders in the construction industry to reduce project GHG emissions. At the state level, Departments of Transportation have launched a movement toward addressing sustainability through the life cycle of a pavement. Some of these efforts are focused on the monitoring and reduction of project GHG emissions in construction operations. For example, California has legislatively mandated the reduction of GHG emissions across all sectors (CEPA, 2006).

There are different ways of assessing and reducing GHG emissions of highway construction operations. The life cycle assessment (LCA) perspective supports the choice of products and processes that reduce GHG emissions during the different life cycle phases, namely raw material mining, production and manufacturing, construction, service and end-of-life (Santero et al., 2011). Current investigation of GHG emissions emphasizes the selection of resource on site (Cass and Mukherjee, 2011; EPA, 2006b; Guggemos and Horvath, 2006). This paper considers emphasizing construction strategy management. In preliminary research, Cass et al. (2011) has shown that there is a likely relationship between project delays and increased GHG emissions.

While decisions regarding use of different pavement material types are often made at the agency level, decisions to reduce GHG emissions during the construction phase are within the contractors' control. Sometimes such decisions place a financial burden on the contractors. For example, equipment larger than 175 HP made prior to 1996 tend to produce more GHG emissions than recent models (Guggemos and Horvath, 2006). This may require a contractor to consider a potentially expensive fleet update to achieve lower project emissions. In contrast, this study presents a method that advocates inexpensive improvements to planning and management to reduce emissions.

Methodologically speaking, the primary challenge of this research lies in directly observing the impact of different management strategies on project performance, for the same project and given the same conditions. Often the impacts of a particular strategy can be undermined by the occurrence of an unexpected disruptive event external to the project - such as bad weather or a change order. The timing of such external events plays a crucial role in deciding the ultimate fate of a strategy. This points to the use of statistical and simulation based methods that allow the assessment of alternative strategies. Zhou et al. (2012) proposed analytic and simulation models to identify optimal or near-optimal green production strategies. Changbum Ahn et al. (2010) used discrete-event simulation to plan construction operations by comparing GHG emissions of alternative operations. However, the method did not consider the decision-makers' responses to contingencies during the construction process.

This research uses a general purpose interactive simulation platform, the Interactive Construction Decision Making Aid (ICDMA) (Anderson et al., 2009; Rojas and Mukherjee, 2006a). It can be used as a test bed for multiple simulations, that are run under varying conditions and management strategies, for a given construction project. It allows decision-makers to respond to project contingencies by (re)allocating resources during the simulation process. Previous research in ICDMA has established analytical techniques to assess strategies' performance in cost and schedule management (Tang et al., 2010a, b). This paper applies similar assessment techniques to assess the impact of alternative strategies on project GHG emissions.

The second methodological challenge is to validate the simulation method. The as-built history is only a particular instance of a project realization in reality. Comparing this single realization to the distribution of project histories generated from the simulated environment is not a true validation. However, it does provide a reality check on the reasonableness of the simulation outcomes and is a step in the right direction (Martinez, 2010). It is expected that the true validation of such methods lies in longitudinal simulations across multiple projects in the long term, which is our future work and not addressed in this paper. For the purpose of this paper, we compared the as-simulated outcomes against the actual as-built outcome to check the reasonableness of the simulation outcomes. The case study used is a real highway construction project, which was closely observed and documented. The next section describes the empirical study of the highway construction project in question.

3. Empirical analysis

The empirical analysis involved a ten-mile concrete pavement re-construction project in Southeast Michigan. It studied the reconstruction of the East Bound section of a major interstate highway in 2009. This section illustrates the gaps between as-planned and as-built project GHG emissions due to project delays. First, it explains how as-planned and as-built project data is collected. Second, it calculates as-planned and as-built project GHG emissions. Third, it identifies and analyzes the differences.