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Implementation of Sustainability Concept in Capstone Projects

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Abstract

Capstone or senior design is a mandatory course during the senior year of any undergraduate engineering discipline. The students apply their cumulative knowledge gathered over the other technical courses taken during the study. While the capstone projects are designed to check the students' overall scientific understanding of the subject matter, often the sustainability component of the project is overlooked. Every day, large scale projects are being implemented to construct and repair US infrastructures where the environment friendly and long-lasting materials inclusion is increasing. In addition, civil engineers can contribute to cut down carbon emission using new and sustainable methods of construction. The American Society of Civil Engineers (ASCE) has also put emphasis on the sustainable future without degrading the quality and availability of natural resources. To keep it mind, the sustainability component was included in the Capstone Project during Spring 2021 and Spring 2022 semester. The purpose of the current study is to document the sustainability element of the capstone project. In the Spring 2021 semester, students determined the carbon footprint of an exit ramp built on a major highway. The team calculated the amount of carbon-dioxide (CO_2) generated from the construction and the savings from cutting down the commute time related emission. In the end, the number of years were reported to reach the breakeven point. In the Spring 2022, the capstone team determined the feasibility of different alternative materials i.e. recycled asphalt pavement for road construction and compared the Green House Gas (GHG) emissions from various alternatives. It was found that, the usage of recycled materials would considerably lower the GHG emissions compared to concrete road construction. Outcome of this study will assist the instructors to design their capstone class including the sustainability section.

Introduction

Civil engineers have a unique responsibility to the society and the nation. They have the responsibility to advance the infrastructure needs of the society in such a way that not only meet the current demand but also the future needs in a social and environmentally responsible way. They must design and practice in the field in a compatible manner which echoes the practice of sustainable development. Civil engineers play a key role in designing and building the infrastructure that meet the needs of the public and society. In the recent years the idea of sustainability and resilient infrastructure is more prevalent than any other point in time. The practice of sustainability is everywhere now from renewable energy to curbside recycling programs. The demand for products infrastructure and amenities are expected to grow in the coming decades so that we need to be aware to make sure that the development has minimal environmental impact. Moreover, the development should not jeopardize public health and safety.

Future civil engineers must be able to create engineering solutions that not only satisfy technical and economic requirements but also consider the environmental and sustainable dimension of design. The focus of civil engineering construction and management has put emphasis on the infrastructure development based on economic consideration in the last five decades. However, the construction boom missed the environmental and social art aspect which are equally important for the stakeholder of this projects [1]. While the concept of sustainability is slowly infusing into the civil engineering projects, the students are not receiving any formal education in the undergraduate curriculum on it. As the frequency and extent intensity of the natural disasters are on the rise, it is very important to train the next generation engineers on the sustainability concept from the classroom level. For sustainability to be addressed by civil engineering professionals, students must be educated and trained to consider the concept of sustainability to accommodate it in any construction project.

Capstone/Senior design class intends to accumulate the experience of the students gained from courses in the curriculum. Students are responsible for selecting a real-life project, planning and milestone identification, implementation of the work, written project specification, oral presentation, and a final written report. The capstone project is so comprehensive in nature that it provides the faculty to assess a wide range of student learning that is directly related to student outcomes of the ABET requirement. In addition, the students also work as a team to accomplish the goal of the class. In order to attain the program educational objectives (PEO), five Student Outcomes (SO) are set. Capstone Design class hosts the student outcome criterion 5 which demonstrates the students' ability to work in a team. Three performance indicators (communication, fulfilling responsibilities, listening) are used to judge the outcome of the class.

Incorporating sustainability into civil engineering curriculum poses a challenge to overcome the already constrained curriculum of 120 to 128 credits in most schools. Two basic strategies have been found in the literature from the faculties attempting to incorporate sustainability [2]. The first approach is the stand-alone method where a separate three credit course is offered to educate the students on sustainability while the other is module method. In the latter method, modules are designed to fit into one lecture or over a series of lectures sometimes via guest appearances. Dancz et al. (2017) reported in their study that students incorporated sustainability in senior design only if it is an expectation from the instructor [2]. The authors reported raising the bar of sustainability by engaging a sustainability expert could be a viable option for the instructor to adopt sustainability in their class. Scott et al. (2013) adopted sustainability component in senior design by a real-world project [3]. The authors concluded that sustainability impacted students critical thinking and increased knowledge, but it also yielded a high workload for the students and faculty. In order to increase the student's awareness on sustainability, Brunell (2019) incorporated United Nations Sustainable Development Goals along with the ASCE Envision Rating System in the capstone design class [4]. The study summarized 13 design projects focused on the design of infrastructure, pedestrian bridge, flood control project, multistory building, and hydropower dam. The author concluded that encouraging students to experience design activities focused on sustainability better prepares them for the global challenges the students will face in their course of career.

