S-STEM PROGRAM PROJECT:
CONSTRUCTION MATERIALS AND OPERATION
MANAGEMENT TO MINIMIZE GREENHOUSE GAS
EMISSIONS

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April 22, 2011
INTRODUCTION
Future policies may mandate the monitoring and reduction of greenhouse gas (GHG) emissions from public agencies and private industries. In response, research is investigating metrics that can measure GHG emissions, and influence best practices. These best practices promise to reduce the impact of construction, rehabilitation and maintenance of transportation infrastructure. In addition, it is important for public agencies, owners, and contractors to have knowledge about such metrics and best practices. The overall objective of this research is to develop recommendations for sustainable construction and management of highways. This is accomplished by analyzing the project’s schedule, location, site layout conditions, and equipment usage, to identify significant GHG emission sources. In addition, the impact assessment of a highway construction project is analyzed to identify operation and planning components of the construction phase that have significant GHG emissions. As a result, the paper identifies the key contributors and outlines recommendations to reduce them. The framework will support decision-making in the industry and provide researchers a significant information base, which can be mined to promote continuous improvement in metrics and standards to identify best practices. This will eventually inform the implementation of best practices involving the reduction of GHG emissions. This will also provide support in the selection of alternative pavement materials and construction methods that are environmentally sustainable and economically viable.

The challenge posed by global climate change is motivating state and local transportation agencies to investigate strategies that reduce the life cycle GHG emissions associated with construction and rehabilitation of highway infrastructure. This has led to investigation of the different life cycle phases of pavements. While the materials manufacturing and production phases have received significant attention, there has been limited emphasis on studying the construction phase to understand how construction schedules and processes can be best managed to reduce carbon emissions. The specific components of the construction phase that need to addressed are:

- Construction equipment use
- Material use on site
- Distances travelled on site during construction operations
- Distances travelled to and from the construction site while transporting raw materials
- Quality of construction
- Rework and extended equipment usage due to schedule delays
- Extra work and extended equipment usage due to changing site conditions

All these factors directly impact the GHG emissions of the construction phase in particular, and in specific cases can influence design and construction management decisions. In previous research, the authors have illustrated a method to develop inventories of materials, equipment usage and construction travel distances, and applied a hybrid Life Cycle Assessment (LCA) approach to calculate the GHG emissions associated with highway construction[1]. This paper presents the next logical step in investigating GHG emissions of the construction phase by presenting a method to analyze the impacts of construction schedules and schedule delays.

The objective of this study is to investigate how schedule analysis can be used to reduce GHG emissions during the construction phase. The paper presents a method to collect and analyze construction project management data, and calculate associated impacts by
comparing the GHG emissions of the as-planned and as-built schedules. The method is illustrated using a case study in Michigan. The goal of this research is to provide state agencies and construction management stakeholders recommendations for construction best practices that reduce project emissions by specifically accounting for project and site specific conditions. The significance of this research is that it takes a critical step towards understanding the influence of project specific factors and site conditions on GHG emissions of pavement sections.

**BACKGROUND**

Current research efforts emphasize prescriptive approaches that present general conclusions regarding the comparative impacts and performance of alternative pavement materials using estimated inventories [2-5]. Life Cycle Assessment (LCA) methods have been used to develop impact assessment metrics and methods that are dependent on estimated or observed construction inventories (materials installed, equipment used in construction and maintenance operations) to discriminate between alternative pavement designs. In comparing different types of pavements, implicit assumptions are made that uniform conditions apply to both pavement types throughout the construction and use phases. This often leads to misleading conclusions. Instead, in this study, the emphasis is shifted from comparing pavement types to understanding the sensitivity of project emissions to construction site layout and project performance.

**OBJECTIVES**

The goal of this research is to provide state agencies and construction management stakeholders’ recommendations for construction best practices that reduce project emissions by identifying efficient methods in construction site planning, schedule management and operations management. It builds on a body of research in lean construction that aims to reduce construction waste and deliver projects faster and at a lower cost, by particularly assessing highway construction processes from the perspective of reducing GHG emissions and considering trade-offs in project cost and duration if any.

