5th International/11th Construction Specialty Conference
5e International/11e Conférence spécialisée sur la construction

Vancouver, British Columbia
June 8 to June 10, 2015 / *8 juin au 10 juin 2015*

COMPARISON OF CONSTRUCTION EQUIPMENT EMISSIONS FOR SEVEN CONSTRUCTION PROJECTS

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Abstract: This paper reports on the results of field studies of seven transportation infrastructure projects. The results of two road projects are compared to four street and utility projects and to a commercial building project. The study results show that road construction emits a much higher quantity of emissions than building construction; that the emissions calculated with published data are higher than those from field data; and that backhoes, motor graders, and bulldozers produce the highest total emissions. This paper adds to our understanding of emissions estimates from multiple project types and data sources.

1 INTRODUCTION

Typically, an infrastructure project is studied from different perspectives during planning and design phases to assess the impact the project will have on the community, the existing infrastructure system, and the environment. Such analysis is particularly intense during the development of highly visible transportation projects, especially highway projects. The impacts of these types of projects are visible and obvious to the general public.

Air pollution emissions are one of the effects that are of special interest because of the dangers they pose to health. The impact of future emissions from passenger cars, heavy-duty trucks, and other vehicles that use transportation infrastructure is an important area of study during the early phases of a project. However, such study does not typically include construction equipment emissions assessments, leaving a full understanding of the emissions produced during the infrastructure development processes as a void in the body of knowledge.

This paper addresses that knowledge void. Seven actual construction projects located in central North Carolina were studied in numerous ways to assess their emissions generation. This paper compares those projects, reports some of the key findings of these studies, and makes observations about their significance.

The research question addressed in this particular paper is, “to what extent, if any, do different project types vary in their emissions during construction?” To answer this question we compared emissions forecasts from two road projects, to four street and utility construction projects, and to a building construction project.

Results from the different types of projects can be used to understand how the emissions profiles change, not only between projects but also between different activities and schedules, over time. These comparisons begin to reveal general emissions patterns and rates. This enables us to calculate emissions factors per dollar or per productivity unit and these factors can then be used to forecast emissions for numerous other projects during their early planning stages, thus improving design alternative selection. At this point the research question "are there metrics by which emissions forecasts can be compared across various project sizes and types?" is addressed.

1.1 Scope

This paper focuses on forecasting emissions from the exhaust system of nonroad construction equipment during the construction process. The six pollutants studied are hydrocarbons (HC), nitrogen oxide (NO_x), carbon monoxide (CO), particulate matter (PM), sulfur dioxide (SO_2), and carbon dioxide (CO_2). Emissions from other parts of the equipment such as the braking system are not included. This paper also does not include other air pollution produced during the construction project such as fugitive dust.

The equipment used for the calculations in this paper was categorized using the tier system derived from the US Environmental Protection Agency (EPA) regulations. Engine tier is a categorization of equipment by age and by regulated emissions quantities for that age. Engines can be identified by the emissions levels that were in place for that model year with each subsequent tier being more restrictive with respect to allowable emissions quantities [EPA 2010].

2 LITERATURE REVIEW

One interesting recent study focused on greenhouse gas (GHG) emissions during the construction of transportation projects in Korea [Kim et al. 2012]. The paper focused on CO_2, methane, and nitrous oxide emissions presented as CO_2 equivalent. The paper presented an estimation of GHG emissions for two highway projects. The key finding was that earthwork activities consumed more fuel than any other activity and that dump trucks (on-road equipment) are the highest emitters of pollutants. Using these results, the authors calculated emissions during earthwork activities. The optimal equipment fleet for each activity was determined using typical equipment combinations. The activities and emissions quantities were determined using the design documents for each project. Thus, the estimates produced by the authors are based on published data.

Cui and Zhu [2011] surveyed the use of green contracting strategies by state DOTs. The survey was completed by 39 states of which 25 reported using some type of green strategy. The findings indicated that New York, California, Washington, Oregon, and Illinois have green strategy programs that are enforced either by the state government or by DOT. This paper also mentioned that EPA recommends the use of the Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects (PaLATE) to calculate the economic and environmental effects of an existing, proposed, or hypothetical highway construction projects. The output of the tool includes the energy use and emissions produced during the construction and maintenance phases of a project, including material transportation. However, PaLATE is currently only applicable to roadway construction, it only operates at the project level, and it does not assess the impact of individual construction project activities, which is a critical element addressed herein.