Valdes-Vasquez and Klotz (2011) presented four teaching approaches for increasing student awareness in social sustainability dimension [5]. The author discussed about the community involvement, corporate social responsibility, safety through design, and social design in their teaching approaches. However, the discussion of the approaches was limited to theoretical boundary. The authors did not present any implication of this approaches in the paper. As such the current study was aimed to implement a sustainability component in the undergraduate level class. The student adopted sustainability component in their senior project for consecutive 2 spring semesters. In one class, the students calculated the carbon footprint for a highway project. In another class, they students perform the life cycle analysis (LCA) for another construction project. The paper describes in detail the sustainability component of the design. This study will assist other engineering and engineering technology educators to include sustainability design component in their corresponding courses.

Background

While sustainability was arguably a niche concern prior to the 1990s, it is a topic of everyday conversation today. Acting in a sustainable manner is a challenging task for civil engineers. Engineers do not have the luxury to choose between sustainable design and ignoring the principle of sustainability. This claim is based on the first canon of the American Society of Civil Engineers (ASCE) code of ethics where it is stated that engineers should consider the safety and welfare of the public as their first priority. The code of ethics hosts 7 fundamental canons that a civil engineer should always follow. The first of the seven cannons describe the concept of sustainable development.

Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties." [6]

The recent infrastructure bill passed by the government includes a lot of new civil engineering infrastructure construction and repair. The Infrastructure Investment and Jobs Act (IIJA) includes $1.2 trillion USD funding for bolstering the resilience of infrastructure in the US, but funding just lays the groundwork [7]. The success of these efforts is dependent upon the civil engineers and contractors who will do the work. The findings on sustainability appear to uphold the promise of improving the resilience of US infrastructure in the IIJA. However, most of the engineers and contractors are struggling to adopt the strategy to reduce the impact of flooding, hardening of infrastructure to avoid vulnerability to attacks, and design assets to function effectively during/after a disaster. As such, increasing the sustainability component is a key priority for civil contractors and engineers.

Carbon Emission Estimation from a Highway Construction Project

In the Spring 2021 semester, the students estimated the carbon emission from a massive highway project in the New York State. The construction of $50 million dollar 'Albay Airport Exit 3' was a key project within the past decade for the New York State Department of Transportation (NYSDOT) and created a direct exit off the thruway interstate 87 to Albany International Airport. The construction of this exit was done to help alleviate the drastically bad level of service (LOS) and traffic delay within the roadways surrounding Albany International Airport. The carbon case study on this project was conducted to perform future implications and potential future study which may become a normal practice on all transportation construction project in the future.

The goals of the carbon case study for the construction of Exit 3 off I-87 were to:

- find the carbon emissions due to construction activities
- find the carbon emissions saved due to reduced travel distance/time
- find the time where the carbon emissions from construction equal that of the carbon emissions saved (break-even analysis)

Assumptions

To achieve the goals of a giant project like it, assumptions had to be made. The assumptions for this carbon study were as follows:

- The CO_2 emissions from the delivery and production of construction materials are that of the national average
- The delivery distance for these materials from the production plant to the worksite is 30 miles round trip
- The use of miscellaneous construction vehicles during the duration of the project amounts to 100 tons of CO_2 emissions

The reasoning for these assumptions is that it makes the case study stronger and much easier to understand. Although there may be some deviation from these assumptions that could have occurred during the construction process, following the national average, assumed delivery distance, and the assumption of miscellaneous construction vehicles emissions is common in studies of this nature.