Therefore, the objectives of this research are:

1. Develop a method to collect site condition and project schedule data by extending current field practices.
2. Develop an easily reproducible method to generate as-built resource loaded schedules and traces of actual operation performance from the data.
3. Develop emission control metrics that are similar to schedule cost and duration control metrics to assess project emission performance.
4. Based on a comparison of as-planned and as-built schedule data across typical construction and rehabilitation projects, identify strategies and trade-offs that reduce GHG emissions of the construction phase.
5. Simulate the as-built schedule utilizing alternative scheduling methods to optimize performance
6. Recommend best practices to decision-makers and construction managers.

**METHODOLOGY**

Building on previous research, construction management software was used to collect data from the construction phase of the project.
**DATA COLLECTION**

Michigan Department of Transportation (MDOT) requires the use of software called FieldManager™ created by InfoTech Inc. on all their construction and rehabilitation contracts. It is a Microsoft Windows based interface designed for use by state transportation agencies, local governments, engineering consultants, and large contractors. Inspectors (on behalf of MDOT) record general site information, contractor personnel and equipment, and material postings and quantities information on a daily basis using the Inspector’s Daily Report (IDR). Researchers at Michigan Tech accessed the IDRs directly from the FieldManager™ database. The following three fields of the IDR were used to accurately investigate the as built schedule:

**General Site Information**

As the name indicates, this field defines the context within which the construction operations for the day were conducted. It includes the days and times work was performed, weather conditions on-site, general observations about site conditions, and site-specific location of the work being performed.

**Contractor Equipment**

The contractor personnel and equipment inputs of the IDR are critical to quantifying project emissions. Recent studies have shown that energy use and emissions of construction processes are primarily due to construction equipment use, which can account for 50% of most types of emissions. In addition, equipment larger than 175 HP. made prior to 1996 tend to have greater emissions than more recent models[7]. Type and quality of construction equipment used on-site significantly impacts a project’s total emissions. The primary equipment used on the controlling activities throughout the project was recorded from this field.

**Material Posting**

IDRs tracked progress on each pay item as specified in the construction contract. It recorded the location, station information and quantities of materials associated with each activity. This data was used to develop an as-built record of procured and installed pay items. Actual productivity and schedule of the construction project was also monitored using postings of material installed per day and general site information. This information can also be used to calculate the item wastage or excess usage by comparing the as-planned items in the original estimate (bid-tab) to the actual installed materials. Using as-built quantities in the calculation of life cycle impacts and emissions is significantly more representative of project impacts compared to similar calculations done with estimated quantities. Data collected across similar and different construction projects can be analyzed by classifying across pavement designs, construction operations and site-specific conditions to highlight sensitivity of impacts and emissions to local and regional variables.

**DATA DEFINITION**

The collected data was used to develop the as-built resource loaded schedule. The as-planned schedule was developed using the progress schedule (MDOT Form 1130) that is submitted by contractors to MDOT project delivery engineers before the construction start date. The form outlines construction activities along with proposed starting and end dates for each activity. Driving activities defining the actual construction of the roadway were identified and used. Henceforth they are referred to as primary activities. These activities were assigned a division of work and section number as defined in MDOT’s Standard Specifications for Construction[8]. In addition, a controlling pay item was identified to represent each activity.
These driving activities and controlling items were used to characterize the parameters in the schedule analysis.

It was necessary to identify primary activities and controlling items when assessing differences in schedule performance because the scope of this analysis is to investigate GHG emissions associated with the highway construction process in particular. The activities were chosen so that they are representative of typical highway construction projects. Therefore, mainline paving activities are considered as primary activities as they are common to all projects and variation in them due to site conditions can be compared across projects. However, traffic control activities were excluded as they may vary significantly from project to project and are not strictly part of the roadway construction process.