A paper by Avetisyan et al. [2012] presented a decision model to select construction equipment for transportation projects. The authors assert that the model can be used for any type, location, and conditions of construction projects. The inputs for the model are derived from information provided by the contractor and included the amount of work and time available for each activity, details about equipment capacity and compatibility, operational and maintenance cost, engine tier specifications, and emissions rates. The model can be used to optimize equipment selection by cost and emissions production. The result of the model is a list of equipment that should be used for the project and the tier for each item of equipment. However, it is not clear from the paper which factors were used to determine the equipment fleet and which equipment characteristics were studied. Only one case study was used to test the model. Finally, there is no way to benchmark their model.

In summary, research has been conducted in auto emissions, other on road vehicle emissions, life cycle emissions, standards development, emissions regulations, sustainability, and green infrastructure. However, other than previous work examining four street and utility projects [Arocho et al. 2014] and the project by Kim et al. (2012) (that looked at GHG emissions during the earthwork activities of highway construction projects) little has been done in measuring and benchmarking emissions from nonroad construction equipment performing actual highway construction work. This paper makes a contribution toward filling a part of that void. Furthermore, it is worth noting that life cycle analyses estimate the quantity of emissions produced during the construction process. The work described herein provides quantification for the construction process to fill that void (replace the estimate) in existing life cycle models.

3 PROJECT DESCRIPTIONS

This section presents brief descriptions of the two highway, the four street and utility, and the building projects analyzed herein. Table 1 shows the basic characteristics of these seven projects. The first four projects are the street and utility projects. Apex and Wake Forest are the two road construction projects. The Building project was a 13,400 square foot commercial building that included parking and site work.

Table 1. Project Characteristics

Project	Total Cost	Year Built	Construction Duration (days)	Length (ft)	Description
Little Street Roadway	$179,000	2011	65	600	Street and utility improvement
W. Burkhead Street	$103,860	2012	9	500	Street and utility improvement
Sutton Place Phase 1	$219,540	2009	49	930	New development
Sutton Place Phase 2	$622,660	2009	101	2,813	New development
Apex	$862,881	2012	124	2,600	Relocation
Wake Forest	$203,000	2013	13	1,300	Widening
Building	$1,454,720	2009	125	NA	Commercial Building

Table 2 shows the construction activities associated with the transportation projects. The building project was not added to Table 2 because the activities needed for it (e.g., earth movement and excavation for the utility connection and foundation, and grading and paving needed for the landscaping and parking area) do not correspond well with the activities for the transportation projects.

4 RESULTS

In this section the paper compares the emissions from the three distinct project types (road, street and utility, and building) for all of the seven projects.

4.1 Project Type Comparison with Tier 3 Equipment

This section shows the emissions results using Tier 3 as the reference for all equipment used. In Table 3 the average daily emissions for the four street and utility projects are lower than the average daily emissions for the building project. The emissions for the two road projects (calculated using the field data) are almost double the emissions for the street and utility and building projects for all the pollutants. The emissions estimates for the road projects using published data (RS Means) are even higher than those using field data (with the exception of PM).

Table 2. Project Construction Activities

Construction Activities	Projects					
	Little Street	West Burkhead	Sutton Place Phase 1	Sutton Place Phase 2	Apex	Wake Forest
Mobilization	X	X	X	X	X	X
Staking and layout	X	X	X	X	X	
Clearing and grubbing			X	X		
Demolition and removal of existing asphalt	X	X				
Erosion control measures			X	X	X	
Earthwork and grading			X	X	X	X
Demolition: sewer, storm, and water systems	X					
Initial grading and excavation		X				
Installation of new sanitary sewer system	X	X	X	X		
Abandon existing sewer		X				
Installation of water distribution system	X		X	X		
Installation of storm sewer	X		X	X	X	X
Remove and replace curb on adjacent streets		X				
Curb installation					X	X
Prepare subgrade	X	X	X	X	X	X
Paving	X	X	X	X	X	X
Traffic signals					X	
Final clean up, punch list, and demobilization	X	X	X	X	X	