National Average Emissions

The national average of emissions for construction material production is found within a study done by the National Ready Mixed Concrete Association. This was conducted in efforts to lower the national average. Using the drawings from the construction of Exit 3 off I-87 the amount of materials used for this project are; concrete: 621.37 cubic yards, asphalt: 2500 tons. The national average for production and delivery of materials are as follows [8]:

- Concrete: 3,785 lbs of CO_2 per 1 cubic yard produced
- Asphalt: 1 lbs of CO_2 per 1 ton produced
- Delivery of Materials: .35 lbs of CO_2 per mile of delivery

Carbon Emissions from Construction

Using the findings for the material usage and the national average CO_2 emissions, the carbon emissions from construction was calculated. The total usage of concrete within this project was found to be 621.37 cubic yards. The national average of emissions from plant production of concrete was found to be 3,785 lbs of CO_2 per cubic yard produced. Using these values, the calculation of CO_2 emissions for concrete and asphalt for the construction of this project is shown below.

<u>Plant Production (Concrete)</u>
621.37 cubic yard * 3,785 lbs of CO_2 per cubic yard = 1176 tons of CO_2

<u>Delivery of Concrete</u>
The average concrete delivery truck holds 10 cubic yards of concrete, using this the total trips to deliver the concrete to this site can be found to be 62.
62 trips * .35 lbs of CO_2 per mile * 30 miles = .4 tons of CO_2
Concrete Total: 1176.4 tons of CO_2

The total usage of asphalt within this project was found to be 2500 tons. The national average of emissions from plant production of concrete was found to be 1lbs of CO_2 per ton produced. Using these findings, the calculation of CO_2 emissions for asphalt for the construction of this project is shown below.

Plant production (Asphalt)
2500 tons of asphalt * 1 lb of CO_2 per ton produced = 2.5 tons of CO_2

Delivery of Asphalt
The average amount of asphalt a truck can bring to the site is 20 tons. Using this the amount of truck trips to delivery this asphalt was found to be 125 trips.
125 trips * .35 lbs of CO_2 per mile * 30 miles = .65 tons of CO_2
Asphalt Total: 3.2 tons of CO_2

Total CO_2 Emissions
Using the data found for the concrete and asphalt CO_2 emissions, as well as the assumptions of miscellaneous construction vehicles, the total carbon emissions from the construction of Exit 3 off I-87 can be found [Concrete emissions (1176.4 tons of CO_2) + Asphalt emissions (3.2 tons of CO_2) + Assumption of Misc. vehicles (100 tons)]. As such, total Emissions from construction of Exit 3 project is equal to 1280 tons of CO_2. It can be seen that more than 90% of the emissions are contributed from concrete (Figure 1). As such, alternative of concrete materials could be a potential to reduce carbon emissions. In the next case study discussed later in the paper, the authors used alternative materials to compare the carbon emissions with concrete.

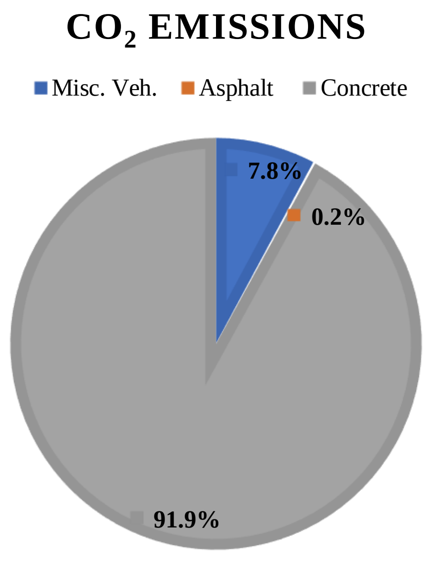


Figure 1: Carbon-dioxide emissions from construction of I-87 project

Breakeven Analysis

Breakeven analysis was done to determine the time it will take for the carbon emissions due to the construction of Exit 3 to be alleviated due to the reduced travel time and distance.

Travel distance saved from construction: The travel distance that is saved due to the construction of Exit 3 for people attempting to go to Albany International Airport from I-87 is 2 miles.

Average CO_2 Emissions from passenger cars: The average emission of CO_2 from passenger cars is 1 lb per mile of travel.

Visitors to Albany Int. Airport: The average amount of cars traveling to Albany International Airport from I-87 that will utilize this new exit is 200,000 cars per year.