The general site information, contractor equipment, and material posting from FieldManager™ were moved to and stored in the data server at Michigan Tech. The information was organized by tabulating the resources associated with each controlling item installed for each of the primary activities for each day of the project. The controlling items identified in the original estimate and schedule was used to access as-built information in FieldManager™. Tables representing daily activity data and daily pay item information were queried. Each query on a controlling item returned the working dates, the identification number, the quantities of material installed and equipment used, station locations and the inspectors’ observations. The importance of this infrastructure is that it can be applied to generate as-built schedules automatically from FieldManager™ data in future projects.

**GHG Emission Estimation**

GHG emissions are estimated for materials associated with the pay items and equipment used on construction sites. LCA tools and emission calculation methodologies are used to calculate the emissions. The data collected through FieldManager™ was used to develop material, and fuel inventories, which in turn were used as an input to the LCA tools. The Economic Input Output-Life Cycle Assessment (EIO-LCA) model was used to estimate the impacts of materials through the life cycle stages of extraction/mining, transportation, and manufacturing. When using EIO-LCA, material costs were obtained through RS Means [9] and then converted to 2002 dollar using applicable cost indexes.

When assessing equipment emissions, the working days from both as planned and as-built schedules were identified to establish extra equipment use. The make, model, type, and Horsepower characteristics of each type of equipment were identified using fleet information provided from the contractor. Using the following equation, the emissions were estimated for each activity’s controlling equipment type.

\[ \text{Emissions} = O_t \times HP \times C_F \times \varepsilon \]

Where \( O_t \) = Operating time factor, \( HP \) =Rated Horsepower, \( C_F \) = Fuel Consumption Rate \((\text{Gal/(HP*hr)})\), and \( \varepsilon \) = emission rate \((\text{lbs CO}_2/\text{Gal})\)

The following assumptions were made:

- Operating Time Factor was assumed to be 45 minutes/hr (0.75)
- Working Day = 10 hours
- Fuel Consumption Rate = 0.04 Gal/(Hp*hr) (Peurifoy and Oberlender 2002)
- Emission Rate = 22lbs CO_2/Gallon [10]
SCHEDULE ANALYSIS

Pay item quantities were mined directly from FieldManager™ to create the as-built schedule. The as planned and as built schedules were compared and outlined in the following manner:

- Pay Item Quantities: Identify shortage and excessive usage.
- Material Emissions: Identify emissions from the manufacturing of the controlling items
- Equipment Emissions: Identify the emissions from the controlling equipment.

CASE STUDY

The case study involved is a ten-mile concrete pavement re-construction project during the Summer of 2009. Along the ten-mile length of the job, pavement removal, earthwork and paving operations were being performed in sequence. Therefore, the primary activities and associated controlling items identified were:

- Primary Activity: Remove Concrete Pavement, Controlling Item: Pavement Removal
- Primary Activity: Grade Subbase, Controlling Item: Station Grading
- Primary Activity: Install Drainage, Controlling Item: Underdrain Pipe
- Primary Activity: Place Base Material, Controlling Item: Geotextile Separator
- Primary Activity: Pave Mainline, Controlling Item: Non-reinforced Concrete

Figure 1, shows the as-planned schedule and as-built schedule production rates. The X-axis represents the time and the y-axis representing the cumulative completion percentages of each activity. Primary activities and controlling items included shoulder construction. The analysis was done for only the eastbound lanes of the project. When calculating the as-planned resource loaded schedule the bid tab quantities were used. However, the bid tab quantities, for each pay item represent the entire project, not just the mainline. Therefore, the ratio of as-built mainline quantities to that of the total quantities was applied to the bid tab quantities to calculate the as-planned quantities.

Each activity was assigned controlling equipment, as follows:

- Remove Concrete Pavement: Pavement Breaker
- Grade Subbase: Grader
- Install Drainage: Trencher
- Pave Mainline: Concrete Paver
- There was no equipment related to the primary activity of placing base material as the related controlling item only required manual labor (4-man crew to place the geotextile separator.)