Table 3. Average Grams per Day for Tier 3 Equipment

Project Type	Pollutants					
	HC	CO	NOx	PM	CO_2	SO_2
Building	538	4,610	4,720	428	6.03E+05	130
Average Street with Utilities (4 Projects)	467	3,820	4,290	13.2	4.51E+06	792
Average Field Roads (2 Projects)	1,010	7,270	7,780	708	7.81E+06	1,400
Average RS Means Roads (2 Projects)	1,660	10,700	9,260	42.5	8.29E+06	1,460

Table 4. Grams per Square Foot of Pavement for Street and Road Projects for Tier 3 Equipment

Project Types	Pollutants					
	HC	CO	NOx	PM	CO_2	SO_2
Average Street with Utilities (4 Projects) (Field and RS Means combination)	0.73	6.06	6.55	0.02	6760	1.19
Average Field Roads (2 Projects)	1.51	10.7	11.5	1.39	11,400	2.03
Average RS Means Roads (2 Projects)	1.75	11.5	10.6	0.05	9,570	1.68

4.2 Comparison Between Field and RS Means Results

To better understand the differences between field and published data the total emissions calculated using field data were compared to those calculated using RS Means data for the Apex and Wake Forest projects. We found that the difference in the equipment fleet between the two data sources is the largest contributor to the total emissions difference shown in Tables 3 and 4. To illustrate this finding Table 5 shows the field and RS Means fleets for the Apex project and clearly shows the difference in equipment used.

Table 5. Comparison of Equipment Fleet for the Apex Project

Field				RS Means	
Equipment Type	**HP**	**Equipment Type**	**HP**	**Equipment Type**	**HP**
Air Compressor	117	Front End Loader	200	Aggregate Spreader	203
Asphalt Distributor	5.5	Grader 1	135	Paver	130
Backhoe	100	Grader 2	135	Backhoe	48
Brush Chipper	85	Loader	128	Brush Chipper	130
Bulldozer 1	130	Milling Machine	140	Concrete Pump	77
Bulldozer 2	121	Mini Excavator	39.4	Concrete Saw	44
Bulldozer 3	140	Mixer	25	Crawler Crane	173
Bulldozer 4	90	Mulch Blower	33.5	Crawler Loader	189
Bulldozer 5	90	Paver	174	Curb Machine	99
Bulldozer 6	121	Pneumatic Roller	80	Dozer	200
Bulldozer 7	90	Roller 1	145	FE Loader Wheel 1	96
Compact Track Loader	84	Roller 2	99	FE Loader Wheel 2	196
Curb Machine	130	Roller 3	33	Grader	158
Excavator 1	100	Roller 4	99	Hydraulic Crane	315
Excavator 10	232	Rubber Tire Loader	196	Mulcher	275
Excavator 2	140	Scraper 1	175	Pavement Profiler	750
Excavator 3	140	Scraper 2	265	Pneumatic Roller	100
Excavator 4	140	Skid Steer 1	56	Crane 1	100
Excavator 5	140	Skid Steer 2	46	Crane 2	85
Excavator 6	169	Straw Blower	125	Tandem Roller	129
Excavator 7	100	Tandem Roller	100	Trencher	12
Excavator 8	386	Trench Roller	18		
Excavator 9	140	Trencher	120		

The emissions per activity were also calculated using both data sources for both projects. Tables 6 and 7 show total emissions per activity for the Apex project for field data and RS Means, respectively. The activities with the largest contribution to emissions were consistent for field and RS Means data with earthmoving and paving activities on the top of the list for both. These activities are performed by simultaneously using many different items of equipment that results in a large quantity of emissions.

