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The Impact of Route Planning on Greenhouse Gas Emissions in Construction Transportation

M.Amiri[1], F.Sadeghpour[2] and S.Tahmasseby[3]
[1] M.Sc. Student, Department of Civil Engineering, University of Calgary; mamiri@ucalgary.ca
[2] Assistant Professor, Department of Civil Engineering, University of Calgary; farnaz@ucalgary.ca
[3]Postdoctoral Fellow, Department of Civil Engineering, University of Calgary; stahmass@ucalgary.ca

Abstract: Transportation is considered as a major contributor to the global increase of the Greenhouse Gas (GHG) emissions. In Canada, transportation sector was responsible for 24% of the total GHG emissions in 2010. In the same year, carbon dioxide (CO_2) emissions from human activities constituted 79% of the total GHG emissions. A large portion of these emissions stem from the road freight transportation. In the construction sector, 6 to 8 percent of the total GHG emissions originate from transportation of the building materials (Norman et al. 2006). Behavioural change is considered to be one of the most effective methods of reducing GHG emissions in transportation. The objective of this study is to propose a method to investigate the impact of the route choice, as a behavioural change, on the GHG emissions resulted from construction road transportation. A case study on the delivery of concrete in Ajax, Ontario is conducted to examine capability of the method. The results of this study show that a better route selection can reduce GHG emissions by traveling through less-emitting routes. Beside positive impacts on sustainability, the developed model can interest suppliers in saving costs. As the decreased level of GHG emission can be translated into less fuel consumption, and consequently less fuel costs.

1. Introduction

The developing trend of the transportation network around the world has facilitated quick access to various locations. However, this growing trend has had an adverse impact on the global warming due to vehicle fossil fuel consumption that emits pollutants into the atmosphere (Kamakate and Schipper 2009, Leonardi and Baumgartner 2004, Liitmatainen and Pollanen 2010, Morrow et al. 2010, Nealer et al. 2012, Yang et al. 2009). Of the four sections in the transportation (i.e. road, aviation, rail and maritime), road transportation contributes to over half of the emissions released in the transportation sector and plays the main role in the increasing levels of GHG emissions in this sector (EPA 2013, NIR 2012). In Canada, the distribution of the Greenhouse Gas (GHG) emissions by the economic sector in 2010 shows that the transportation sector emitted 166 Megatons (Mt) of CO2 equivalent (eq) of the total 692 Mt of CO2 eq. This involves nearly one quarter of Canada's total greenhouse gas (GHG) emissions, and consequently, places this sector first among the economic sectors in releasing harmful gases into the air (Env.Canada 2012). The important role of the road transportation in stabilizing GHG emissions, demands the sustainability enhancement in this sector (Kamakate and Schipper 2009, Leonardi and Baumgartner 2004, Liitmatainen and Pollanen 2010, Morrow et al. 2010, Nealer et al. 2012, Yang et al. 2009).

In the framework of the Copenhagen Accord, Canada has committed itself to reduce its total GHG emissions by 17 percent from 2005 levels by 2020 (Env.Canada 2010, UNFCC 2009, UNFCC 2010). However, studies show that without implementing a set of new government policies and incentives, Canada will unlikely achieve the defined goals (Hofman and Li 2009, Hughes and Scott 1997). Different vehicle types account for 18 percent of Canada's total GHG emissions and over half of the GHG emissions from transportation. Hence, in order to control emissions from transportation, it is necessary to implement strategies that address emissions from cars and light and heavy trucks (Env.Canada 2010, Nealer et al. 2012, Steenhof et al. 2006). The first regulated national GHG emission standard in Canadian history, called *“Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations”* was established for passenger automobiles and light trucks in 2010. Furthermore, in order to achieve the GHG emissions goals, another regulation for Heavy-Duty Vehicles (HDV) is currently under development to be implemented between 2014 and 2018 (Env.Canada 2010, Env.Canada 2011).