During the pavement removal operation, the agitation of the soil and the presence of heavy equipment on site enhanced the capillary effect and caused ground water to flood the stretch. In addition, seasonal rains added to the flooding on site and brought all operations to a halt. After the site conditions were re-assessed, an undercut had to be excavated so that a geo-grid barrier could be placed and the sub-grade reconstructed to avoid future incidents of flooding. This resulted in a change order, involving the extra operations needed because of the unforeseen moisture problem. In most cases, it is estimated that there is a 5-10% increase in project costs[11] as result of most change orders - depending on work type, operations, and time. Greater accuracy of preliminary design and estimation methods can reduce the impacts
of change orders. In this example, the unfortunate coincidence of the soil condition, the consequences of heavy equipment on unprepared ground, led to significant project delays as was reflected in schedule delays. (As outlined in Figure 1)

PRELIMINARY RESULTS

Table 1, Table 2, and Table 3 illustrate the differences between as-planned and as-built quantities and emissions from controlling materials and equipment. This highlights where significant reductions can be made. Furthermore, using estimated and actual quantities allows for the investigation of how equipment usage and productivity of each activity affects the overall GHG emissions associated with the project. Actual observed results are investigated using project simulation to analyze alternative project scheduling methods and is described in a latter section. By investigating these differences, recommendations for the design and management of the project can be developed.

This preliminary analysis only analyzed controlling materials and equipment emissions. The simulation analysis (described later) further the analysis and investigates all materials and all equipment represented in the as-built records. This was done by integrating material and equipment information outlined in the as-built records with RS means construction cost and productivity data. Additionally, previous work has allowed for the quantification of GHG emissions associated with non-controlling materials and equipment along with the emissions from material transport and secondary processing. (i.e. batch plant emissions) These types of emission calculation methodologies and values are reported in concurrent MDOT research. (See Acknowledgments 12)

![Figure 1: As-Planned vs. As-Built Schedule](image-url)
Table 1: Quantity Comparison

<table>
<thead>
<tr>
<th>Primary Activity</th>
<th>Controlling Item</th>
<th>Unit</th>
<th>AsPlanned Qty</th>
<th>AsBuilt Qty</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove Concrete Pavement</td>
<td>Pavement Removal</td>
<td>Syd</td>
<td>249065.99</td>
<td>185431.46</td>
<td>-25.55</td>
</tr>
<tr>
<td>Grade Subbase</td>
<td>Station Grading</td>
<td>Syd</td>
<td>448.67</td>
<td>519.32</td>
<td>15.75</td>
</tr>
<tr>
<td>Install Drainage</td>
<td>Underdrain Pipe</td>
<td>Ft</td>
<td>110007.45</td>
<td>107945.00</td>
<td>-1.87</td>
</tr>
<tr>
<td>Place Base Material</td>
<td>Geotextile Separator</td>
<td>Syd</td>
<td>213236.10</td>
<td>217750.15</td>
<td>2.12</td>
</tr>
<tr>
<td>Pave Mainline &amp; Shoulder</td>
<td>Non-reinforced Concrete</td>
<td>Syd</td>
<td>217358.96</td>
<td>229876.19</td>
<td>5.76</td>
</tr>
</tbody>
</table>

