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USING EARNED VALUE MANAGEMENT TO QUANTIFY ECONOMIC, ENERGY, AND ENVIRONMENTAL SUSTAINABILITY IN CONSTRUCTION ACTIVITIES

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Abstract: Earned value management (EVM) has long been used in the construction industry as a project performance measurement and feedback tool that identifies problems early on in order to make adjustments that keep the project on time and within budget. By following the plan-do-check-act approach of EVM, project managers are able to measure and manage the impacts of their decisions. EVM also provides a much-needed framework for linking together three critical aspects of construction sustainability – economics, energy, and environment – by defining the relationships between equipment cost, fuel use, and air pollution. The EVM sustainability framework presented here utilizes well-known construction planning techniques to allocate resources and schedule activities in order to plan, track, and control equipment costs, fuel use, and air pollutant emissions, thus achieving more sustainable construction activities.

1 Introduction

Earned Value Management (EVM) helps answer critical construction project management questions related to economics such as: Is the project ahead of or behind schedule? Is the project under or over budget? How much will the entire project cost? By expanding the principles of EVM, additional questions related to energy and the environment can be answered for the project: When does the project consume the most fuel and emit the most pollutants? Is the project consuming more energy and emitting more pollution than what was anticipated? How much energy will be consumed and how much pollution will be emitted for the entire project? If problems are discovered during the project, EVM helps to identify where the problems are occurring, whether or not the problems are critical, and what is needed to get the project back on track.

Heavy duty diesel (HDD) equipment has a significant role and cost in most construction projects and its use is inextricably tied to fossil fuel consumption and, therefore, air pollutant emissions including nitrogen oxides (NO_x), particulate matter (PM), hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2). Furthermore, NO_x and HC may react in the atmosphere in the presence of heat to form ground-level ozone (EPA 2003). Days exceeding the Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS) (EPA 2013) for ozone limits typically occur between May and September, the same time of year when construction activity is at its peak and HDD equipment is at its maximum usage. The EVM framework presented here is central to a dynamic construction planning process that aims to quantify and ultimately reduce costs, fuel consumption, and emissions from HDD equipment.

2 EVM Framework for Sustainability Planning, Tracking, and Control

During the project planning phase, the EVM framework establishes a baseline of equipment costs, fuel use, and emissions for the entire project (or a particular phase) on a daily timescale via critical path scheduling techniques. This baseline is essentially the "sustainability budget" for the project and it identifies the activities that contribute the most to equipment cost, fuel use, and emissions and when they occur. Some of these activities – specifically those with schedule float - may be moved to a different part of the construction schedule to reduce these peak quantities but still not delay the overall completion date of the project. The critical path activities – those that cannot be moved – are examined to determine if reduction strategies, such as alternative equipment selection, are feasible.

During the construction execution phase, the EVM framework is used to track the daily equipment cost, fuel use, and emissions projections to determine if the actual values are over or under the planned values shown on the baseline. This tracking process reveals which activities need immediate attention with regard to not only cost, which has historically always been the major concern, but also energy consumption and environmental impact. When the problematic activities have been identified, the project manager is equipped to control the situation by recommending strategies that will return the project to its planned sustainability budget.

The major goal of the EVM sustainability framework is to plan, track, and control the episodic costs, fuel use, and emissions that are directly related to HDD equipment. There are three primary objectives:

Objective 1: Plan a sustainability budget for the project. The purpose of this objective is to quantify equipment costs, fuel use, and emissions on a daily basis prior to the commencement of the project execution phase. The results of this objective will serve as a baseline and benchmark for comparison during the tracking and controlling phases of the project. The baseline is created by extending the cost estimating, scheduling logic, and resource allocation techniques that are found in many management textbooks (Gould and Joyce 2003) to include: equipment cost data from the owner's records or other reliable sources such as RS Means Building Construction Cost Data (2011); fuel use data from the owner's records or equipment manufacturer sources such as the Caterpillar Performance Handbook (2008); and equipment emissions data from sources such as the EPA NONROAD Model (2005).