CO_2 mitigated per year: Using the average amount of cars that will be using this new exit, as well as the average CO_2 emissions of those cars per mile, and the travel distance saved the amount of CO_2 per year that will be mitigated due to the construction of this exit can be found.
200,000 cars per year * 1 lb of CO_2 per mile * 2 miles saved = 200 tons of CO_2 per year

Breakeven timeline: Using the amount of CO_2 mitigated per year from the construction of this Exit, the finding for the time needed to equal the CO_2 emitted due the construction can be found. 1280 tons of CO_2 from construction / 200 tons of CO_2 mitigated per year = 6.4 or 7 years (Figure 2).

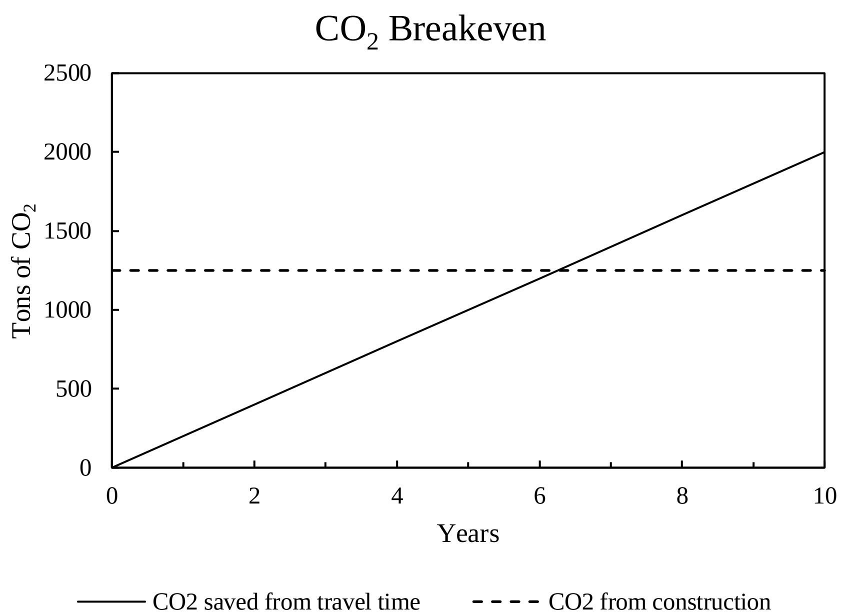


Figure 2: Breakeven timeline from the highway project

Findings from the Spring 2021 study

Within this case study, it was found that concrete was the major contributors of the pollutant gas in comparison with asphalt and other sources. The usage of concrete was emitting 1176 tons of CO_2. As the road was saving some distances for the commuter for the new construction, there was some savings of CO_2 in terms of travel time. It was calculated that the breakeven time for this project would be almost 7 years to offset the CO_2 from construction. These findings shed light on focusing on alternative materials with the least emission. In addition, the usage of electric vehicles (EV) could also reduce the environmental impact as it has zero emission issue. Before conducting this kind of giant project, environmental impact assessment (EIA) should be conducted to find out the best construction practice.

Life Cycle Analysis (LCA) of State Route 12

A growing number of agencies companies and organization along with the governing bodies are including the principle of sustainability in their activities. Sustainability considerations are not new, however increased effort are being made in the recent years to quantify sustainability and to incorporate them in their decision-making progress. The most popular instrument that is used to quantify the environmental performance of sustainability is life cycle assessment (LCA). The concept of LCA originated in the late 1960s to analyze various kinds of emissions from solid waste [9]. In the transportation sector, LCA topic has included the assessment of cement and asphalt binder production, evaluating low carbon fuel standard for the construction and maintenance vehicles, and the evaluation of interaction between transportation infrastructure and human behavior. LCA provides a holistic approach to evaluate the total environmental impact of a particular construction material such as aggregate or bitumen, by considering all the inputs and outputs over its lifecycle, from the raw material production to the end of life (EOL) of the product.

A cradle-to-cradle Life Cycle Assessment (LCA) approach was performed on State Route 12 over Mill Creek culvert repair. State Route 12 over Mill Creek is located in Oneida county within the town of Boonville, New York. Pavement thickness was evaluated using the NYSDOT Equivalent Single Axle Load (ESAL) calculator. This process provides an adequate design of the pavement layers for any road within state. Parameters required for the design are as follows:

- Construction year
- 50-year design life
- Projected construction year Annual Average Daily Traffic (AADT)
- Percent heavy trucks
- Functional classification code of the road

Maintenance strategies of the road was evaluated through the cradle-to-cradle LCA approach.