Table 2: Controlling Item Emissions

<table>
<thead>
<tr>
<th>Primary Activity</th>
<th>Controlling Item</th>
<th>Unit</th>
<th>AsPlanned GHG Emissions (MTCO$_2$eq)</th>
<th>AsBuilt GHG Emissions (MTCO$_2$eq)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove Concrete Pavement</td>
<td>Pavement Removal</td>
<td>Syd</td>
<td>¹NA</td>
<td>¹NA</td>
<td>¹NA</td>
</tr>
<tr>
<td>Grade Subbase</td>
<td>Station Grading</td>
<td>Syd</td>
<td>¹NA</td>
<td>¹NA</td>
<td>¹NA</td>
</tr>
<tr>
<td>Install Drainage</td>
<td>Underdrain Pipe</td>
<td>Ft</td>
<td>45.0</td>
<td>44.1</td>
<td>-2.00</td>
</tr>
<tr>
<td>Place Base Material</td>
<td>Geotextile Separator</td>
<td>Syd</td>
<td>379</td>
<td>387</td>
<td>2.11</td>
</tr>
<tr>
<td>Pave Mainline &amp; Shoulder</td>
<td>Non-reinforced Concrete</td>
<td>Syd</td>
<td>13600</td>
<td>14400</td>
<td>5.88</td>
</tr>
</tbody>
</table>

¹No consumtion of virgin materials
### Table 3: Controlling Equipment Emissions

<table>
<thead>
<tr>
<th>Primary Activity</th>
<th>Controlling Equipment</th>
<th>Controlling Item</th>
<th>Unit</th>
<th>AsPlanned # of working days</th>
<th>AsBuilt # of working days</th>
<th>AsPlanned GHG Emissions (MTCO₂)</th>
<th>AsBuilt GHG Emissions (MTCO₂)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove Concrete Pavement</td>
<td>Pavement Breaker</td>
<td>Pavement Removal</td>
<td>Syd</td>
<td>15</td>
<td>24</td>
<td>5.66</td>
<td>9.06</td>
<td>60.00</td>
</tr>
<tr>
<td>Grade Subbase</td>
<td>Grader</td>
<td>Station Grading</td>
<td>Syd</td>
<td>19</td>
<td>8</td>
<td>14.87</td>
<td>6.26</td>
<td>-57.89</td>
</tr>
<tr>
<td>Install Drainage</td>
<td>Trencher</td>
<td>Underdrain Pipe</td>
<td>Ft</td>
<td>14</td>
<td>22</td>
<td>5.29</td>
<td>8.31</td>
<td>57.14</td>
</tr>
<tr>
<td>Place Base Material</td>
<td>'NA</td>
<td>Geotextile Separator</td>
<td>Syd</td>
<td>'NA</td>
<td></td>
<td>'NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pave Mainline &amp; Shoulder</td>
<td>Concrete Paver</td>
<td>Non-reinforced Concrete</td>
<td>Syd</td>
<td>14</td>
<td>26</td>
<td>11.63</td>
<td>21.60</td>
<td>85.71</td>
</tr>
</tbody>
</table>

¹Geotextile Separator placed by manual labor (4-man crew)

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**SIMULATION METHOD**

The modeling, simulation, and optimization task is aimed at gaining full understanding how the system works and providing direction in improvement. It is divided into steps: (1) build the project in the simulator using alternative scheduling method; (2) run the simulation using different decision strategies; (3) collect the data; (4) analyze alternative decision strategies and propose better strategies. The methodology is presented in Figure 2. To carry the steps, we need a simulation platform that we can use, an easy method to collect the data, and reliable data analysis method.

![Figure 2: Methodology in Optimizing Decision Strategies](image)
The research group has been involved in the development of simulation tools that can be appropriately used for this research. The simulation platform used in this study is called the Interactive Construction Decision Making Aid (ICDMA). (Interface shown in Figure 3) ICDMA is a specific implementation of a general-purpose interactive simulation framework[12]. It simulates a construction project based on the as-planned schedule and costs as defined in a web-based database. The user takes on the role of construction manager/primary decision-maker. The goal is to complete the project on schedule and under budget. During the simulation run, users are presented with random external events that force the simulated project to deviate from its original plan. The users have to respond to those events by making decisions on resource allocation. ICDMA utilizes the response and updates the project. This process continues until the completion of the simulated construction project.

**Figure 3: Interface of Interactive Construction Decision Making Aid (ICDMA)**

Given research resources and experiences available, it is believed that the simulation method proposed can be applied to a highway construction project of interest on the ICDMA and correlates the results to investigate GHG emission metrics.