Several research has been conducted to study the impact of technological and behavioural strategies, such as modal shift scenarios, optimizing fuel efficiency and fuel consumption, travel demand management, improving load factor levels and limiting empty runs on decreasing GHG emissions from road transportation (Chapman 2007, Clark et al. 2002, EPA 2013, Hickman and Banister 2007, Leonardi and Baumgartner 2004, Piecyk and McKinnon 2010). These studies show that changes in *travel patterns and driving behaviours* are effective methods for decreasing the GHG emissions in road transportation (Chapman 2007, Kamakate and Schipper 2009, Leonardi and Baumgartner 2004, Liitmatainen and Pollanen 2010, Morrow et al. 2010, Yang et al. 2009). Moreover, it might be possible to reduce emissions from *construction* road transportation through traffic behavioural changes including route planning (Ahn and Rakha 2008, Barth et al. 2007, Chapman 2007, McKinnon 1999, Piecyk and McKinnon 2010). Route planning reduces trips with high emitting rates, which help improving the environment (Ahn and Rakha 2008, Barth et al. 2007). The objective of this study is to investigate the impact of route selection, as a behavioural change, on GHG emissions from construction transportation. Effective route selection can protect the environment by identifying routes with lower GHG emission rates when transporting construction materials between manufacturing plants and construction sites.

2. GHG Emission Measurement

In this study first step for measuring GHG emission from road transportation is to select a micro simulation environment and accordingly, identifying specific inputs required to develop an effective simulation network for desired location. Previous studies considered various factors to measure the GHG emissions emitted from transportation activities. The most commonly applied factors are distance, speed, vehicle age, road gradient, accessory load, driver behaviour, vehicle load, vehicle efficiency, ideal time, stops, acceleration and deceleration. These factors influence the vehicle Fuel Consumption Rate (FCR) which consequently impacts the GHG emissions (Ahn et al. 2002, Clark et al. 2002, Demir et al. 2011, Jensen 1995, Leonardi and Baumgartner 2004, Liitmatainen and Pollanen 2010, McKinnon and Piecyk 2009, Nazelle et al. 2010, Rakha and Ding 2003, Steenhof et al. 2006, Yang et al. 2009, Zachariadis et al. 2001). This study applies important factors including distance, speed, delay time, load and the number of stops, which also represent a rough estimation of acceleration and deceleration rate impacts (Rakha and Ding 2003). The applied method that takes the simulation outputs to estimate emitting rates is illustrated in Figure 1.