Assumptions

The assumptions of performing the LCA was that State Route 12 would undergo a typical construction and deconstruction process according to its functional classification for specified pavement layers. The typical construction and deconstruction process are described below. In both segment, equipment would be required throughout the process.

<u>Construction Process</u>

Asphalt layers (Top, Binder, Base)

- Paving
- Rolling
- Compacting Gravel

- Distribution
- Rolling
- Compacting

Deconstruction Process

- Asphalt layers (Top, Binder, Base): Milling
- Gravel: Excavation and loading

Maintenance Strategies

According to the NYSDOT ESAL calculator, the thickness of the pavement layers were calculated for a 50 year design period. Although, maintenance on roads should be considered and calculated for each layer constructed. The maintenance also depends on the material used for the construction process as per specifications. Whether the design can provide sustainable practices such as the use of recycled materials gathered through the deconstruction process, maintenance will be required in "x" amount of years for each layer. Recycled materials such as Recycled Concrete Aggregate (RCA) and Recycled Asphalt Pavement (RAP) can be used after treatment and testing. Therefore, the impact of using these alternative materials must be evaluated as well. Maintenance strategies can be evaluated for lifetimes of 20 to 80 years depending on the layer.

Carbon Emissions

It is important to always consider the amount of carbon dioxide (CO_2) released into the atmosphere as it is severely detrimental to the environment. As we continue to push for a greater future, the decrease in CO_2 emissions is significant. The construction of an average one lane, one mile road can take up to 3175 tons of carbon dioxide. It is difficult to completely design for zero CO_2 emissions, however if the amount can be lessened it is key to push for it.
Concrete pavement and asphalt pavement are widely used for road construction around the world. Therefore, it is important to calculate the amount of greenhouse gas production that each produces and design for a lower carbon footprint. According to "Asphalt Pavement Alliance", concrete pavements, consisting of cement, produce a high amount of carbon dioxide when being produced. As stated, "For every 1,000 kg of Portland cement, approximately 730 kg of carbon dioxide is produced." Data was gathered by the "Asphalt Pavement Alliance" using VicRoads project, to illustrate the amount of greenhouse gases released into the atmosphere for each pavement [10]. Table 1 below shows the emissions for this project.

Table 1: Greenhouse Gas Emissions (Initial Construction) for State Route 12

Pavement Type	**CO_2 (tons/km)**
Asphalt	347
Concrete	1497

It is also important to recognize the greenhouse gas production over a 50-year life cycle. Data was collected for three types of pavement materials: perpetual asphalt pavement, conventional asphalt, and concrete pavement (Table 2).

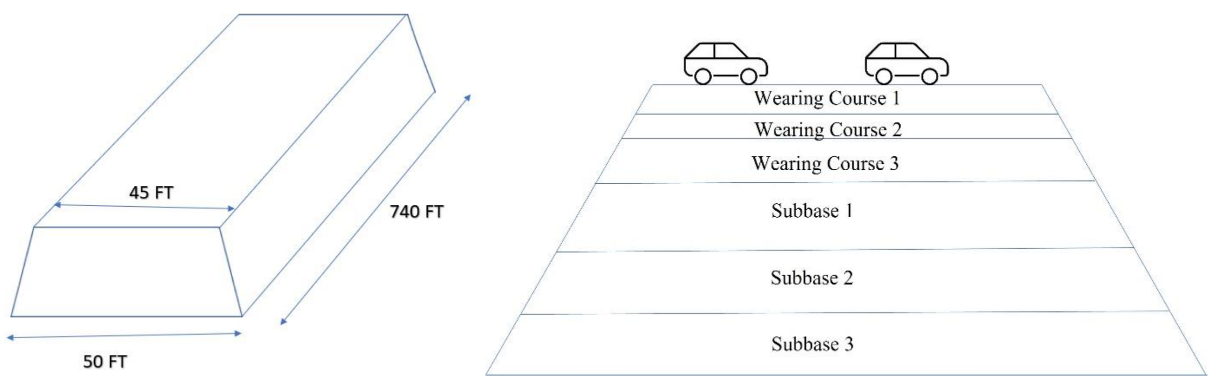
Table 2: Greenhouse Gas Production (50 Year Life Cycle)

Pavement Type	Initial Construction + Maintenance CO_2 (tons/km)
Perpetual Asphalt	463
Conventional Asphalt	500
Concrete	1410

As reinforced with accurate data retrieved by VicRoads project, it can be proven that the use of asphalt pavement for road construction can decrease the amount of greenhouse gasses released into the atmosphere. Whether engineers may wish to design for a perpetual asphalt pavement, conventional is proven to help pursue the same goal.