Using the simulation software helps give deeper insight into how the system works. The algorithms have been verified and the simulation platform has been illustrated using a historical case study. This research project provides the simulation platform with a second case study which can then be illustrated and compared to actual observed results (as-built data obtained earlier). The key point of the simulation is to understand the relationships and components influencing the project’s outcomes, in this case, greenhouse gas emissions. In this study, alternative schedules were investigated using the simulation platform to mimic the as-built schedule described earlier and is used to assess the optimal construction scheduling method to minimize GHG emissions.

**SIMULATION AND ANALYSIS**

The alternative scheduling methods investigated in the simulation analysis are as follows:

- Critical Path Method (CPM)
- Linear Scheduling (LS)
• Progress Schedule (Contractor’s as-planned schedule)

Strategies were developed as guidelines to complete the construction project, aiming towards specific goals defined by the construction manager (user). The Crash Strategy and the Control Strategy are the two strategies developed to investigate the sensitivity of the scheduling method implemented.

The objective of the control strategy is to simulate the as-planned project without any unplanned interruptions (i.e. delays, material shortages, etc.) - this is strictly speaking, an emulation of the project. It provides a baseline to compare the performance of alternative decision strategies that are used to manage scenarios resulting from delays and interruptions. The outcomes of the simulation are illustrated in Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Critical Path Method</th>
<th>Linear Scheduling</th>
<th>Progress Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>79 days</td>
<td>72 days</td>
<td>154 days</td>
</tr>
<tr>
<td>Emissions (CO₂)</td>
<td>840 MT</td>
<td>836 MT</td>
<td>807 MT</td>
</tr>
</tbody>
</table>

When the control strategy was used, the linear scheduling method resulted in a shorter duration than other scheduling methods. The progress schedule method had the lowest cost and the least greenhouse gas emissions, but had the longest duration. This expected because contractors tend to submit conservative schedules.

The next decision strategy referred to as the Crash Strategy was implemented on a simulation of the project using the Critical Path Method and Linear Scheduling Method for defining the as-planned schedules. In this case, the program explicitly simulated unexpected interruptions and their impacts on the schedule. The objective of Crash Strategy is to aggressively allocate resources to activities, ahead of schedule, in apprehension of unexpected interruptions. The outcomes of the simulation are illustrated in Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Critical Path Method</th>
<th>Linear Scheduling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>65 days</td>
<td>61 days</td>
</tr>
<tr>
<td>Emissions (CO₂)</td>
<td>825 MT</td>
<td>786 MT</td>
</tr>
</tbody>
</table>

The results show that, compared to the baseline (Table 4), when the crash strategy is used, the critical path method shows a 17.7% and 1.7% reduction in schedule and GHG emissions respectively, while the linear scheduling shortens the duration, and GHG emissions by 15.3% by 5.9% respectively.

All the analysis shows that linear scheduling method is more appropriate in reducing the greenhouse gas emission with a shorter duration, especially when combined with crash strategy.
RESULTS & DISCUSSION

A preliminary comparison of controlling materials and equipment was assessed to illustrate discrepancies in estimating a project’s impacts and actual observed impacts. This also highlights the significance of using actual observed data. The preliminary comparison of the as-planned and as-built schedules shows a significant increase in equipment use on site, resulting in 7.8 Metric Tons (MT) of extra CO\textsubscript{2} emissions. This is equivalent to the emissions produced in generating electricity to power an entire household for one year, or the emissions from 325 propane cylinders used for home barbeques\cite{13}. The emissions due to extra materials installed and rework was estimated from the difference in the quantities between the as planned and as built schedules. The impact of the extra materials used, as measured from their manufacturing phase, was approximately 807 MT of CO\textsubscript{2} emissions. This is equivalent to providing electricity to 100 homes for an entire year or the emissions from 33,000 propane cylinders used for home barbeques\cite{13}. The moisture problem encountered on site during the pavement removal operation along with the re-construction of the sub-grade and installation of the geo-grid barrier was largely responsible for the excess emissions.