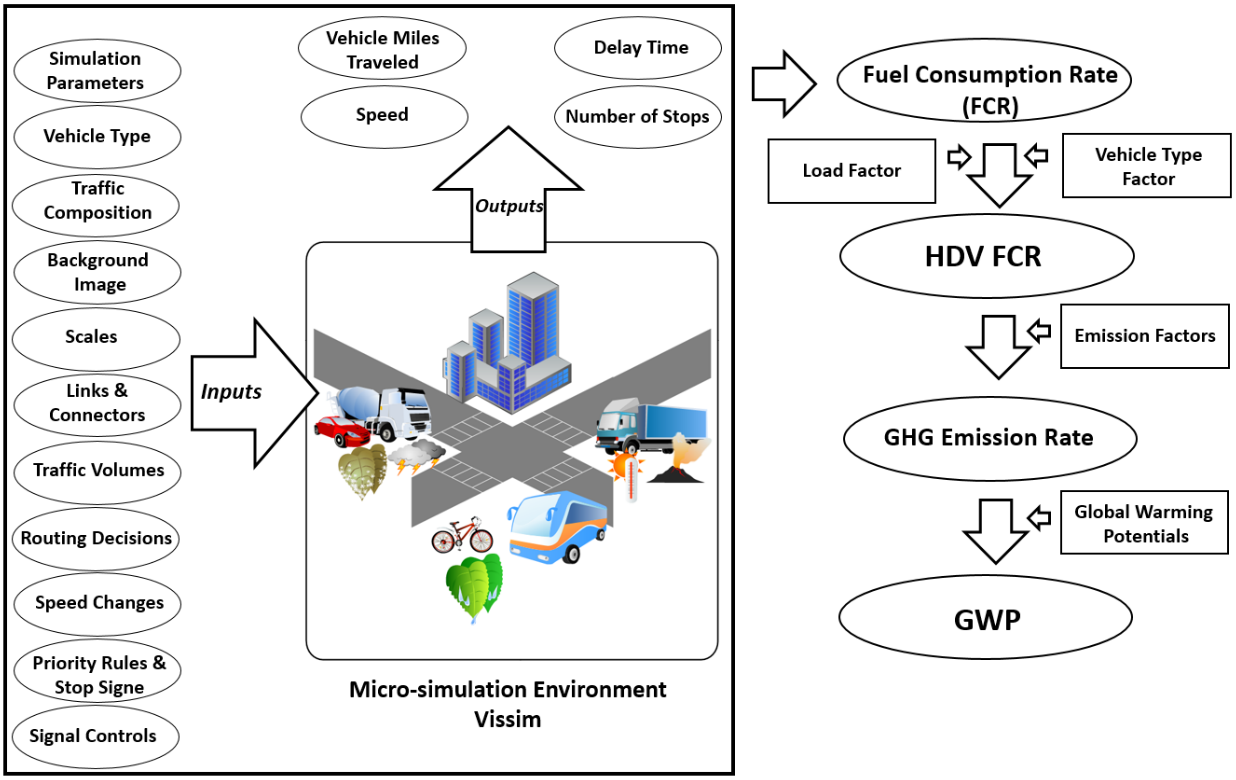


Figure1. GHG Emission Measurement Method

After completing the simulation, next step is to calculate the fuel consumption using simulation outputs including vehicle miles traveled, speed, delay time and number of stops. The fuel consumption (F) in gallons (gal) was calculated given the following equations (PTV-TS 2012, SynchroUG 2006):

[1] $F = (TT \times k_1) + (TD \times k_2) + (NS \times k_3)$

where, TT is Total vehicle Travel in miles (m), TD is Total Delay in hours (hr) and NS is Number of Stops in vehicles per hour (vph). Moreover, k_1, k_2 and k_3 are Equation 1 coefficients, which are calculated as follows:

[2] $k_1 = (7.528 \times 10^{-2}) – (1.589 \times 10^{-3} \times S) + (1.506 \times 10^{-5} \times S^2)$
[3] $k_2 = 7.329 \times 10^{-1}$
[4] $k_3 = (6.141 \times 10^{-6} \times S^2)$

where, S is the cruise Speed in mile per hour (mph).

The fuel consumption represented above (Equation 1) does not consider the load and vehicle type effect (Stevanovic 2009; Stevanovic et al. 2009; SynchroUG 2006). Load impacts the GHG emission level significantly. To consider the load effect, fuel consumption calculated by Equation 1 was multiplied by a load factor. Based on Canadian vehicle survey summary report, the fuel consumption of diesel-powered trucks is approximated 33.4 Litre per 100 km in 2009 (NRC 2012). This consumption rate rises to 62.5 L/100 km when the truck is fully loaded (Artenian 2010). Hence, the fuel consumption estimated for the loaded truck by Equation 1 was multiplied by 1.87 to account for the load impacts.

Other factor having a significant influence on Heavy Duty Vehicle's (HDV) Fuel Consumption Rate (FCR) is the vehicle type. Results from Equation 1 are applicable only for light vehicles (cars). Hence, a correction coefficient is needed to account for fuel consumption differences between cars and HDVs. Based on Canadian vehicle survey summary report, HDVs consume 3.15 times more fuel than light vehicles. This coefficient is used to compensate fuel consumption differences stem from vehicle type. Table 1 outlines the corresponding coefficient that captures the impact of the vehicle type on FCR.

Table 1: Effect of the vehicle type on FCR (NRC 2012)

Vehicle Type	Fuel Consumption Rate (Litre per 100 km)		
	Gasoline	Diesel	Conversion coefficient
Light vehicles (Cars)	10.65	10.6	1
Heavy Trucks (HDVs)	-	33.4	3.15

The GHG emission is estimated based on the HDV's fuel consumption values after adding the correction coefficients to the Equation 1 results. In order to calculate emission rates, HDVs' FCR are multiplied by GHG emission factors for CO_2, CH_4 and N_2O. Table 2 shows emission factors for heavy diesel vehicles in gram per litre of fuel consumed (g/L).

Table 2: Emission Factors for Energy Mobile Combustion Sources (Env.Canada 2011)

Source	Emission Factor (g/L)		
	CO_2	CH_4	N_2O
Heavy-duty Diesel Vehicles	2663	0.14	0.082

Next step is to determine how much heat can be trapped in atmosphere by the emitted gases. The GHGs' atmospheric lifetime and heat-trapping potential differ based on the mass of each specific gas. However, the Global Warming Potential (GWP) makes it possible to compare the heat-trapping abilities relative to mass of the CO_2 over a specific time period. Table 3 summarizes the GWP for the chosen GHGs in this study (CO_2, CH_4 and N_2O). It represents CO_2 amount with the same heat-trapping effect as the specific GHG over a hundred year time horizon, known as the carbon dioxide equivalent (CO_2 eq). Values from the latest recorded GWPs are applied in this study (see Table 3).