Excel Software for LCA

We used one excel tool named PaLATE developed by Professor Arpad Horvath from University of California (UC) Berkley for LCA calculation. We did a Life cycle analysis for three different types of pavements. The first one was asphalt pavement with no reclaimed materials in the construction (No RAP). The second option was asphalt again but with material that used 30% RAP. Then we had a third option which was only concrete layer. By using this excel file we were able to determine which of the three was the most sustainable option for our project. The excel tool was used for a straight segment of a road. With the road width information from the drawings, Figure 3 shows the dimensions and the layers of the road used for the analysis.



(a) (b)

Figure 3: (a) Dimensions of the pavement section, and (b) layers of the pavement section

The layer specification is going to be the same for the No RAP and the 30% RAP. This is because the only difference is the material that is being used for these two different pavement types. The layer thickness is obtained from the ESAL calculator from the NYSDOT website (Table 3 and Table 4).

Table 3: Layer Specifications for No RAP and 30% RAP

Layer	Width [ft]	Length [miles]	Depth [inches]	Volume [yd^3]
Wearing Course 1	45	0.14	1.5	154
Wearing Course 2	46	0.14	2.5	262
Wearing Course 3				0
Subbase 1	48	0.14	5	548
Subbase 2	50	0.14	12	1369
Subbase 3				0
Subbase 4				0
Total			**21**	**2333**

Table 4: Layer Specifications for Concrete pavement

Layer	Width [ft]	Length [miles]	Depth [inches]	Volume [yd^3]
Wearing Course 1	45	0.14	9	924
Wearing Course 2	0	0	0	0
Wearing Course 3				0
Subbase 1	48	0.14	5	548
Subbase 2	50	0.14	12	1369
Subbase 3				0
Subbase 4				0
Total			**26**	**2840**

Material Usage

The material usage is an important part of the LCA because it shows what exactly is being used and where it is coming from. Some materials are going to give off more pollution, so it is important to determine what is being used and how much material is being used for our three different options. For the analysis, the study used the nearby aggregate and other quarry from the university location. For example, the nearest aggregate stockpile was 14 miles from the campus.

<u>Aggregate and Coal Fly Ash</u>
Name: Hanson Aggregates
Distance: 14 miles

<u>Petroleum</u>
Name: Conservative Petroleum in Marcy, NY
Distance: 32 miles

Asphalt
Name: Alliance Asphalt
Distance: 30 miles

Concrete
Name: Cold Spring Construction Co.
Distance: 3.77 miles

Table 5 shows the material and their transportation distance for the material on the first wearing course with No RAP condition. The same steps were repeated for the second wearing course and subbase layers. The total amount was taken from the layer specifications and then that was broken up into each material. The asphalt was 94% virgin aggregate, 5% bitumen, and 1% coal fly ash. Similar calculation was conducted for the 30% RAP and concrete condition. The concrete mix design used was three parts stone, two parts sand, and one part water. The total volume was found on the design layers specifications that was broken up into each material. The transportation distances were found using NYSDOT Materials Supplier Viewer.

Table 5: Material and Transportation for No RAP

Material	Density [tons/(yd^3)]	New Asphalt Pavement (yd^3)	One way transport distance	Transportation Mode
Virgin Aggregate	1.25	144.7	14	Dump truck
Bitumen	0.84	7.8	32	Tanker truck
Cement	1.27	N/A		Cement truck
Concrete Additives	0.84	N/A		Tanker truck
RAP transportation	1.85	N/A		Dump truck
RCM transportation	1.88	N/A		Dump truck
Coal Fly Ash	2.2	1.5	14	Cement truck
Coal Bottom Ash	2	N/A		Dump truck
Blast Furnace Slag	1	N/A		Dump truck
Foundry Sand	1.5	N/A		Dump truck
Recycled Tires/ Crumb Rubber	1.92	N/A		Dump truck
Glass Cullet	1.93	N/A		Dump truck
Water	0.84	N/A		Dump truck
Steel Reinforcing Bars	0.24	N/A		Dump truck
Total: Asphalt mix to site	1.23	154	30	Mixing Truck
Total: Ready-mix concrete mix to site	2.03			Mixing Truck

Analysis Results

From three different pavement conditions (No RAP, 30% RAP, and Concrete), various charts were generated to show how much pollution these different pavement types would give off.