The actual observed data that was assessed in the preliminary assessment was then simulated using the software described. This was done to explore and consider alternative control strategies and scheduling methods. It also allowed researchers to investigate total materials and equipment represented in the as-built information and estimates the entire project’s carbon footprint. The results from this analysis permitted the conclusion on which control strategy and scheduling method minimizes GHG emissions. It was found that that linear scheduling method combined with the crash strategy minimizes the greenhouse gas emission associated with the highway project, also while maintaining the shortest duration.

Specific sustainability aspects that this research advances are the contributions it makes towards assessing the environmental implications of highway construction and rehabilitation. The described methods can supplement Life Cycle Analysis in which economic and social implications can also be assessed. The methods developed in this research promise to increase project efficiency and reduce overall waste and pollution. This efficiency also necessitates cost savings as a result of the lean techniques introduced. With actual observed historical construction data and emission metrics these methods promise to reduce long-term environmental impacts and greenhouse gas emissions, advancing the overall sustainability of transportation infrastructure.

The pertinent question raised is: how much should contractors and owners explicitly budget into their operation planning and management budget to avoid these delays and extra emissions, and more critically, at what point is the return on investment worth the savings in emissions. This leads to a multi-objective trade-off problem that is very similar to the time-cost trade-off problem. Alternatively, with appropriate benchmarking of emissions for typical highway construction projects, DOTs could consider incentive contracts that provide contractors incentives to reduce emissions during construction. While this is a very attractive idea, it also requires a reliable method that can be used to measure construction site emissions. The method presented in this paper is a first step in developing such methods.

Future investigation will lead to exact recommendations regarding specific construction operations. For example, what spatial and schedule constraints need to be explicitly considered when staging the paving operation and locating the batch plant, to minimize construction site travel distances. This research is in line with the development of point-based systems for reducing the emissions from highway construction, such as Green Roads\cite{14}, which provide top-down prescriptive recommendations to practitioners. Results from more detailed analysis of construction schedules and operations will lead to bottom-up corroboration of such principles.
CONCLUSION

The result of this investigation shows that schedule delays and rework resulting from unexpected change orders during the construction process can lead to more than expected emissions on construction sites. Therefore, appropriate management of construction schedules and optimal use of materials and equipment on site during construction can significantly help in lowering emissions during highway construction. When considered for multiple construction projects across the nation, a focus on reducing emissions through better management of construction projects can result in significant savings. Management best practices developed in areas of lean construction and lessons learnt from construction operation simulations and planning can be transferred and applied very successfully to achieve these goals. Therefore this paper presents a first step towards more detailed future research.

ANTICIPATED OUTCOMES

Outcomes from this study will enable state and local agencies to develop context sensitive strategies and construction best practices, that reduce emissions on any given highway construction project. As a result, the project can help identify the key GHG contributors and outlines recommendations and strategies on how to reduce them. The goal of this research is to develop general methods that will enable state and local agencies support decision-making using actual construction site data pertinent to local highway infrastructure.

The introduced method also emphasizes the measurement and consideration of the influence of site specific influences - a critical component of construction greenhouse gas emissions. Contractors and state agencies can use this method to monitor emissions for projects while they are being constructed. This will enable and support policies that will incentivize contractors to innovate their processes to reduce emissions. In addition, it will help agencies compare the performance of different construction operations in the long run to draw statistically significant conclusions if any, regarding factors that increase or reduce construction emissions.

The framework will support decision-making in the industry and provide researchers a significant information base, which can be mined to promote continuous improvement in metrics and standards to identify best practices. This research will support strategies that reduce long-term environmental impacts and greenhouse gas emissions, advancing the overall sustainability of transportation infrastructure.

ACKNOWLEDGEMENTS

Portions of this research are based upon work supported by the Michigan Department of Transportation under Contract No.#080741 and the National Science Foundation under Grant No. SES-0624118. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of supporting agencies.
REFERENCE