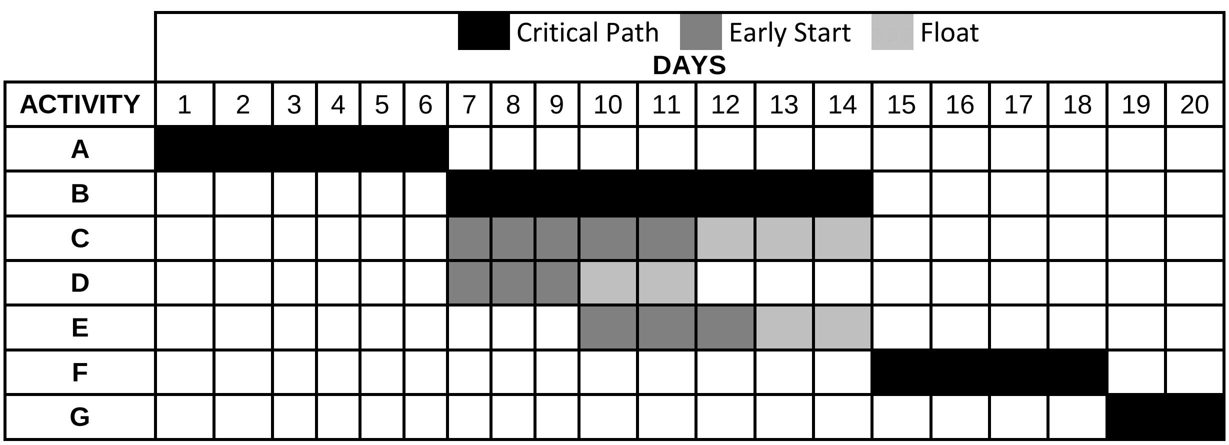

Figure 1: Critical Path Schedule for Example Project

Figures 1, 2, and 3 provide an example of what the critical path schedule, daily equipment cost, daily fuel use, and daily CO_2 emissions may look like for an earthmoving project with seven activities and duration of 20 days. The daily equipment costs were based on activity, crew, and cost data from RS Means Construction Cost data and the fuel use and emissions estimates were calculated with data from the EPA NONROAD model. These figures illustrate how it is possible to convey specific information regarding the economic, energy, and environmental impacts of the project and not only total project costs. It is also possible to see that the greatest equipment economic, energy, and environmental impact occurs on Days 7-11 (Early Start) but Days 10-14 (Late Start).