Table 3: Global warming potentials (GWP) - 100-Year Time Horizon (IPCC/TEAP 2005)

Greenhouse Gas	Formula	Global warming potentials
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298

Finally, the GWP in CO_2 eq is estimated using the following equation (Equation 5) and values in Table 3:

$$[5] \qquad GWP_x = (Em_{(CO2)x} \times 1) + (Em_{(CH4)x} \times 25) + (Em_{(N2O)x} \times 298)$$

where, GWP_X is Global Warming Potential for path X in CO_2 eq, $Em_{(CO2)x}$ is CO_2 emitted from traveling through path X in kg, $Em_{(CH4)x}$ refers to CH_4 emitted from traveling through path X in kg and $Em_{(N2O)x}$ represent N_2O emitted from traveling through path X in kg.

3. Micro Simulation

This study uses a traffic micro simulation tool (Vissim) to develop a simulation network as the first step of the GHG emission calculation process. Vissim provides a suitable tool for environmental impact studies as it considers various important emission indicators including distance, speed, number of stops behind traffic signals along routes and delay time. A case study in the Ajax, Region of Durham, Ontario is conducted using the above procedure. To identify the optimized path in terms of environmental impacts, first step is to simulate the specified location using Vissim as described by the following.

The simulated network is consist of an eight hour simulation representing 28,800 simulation seconds to capture the traffic flow during am, noon and pm peak and off-peak hours in the area. Since the ready mix concrete has to be delivered within an hour of mixing, suppliers avoid delivery during rush hours (Artenian 2010). In other words, the effect of rush hours is not considered in this study due to the fact that the majority of the concrete delivery happens during off-pick periods. Therefore simulation data collected from the smallest traffic congestion, which belongs to 9am until 3pm. However, simulating am, noon and pm peak and off-peak periods warm up the network before delivery trucks enter and let them end up their destination.

For the purpose of this study a specific HDV type has been defined for Vissim using the vehicle type window. This type of vehicle has two subclass: a loaded and an empty vehicle, enabling calculation of the GHG emission when truck travelling from manufacturing plant to the construction site (delivery route) and accordingly returns to the manufacturing plant (return route). The road traffic consists of three main vehicular compositions: cars, HDV loaded and HDV empty. HDVs moving through the simulated network are the ones selected for estimating the GHG emission levels as they travel from the manufacturing plant to the construction site and return. In order to simplify the analysis, the presence of the other HDVs has not been considered in the network as they partake less than 5 % of the traffic composition in the area.

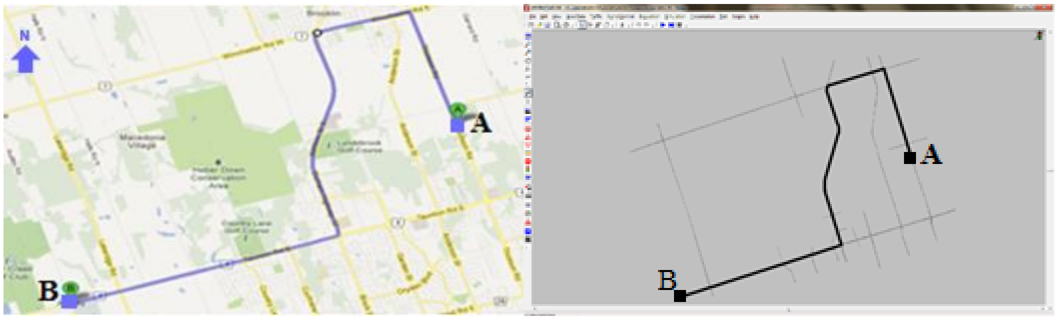
Google Maps is initially used to upload the background image and to set the scaling information. Thereafter, the corresponding links and connectors were created according to the background image. The only available data collected from the Regional Municipality of Durham was the traffic volume which belongs to a nearby intersection of two arterials. This data was used to determine the traffic volume for main intersections in the network. Specific routing decision commands were set for the HDVs between origin and destination; thus, HDVs just traverse through a given path between the manufacturing plant and the construction site. Three typical signal controls patterns were applied for the existing intersections in the network based on the road classifications and traffic volumes.