Table 6. Field Emissions per Activity for the Apex Project

Activity	Pollutants (Thousands of Grams)					
	HC	**CO**	**NOx**	**PM**	**CO_2**	**SO_2**
Mobilization	0.38	3.68	4.96	0.67	5,700	1.00
Clearing and Grubbing	36.7	236	250	39.8	220,000	38.6
Erosion Control	4.91	34.9	52.5	6.08	48,100	8.45
Grading	55.2	395	424	68.4	414,000	72.7
Storm Drain	17.0	106	101	17.1	984,00	17.3
Concrete Work	3.07	19.7	14.3	2.95	11,600	2.03
Guardrail and Fence	4.23	20.7	6.90	2.91	4,990	0.88
Markings and Signs	0.92	3.60	11.0	0.89	8,110	1.42
ABC and Paving	28.1	197	228	33.6	222,000	38.9
Traffic Signals	2.37	22.2	19	3.47	15,700	2.75
Utilities	4.88	24.1	14	3.64	10,800	2.25

Table 7. RS Means Emissions per Activity for the Apex Project

Activity	Pollutants (Thousands of Grams)					
	HC	CO	NOx	PM	CO_2	SO_2
Mobilization	0	0	0	0	0	0
Clearing and Grubbing	48	294	197	1	147,000	26
Erosion Control	50	333	280	1	265,000	47
Grading	13	100	116	0	120,000	21
Storm Drain	8	32	121	0	110,000	19
Concrete Work	0	2	3	0	3,020	1
Guardrail and Fence	4	31	34	0	34,400	6
Markings and Signs	0	0	0	0	0	0
ABC and Paving	21	197	242	1	237,000	42
Traffic Signals	0	2	3	0	2,630	0
Utilities	2	8	24	0	22,100	4

Another metric used to compare the two different data sources is emissions per day. Figure 1 shows CO_2 emissions by day for both field and RS Means for the Apex Project. The RS Means calculation resulted in shorter project durations than the actual duration but matched up well in emissions quantities per day. The emissions per day metric for the field data was 8.55×10^6 grams of CO_2 while the RS Means data resulted in 8.82×10^6 grams of CO_2. The results for the other pollutants are also comparable between the two data sources. Figure 1 show that the project schedule for the field data was 124 days while the schedule for the RS Means data was 77 days. The difference in duration between the two is due to the difference in equipment fleet. The difference in productivity of the different equipment resulted in different activity durations even when the same quantity of work was used for both.