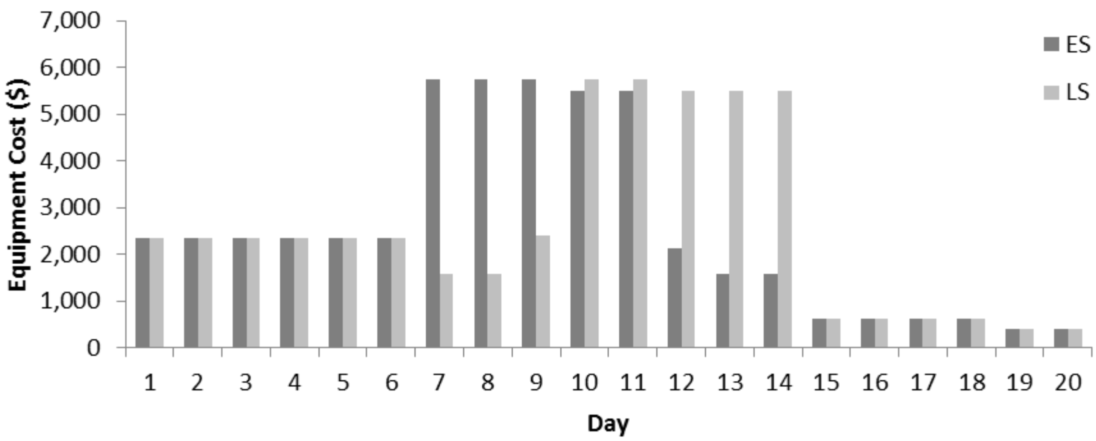

Figure 2: Daily Equipment Costs

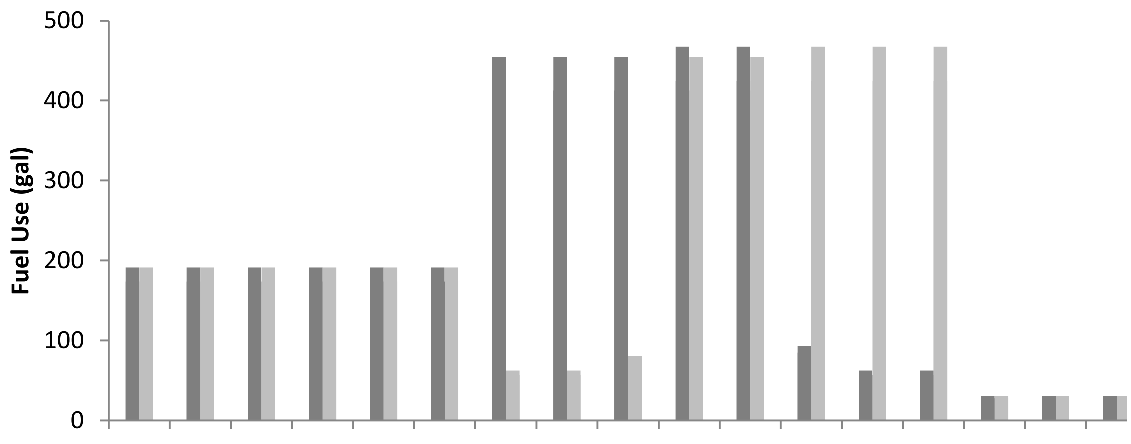

Figure 3: Daily Fuel Use and CO_2 Emissions

Objective 2: Track the performance of the sustainability budget for the project. The purpose of this objective is to compare the actual equipment costs, fuel use, and emissions to the baseline in the sustainability budget and identify sources of uncertainty and variability. This is accomplished on a daily basis by simply recording the equipment usage in hours and then multiplying the usage by equipment cost per hour, fuel use per hour, and emissions per hour to obtain the daily results; thus, the project manager can determine if the project is over or under the sustainability budget. Results of this objective are performance indicators based on an earned-value approach (Oberlender 2000). For example, emissions performance indicators include Emissions Variance (EV = Planned Emissions – Actual Emissions) and Emissions Performance Index (EPI = Planned Emissions ÷ Actual Emissions). These values indicate if the activity or overall project has emitted more or less emissions than was planned. A positive EV and an EPI greater than 1.0 indicate that actual emissions are lower than what was planned; however, a negative EV and an EPI less than 1.0 indicate that the activity is emitting more pollutants than what was planned. Again, these sustainability performance indicators are simply an extension of the metrics with which construction project managers are already familiar.

Objective 3: Control the project by identifying strategies for reducing costs, fuel use, and emissions. The purpose of this objective is to determine ways to reduce fuel use and emissions over the duration of a construction project. For example, Figure 3 shows that CO_2 accumulates in the atmosphere later in the project based on the late start schedule; thus, a project manager may decide to move some of the activities with float to later in the project schedule in order to reduce the build-up of high levels of CO_2 that will remain in the atmosphere longer. This is particularly important for other pollutants, such as NO_x and HC, which form ground-level ozone in the presence of heat. Float activities that emit NO_x and HC could therefore be moved to a cooler time of the schedule to help reduce the formation of ground level ozone. Thus, the project manager is playing an active role in the environmental sustainability of the project by simply managing the project schedule.

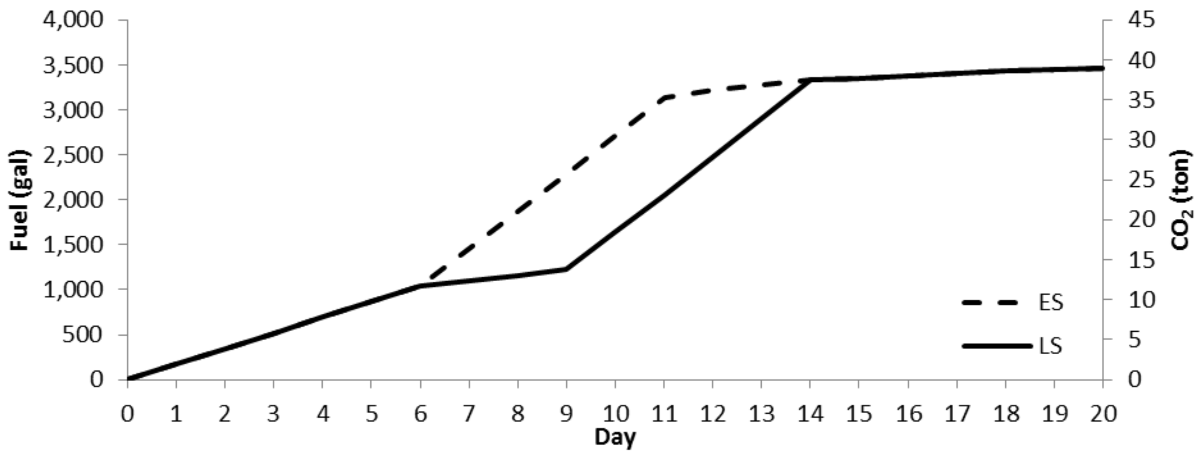

Figure 3: Cumulative Fuel Use and CO_2 Emissions

3 Conclusion

A major outcome of the EVM sustainability framework is a new and innovative ability to incorporate emissions data into a construction project schedule in order to reduce *energy* consumption and improve *environmental* sustainability while still addressing the *economic* concerns of the project. Such an accomplishment is beneficial to the construction industry and the general public. Specifically, it helps local, state, and regional governments maintain attainment status - or return to attainment status - with current and proposed EPA standards for pollution. Consequently, reducing emissions leads to improvements in public health and environmental quality. Three themes to the outcomes of the EVM sustainability framework are accurate estimates of equipment costs, energy consumption and environmental impacts for construction activities; improved strategies for reducing costs, energy consumption and environmental impacts; and new knowledge for filling research gaps in construction sustainability, particularly with regard to project life cycle cost analyses.

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