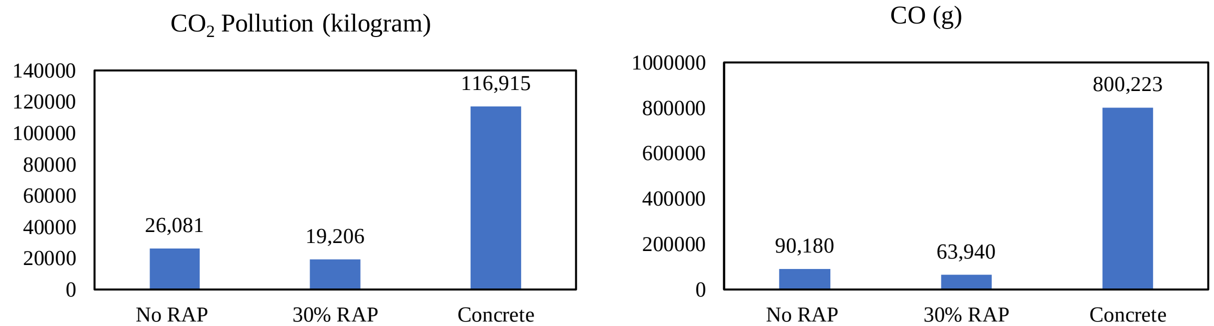


Figure 4: Carbon dioxide (CO_2) and Carbon monoxide (CO) emissions from various pavement configurations

As seen in Figure 4, the 30% RAP is giving off the least CO_2. Carbon dioxide is a pollution that is bad for the environment and should be limited. It is shown here that the 30% RAP pavement type has the least amount. Carbon Monoxide (CO) is like Carbon dioxide because it is another type of pollution, and same results that showed that 30% RAP gives off the least amount of Carbon Monoxide. It is consistent with the carbon emissions found in the Spring 2021 study where concrete was emitting the highest amount of carbon. In addition to the carbon, a quick look on other pollutants such as NO_x pollution (Nitric Oxide and Nitrogen Dioxide) and particulate matter (PM_{10}) also revealed that concrete pavements are emitting the highest amount of pollutant (Figure 5). NO_x pollution has negative effects on the tropospheric ozone layer and contributes to the formation of smog and acid rain. PM_{10} stands for particulate matter which is just a type of air pollution.

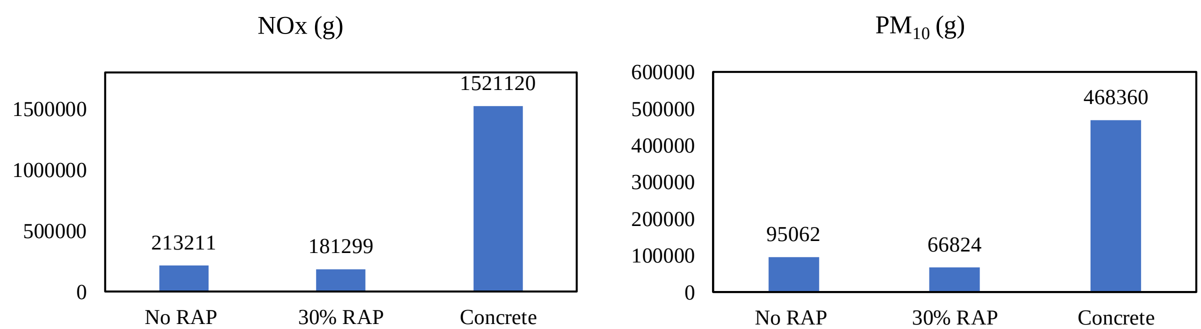


Figure 5: NO_x and Particulate matter (PM_{10}) emissions from various pavement configurations

Findings from the Spring 2022 study

State Route 12 over Mill Creek should be designed using asphalt pavement with a 30% RAP because that is what gives off the least amount of pollution. This makes the 30% RAP option the best sustainable option because it is the best for the environment. Sustainability is one of the most important parts to any construction project and needs to be accounted for. As the natural sources of virgin aggregate are depleting, it is customary to use the alternative sources of this raw material. Recycled aggregate such as RAP is the mostly available alternative pavement material in comparison with the virgin aggregates. However, the highway agencies should be careful on using the percentage of recycle the materials. As the strength and stiffness of the recycled materials are not as the same of the virgin aggregates, experiments should be conducted before the uses of the actual percentage of recycled materials.