After completing the simulation, data (travel distance, speed, delay time and number of stops) for 420 deferent HDVs travelling through the specified paths are collected as outputs. Then the simulation outputs are plugged in Equation 1 to calculate initial FCR. Results from Equation 1 are improved by adding load and vehicle type factor. After calculating the HDVs' FCR, emission factors (see Table 1) are applied to estimate emissions from each path and at the end GWPs (see Table 3 and Equation 5) are added to estimate final emission rates for each path.

4. Case Study and Results

To find the path with least GHG emission rate, a case study for delivery of concrete is done using the method presented in this study (Section 2). A construction site near 600 Taunton Road, Ajax, Region of Durham, Ontario and a batch plant located at 4860 Thickson Road North, Whitby, Ontario, Canada are chosen for the study. The case study is selected from a research done by Artenian et al. 2010 to be able to compare results with findings of the GIS model developed in that study. Three paths suggested by Google Maps between the aforementioned locations are examined to find the least-emitting route. The method also gives the ability to explore the effect of delay times and the number of stops, which also approximately include vehicle's acceleration and deceleration level, on the GHG emission rates (Rakha and Ding 2003). In the upcoming subsections, the results after calculating GHG emissions for each path are presented.

Path I: choosing this 13.7 km path leads to nearly a 17 minute journey time for trucks. 11 traffic signals positioned along the path. Figure 2 depicts Path I in Google Maps and simulated Vissim network separately.

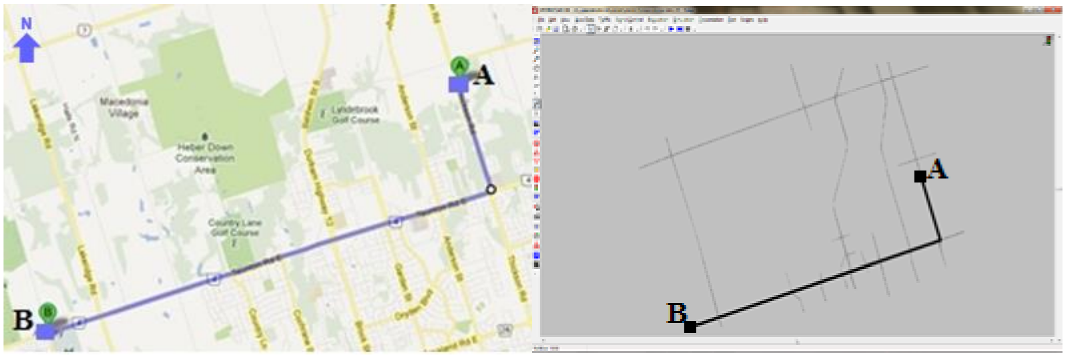


(a) (b)

Figure 2: Path I, a) Path I in Google Maps, b) Path I in Vissim

The GWP for Path I, when the truck is fully loaded, ranges between 33.7 to 44.2 kg of CO_2 eq with the average of 37 kg of CO_2 eq. The GWP varies because of the difference in the number of stops and delay times that each truck may experience during its specific trip. The results demonstrate that HDVs experience between 7 and 11 stops and suffer a delay time varying from 6.26 to 9.54 minutes. The GWP for the return route, when truck is empty, is estimated between 18.7 and 31.2 kg of CO_2 eq, with the average of 22.8 kg of CO_2 eq and possibility of 6 to 9 stops. Moreover, the total GWP, which captures both delivering and returning routes, is estimated around 59.8 kg of CO_2 eq for this path.

Path II: The alternative path with nine positioned traffic signals is 9 km long. It takes around 14 minutes to traverse along the path. Figure 3 illustrates path II on Google Maps and Vissim network separately.

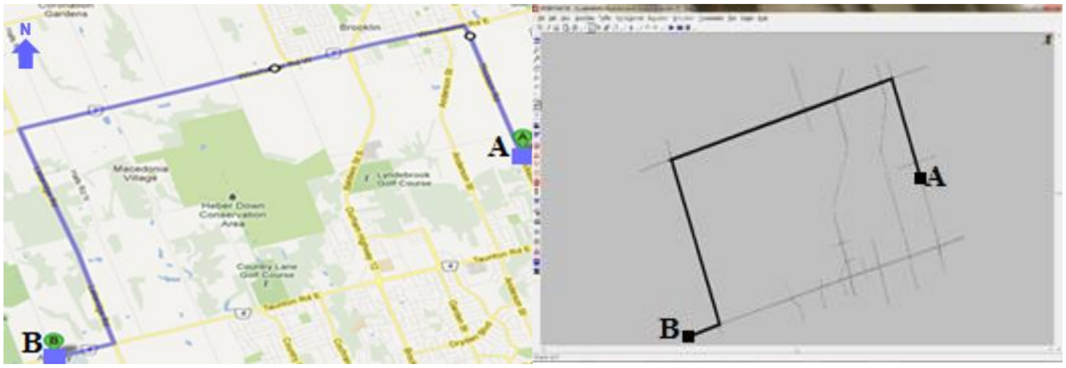


(a) (b)