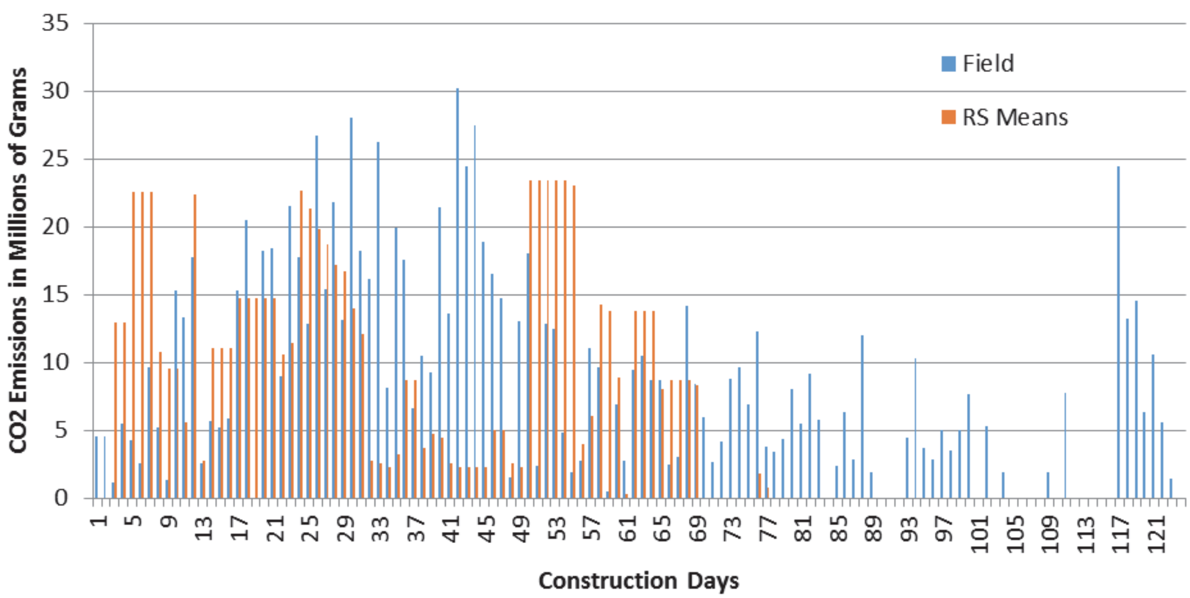

Figure 1. Apex CO_2 Emissions for Field and RS Means

5 CONCLUSIONS

Our seven projects clearly indicate that RS Means data often produces a different emissions estimate than the results obtained using field data. Where these differences exist they are largely due to the differences in fleet composition recommended by RS Means versus the fleet composition a contractor might actually use. However, on an emissions per day basis, published and field data matched well thus verifying the utility of this emissions metric. Finally, we also found that earthmoving and paving activities are by far the largest polluting activities.

The projects compared in this paper have differences not only in type but also in size and complexity. The Wake Forest project was a simple and small road widening project that lasted 13 days. The Apex project included the relocation of a road and an intersection and lasted 124 days. The street and utility projects included the installation of water distribution, sewer, and storm water systems, while the building project was a medium-sized commercial structure. These projects are typical of different construction projects types, although we readily acknowledge that they are not fully representative of all construction project sizes and types. Still, they do provide insight.

Our first research goals was to determine the extent to which project type affects the total quantity of emissions produced. The comparison presented on this paper shows that it is possible to calculate emissions metrics to compare different types of projects.

Another research goal was to determine how different project types vary in their emissions during construction. The results showed that the Apex and Wake Forest projects had similar emissions profiles with large amounts of emissions produced during earth movement and paving activities. This emissions pattern was similar to the one presented by the street and utility projects. Furthermore, the road and street projects produced pollutant emissions throughout the entire duration of the project. In contrast, the building project produced the majority of its emissions at the beginning of the project with almost all the emissions produced during the first two thirds of the project and two thirds of the emissions were produced before the project was even half completed.

More work is needed to increase the number of projects for which forecasts have been produced. However, this very small sample shows that it is possible to identify patterns of emissions production for different types of projects, thus enabling us to begin to develop an inventory and a hierarchy of project type emissions production, thereby alerting designers, in early project stages, of potentially dangerous emissions situations that are a function of project type.

The third research goal addressed whether or not emissions metrics could be used to compare different project types. One such metric was emissions per day. The results showed that all highway projects had higher emissions than the building. However, emissions per day may not be a good method to compare different projects because this metric can vary depending on schedule changes that do not affect total emissions. A better metric for comparison is emissions per unit, but the building project did not have a production unit comparable to the road and street projects. When the street and utility and the road projects are compared using emissions per square foot the results showed that road construction produced more emissions than street and utility projects.

Calculations presented herein included total emissions, emissions per activity, and emissions per equipment type. Activities with a larger contribution to total emissions include earth movement and paving. The activities with the largest contribution for the Apex project were clearing and grubbing, grading, and aggregate base course (ABC) and paving. Gravel subgrade and backfill were the activities with the largest emissions for the Wake Forest project. The emissions for these activities were the highest for both the field and RS Means estimation methods and are all similar in nature.

The equipment types with the largest contribution to total emissions were motor graders, backhoes, front-end loaders, and bulldozers. The large contribution of some of these types of equipment is linked to their high emissions factors. For other equipment types, such as bulldozers, their large quantity of emissions is due to the long hours of use of the equipment for a variety of different activities.

This study shows that it is possible to use published data to obtain a forecast of total emissions at the early stages of the project, making it possible to have emissions forecasts earlier in the project process. An early forecast can be used during the planning process to compare alternatives or to estimate the environmental impact of a potential project. As with any forecast, the accuracy of the numbers can be improved when additional information is available.

Contractors can use a forecasting model during the construction process to assess their emissions production. The actual equipment type and hours of use can be used as inputs rather than the planned (and potentially highly variable) schedule. The forecast could be used to monitor their equipment use and productivity in addition to monitoring emissions produced. Improving productivity could reduce hours of operation for each item of equipment and could result on lower total emissions for the project.

The data collected during construction could be used to calculate a final total emissions quantity for the entire project. This total could be viewed as an equivalent to an "as-built" emissions total that owners can use to evaluate total effect or future activities to offset this effect. Researchers could use the equipment use and total emissions information to improve emissions metrics for different equipment types.

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