Impact on the Capstone Course at the Institution

After successfully piloting the sustainability component in two semesters, the faculty members of the program discussed the effectiveness of the attempt. Though no formal before and after survey was conducted among the students for the sustainability piece, the instructor had a positive vibe on adding the component permanently based on the student reviews in the course feedback survey and informal discussions during the design class. After discussing in the course improvement plan (CIP) meeting, the faculties of the program changed the course description of the capstone class adding the sustainability component and passed the modification through curriculum committee of the campus. The previous and the modified course description are presented below.

<u>Previous Capstone Course Description</u>: Provides students with the opportunity to work as part of a multi-disciplinary Civil Engineering Technology design team. The course will consist of a design project with presentations and reports. Lectures in professional practice and teaming will augment the design project.

<u>Modified Capstone Course Description</u>: Provides students with the opportunity to work as part of a multi-disciplinary Civil Engineering Technology design team. The course will consist of a design project with presentations and reports. Students will work on planning, analysis of alternatives, and design of selected projects that cross various civil engineering disciplines, and include engineering standards, sustainability, and multiple realistic constraints. Lectures in professional practice and teaming will augment the design project.

Pedagogical Discussion for Instructors

The spectrum of sustainability is quite large. Many students, faculty, corporations define sustainable design based on the fact that environmental impact has been minimized. However, minimal environmental impact does not always guarantee sustainable design. Sustainable designs should embrace the concept of the triple bottom line (People, Planet and Profit). Sustainability is defined as the region where people, planet, and profit overlap. These three *P*s are the pillars of sustainability which have environmental, economic, and social components. A sustainable solution may involve both technical and non-technical approaches.

The capstone instructors can involve the students with cost estimating, carbon calculators, and sustainable construction activities. Concrete and steel are very carbon intense processes for manufacturing and shipping. Engaging sustainability would be a great way to promote both student and faculty interest and show the benefits of green/sustainable construction. It would also be a great way to potentially get some real-world project information from the construction industry partners (which may otherwise go unused) and have students work on some comparisons and number crunching that would not otherwise be done. This is a topic that could see rapidly increasing interest in the foreseeable future. Some of the ideas for class project or capstone design could be as follows:

- What is the carbon impact of using new technologies than the conventional methods
- How much is the carbon emission reduced by using recycled materials
- How much the bio-inspired solution (i.e. vegetated slope) benefit the environment as compared to the concrete walls technique
- What are the dollar values of the various concrete foundation systems (shallow, mat, driven piles etc.)
- What carbon benefits could be re-used for another part of the project

These are some ideas for the educators to start with. The instructors can select any civil engineering discipline i.e. structural, geotechnical, transportation, environmental, construction for sustainability project.

Conclusions

Quantifying sustainability is a challenging work for engineers. Among various attempts to quantify it such as ecological footprint, energy footprint, carbon dioxide footprint, the last one is the commonly used metric by the civil engineers. Although sustainability quantification has some shortcomings such as hidden assumptions and overly simplistic methods, they offer some insight on how our daily decisions are related to sustainability.

The capstone design class is very crucial for the engineering undergraduates as they imply their design is skills in this course learned over the previous semesters. As more and more challenging construction are taking places, the graduating students should embrace the concept of sustainability to reduce the impact of construction materials on the environment. In order to quantify the carbon emission of two construction projects in New York, the students attempted to find out the negative impact of the projects by focusing on sustainability. Some of the key outcomes of the study are as follows:

- Concrete is the main contributor to carbon dioxide emissions to the environment. In addition to the production, transportation also produced harmful carbon dioxide.
- In the I-87 project, it would take almost 7 years to offset the carbon dioxide emissions.
- Electric vehicles usage could lower down the harmful GHG emissions.

- Uses of recycled asphalt pavement reduce the amount of pollutant emitted in the environment. With comparison with the concrete pavement, the rap produced 8 to 10 times lower emission for carbon dioxide, carbon monoxide, nitric oxide, and particulate matter.

Acknowledgement

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