Figure 3: Path II, a) Path II in Google Maps, b) Path II in Vissim

The simulation results show that the GWP for the loaded truck ranges between 28.6 and 40 kg of CO_2 eq. The average GWP for the delivery route is estimated around 33.3 kg of CO_2 eq. The number of stops varies between 5 and 7, whilst the delay time is approximated 5.6 minutes on average. The number of stops for the return route increases from 6 to 8, whereas the delay time is estimated 5.9 minutes. The GWP for the empty truck ranges between 18.3 and 28.1 kg of CO_2 eq with the average rate of 22 kg of CO_2 eq. Therefore, the total GWP originating from both trip legs is estimated around 55.3 kg of CO_2 eq for path II.

Path III: which is a 14.5 km rural road, imposes a 17 minute journey time to HDVs to arrive the destination. The trajectory with 7 traffic signals is depicted by Figure 4.



(a) (b)

Figure 4: Path III, a) Path III in Google Maps, b) Path III in Vissim

The estimated GWP for the delivery route ranges between 29.6 and 39.1 kg of CO_2 eq with the average value of 32.3 kg of CO_2 eq. The number of stops varies between 4 and 7 and the delay time is averaged around 4.3 minutes. The return route yields a GWP ranging between 15.8 and 23.9 kg of CO_2 eq with the average of 19.3 kg of CO_2 eq. The number of stops varies between 3 and 9 with the average of 5.4 stops for each trip. The estimated delay time is around 5 minutes for the return route. Finally, the total GWP for both trip legs is estimated 51.6 kg of CO_2 eq, which is considerably lighter than that of path I and path II. Although path III is 0.8 km longer than path I and 5.5 km longer than Path II the GHG emissions emitted during delivery of concrete along this path is 8.2 kg of CO_2 eq lower than those emitted along path I and 3.7 kg of CO_2 eq lower than path II emissions. The large number of stops and longer delay times along path

I and II cause higher GHG emissions, despite their shorter length. According to the final results, Path III has the lowest GWP. This path is also the longest path among three alternatives with 14.5 km length.

5. Summary and Conclusion Remarks

In this study, the GHG emissions for delivery of construction materials from manufacturing plants to construction sites are estimated using method presented in Section 2. Important emission indicators for HDVs such as distance, speed, delay time, load and the number of stops, which also represent a rough estimation of acceleration and deceleration rate impacts, were taken in to account to calculate the GWP for different feasible paths between manufacturing plants to construction sites. Although the method considers as many significant indicators as possible, other important factors i.e. vehicle age and road gradient with a significant impact on HDV's FCR need to be accounted for in further research. The study results show that the longest path with 14.5 km length benefits from the lowest GWP value which is equivalent to 51.6 kg of CO_2 eq for both trip legs. The method typically justifies the important role of the number of stops and delay times on GHG emission levels. The proposed method also shows that truck's load may double the FCR and consequently increases HDVs emission rates. Obviously, the detailed and up to date information on traffic signals phasing and traffic volume (e.g. Annual Average Daily Traffic (ADT), Peak Hour Factor (PHF)) would increase the accuracy of micro simulation and the outputs and consequently the results.

The GWP values in this study roughly matches with findings by GIS model developed by Artenian et al. 2010 which estimated 33.2 kg of CO_2 eq for one trip leg-delivery route- of Path III. The proposed method in this study calculated 29.6 to 39.1 kg of CO_2 eq with the average of 32.3 kg of CO_2 eq for one trip leg-delivery route- of the same path. This method is examined using delivery of concrete; however it can be transferable and may be applied to other construction materials. Future work will be done to expand the variety of the construction materials. The method presented in this research demonstrates that an effective route decision making not only will be beneficial for construction materials suppliers and may lead to the cost reduction through consuming less fuel, but also, it can protect the environment and increase sustainability by traveling through less-emitting routs. Therefore, this method may help stabilizing GHG concentration in the atmosphere, which is interpreted as the ultimate goal in the context of environmental sustainability.

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