Sustainable Transportation

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Table of Contents

List of Figures

List of Tables

Preface

The completion of this paper was not possible without the support of my family, advisory committee and friends. My wife as a continuous support for achieving this goal, she sacrificed a lot for helping me toward completing this work.

My Advisor, Dr. Ryan Fries, spent a lot of time improving the paper. His continued support and patience made the work much easier for me. He provided me with the hope during difficult times with a lot of good advice to overcome the problems I faced.

My advisory committee member and my instructor for many classes, Dr. Huaguo Zhou, was the first great support during my first semester. His advice toward the required direction in the school, were the best tools for helping me to stand on my feet again. Besides the academic learning, he taught me a lot in everyday engineering life.

Dr. Chiang Lin, as instructor for a course I have and as an advisory committee member, he has always been a great supporter. Beside the rich knowledge he provided for the class, he taught me valuable lessons regarding sharing the information. His lesson is still at the top of my checklist before stepping toward any task.

These efforts and supports made my work come to the life. They required a lot of time but I am thankful. I hope I can payback some of these efforts to whom they helped me, and hopefully I will be able to help others whom may need my help in future.

INTRODUCTION

Global warming and climate change have become a real concern worldwide. These concerns require immediate action from all parties to prevent more damage for our planet. The major actions taking place are the creation of approaches for achieving sustainable development. While the term has many definitions, the most often-quoted definition of sustainable development is the development that *"meets the needs of the present without compromising the ability of future generations to meet their own needs"* [United Nations, 1987].

Since sustainable development became an international priority, sustainability of infrastructure became an active area for this practice. Reducing Green House Gas (GHG) emissions as a major contributor of global warming is the most important step toward sustainable development. The transportation sector is considered one of the major contributors in GHG emissions with the transportation system being the second largest contributor of GHG emission in the U.S. Globally, the transportation sector alone contributes 24.1% of CO_2 emissions worldwide, providing justification for adoption of new techniques and designs for achieving sustainable transportation. Since sustainable development has many definitions, the sustainable transportation also has a variety of interpretations based on the vision and goals of the agency adopting it. The definition used herein is "*sustainable transportation can be viewed as the provision of safe, effective, and efficient access and mobility into the future while considering economic, social, and environmental needs*" [T. Ramani, 2009].

The definitions for sustainable transportation show that progress must be recorded in three aspects: economic development, environmental preservation, and social development, known as three pillars of sustainable development as shown in Figure 1. Sustainable transportation must improve the economic and quality of life and at same time reduces the impacts on the environment.

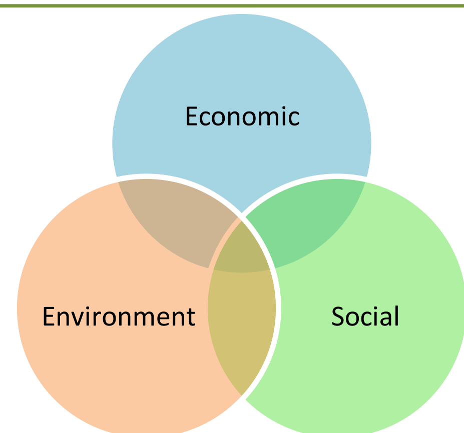

Figure 1: Three Major Pillars of Sustainability

Many steps have been taken toward achieving sustainable transportation. Many related parts of transportation are working simultaneously toward this goal. These attempts have many advantages to the agency itself and to the environment at same time. Using Intelligent Transportation system (ITS) during incident management is one way to reduce the fuel consumption and CO_2eq emissions. The objective of this paper is to 1) review common applications that promote sustainable transportation and 2) analyze the emissions impact of applying intelligent transportation systems for faster incident management.

LITERATURE REVIEW

Overall, sustainability is a delicate balance between the parts of a transportation system. Sustainability improvements affect each agency differently. The transportation agencies are focusing on improvements of roadways and infrastructure. The environmental agencies are focusing on reducing GHG emission and climate change. The energy-related agencies are focusing on fuel consumption and renewable energy. The vehicle manufactures' focus is on fuel efficiency and sales. The federal government, beside all these aspects, their focus will be on the issue of funding and improving quality of life, while the population increases and resources remain finite. This literature review will show the recent practices taken and concepts used toward achieving sustainable transportation. The following section first presents studies recommending changes in public policies and the reviews studies focusing on changes in personal behaviors.

A study on transportation sustainability best practices by the transportation agencies divides the process into two steps. The first step is to increase the system efficiency and infrastructure capacity by considering the full range of demand management. The second step is required if the first step was not sufficient and new infrastructure construction is required. The new project must be designed and implemented in sustainable ways by considering five major aspects in each stage of the project, including minimizing consumption of energy, minimizing raw material consumption, minimizing environmental impacts, supporting vibrant urban communities, and supporting sustainability during implementation [CH2M HILL, 2009].

The increase in population will be about 100 million by 2040. Travel demand increase will raise the concerns on the critical issues for 21st century; the environmental impacts of transportation and climate change [TRB, 2005].

> The GHG emissions from transportation system account for a large share of overall emissions. Locally, the transportation system is the second largest contributor in the United States. The greatest share is from road transportation, approximately 72%. This GHG emission increase from road transportation, both passenger and freight travel, requires a policy review, including type of fuels, vehicle fuel economy, vehicle miles traveled, and the operation/behavior of traffic [AASHTO, 2008].

Globally, Transportation has a huge impact on the global warming and climate change. The urgency of adopting a global policy is a great step toward reducing GHG emission. According to World Resources Institute (2005), the transportation sector alone contributes in 24.1% of CO_2 Emissions worldwide.

In addressing the availability of alternatives for US highway projects, American Association of State Highway and Transportation Officials (AASHTO) has issued a handbook for practitioners. The handbook focuses on the project's purpose and need. Purpose and need are considered important because they lead to a variety of sustainability alternatives that can be taken into account for the same type of projects [AASHTO-a, 2007].

Another handbook published by AASHTO, "Introducing Environmental Management System concepts," can be applied to any Department of Transportation (DOT) activity or facility. The environmental management system can be a basic structure for practicing improved environmental goals, objectives, and targets. These tools can be used for measuring the performance toward achieving these goals. The practices can be within different strategic and business planning offers [AASHTO-b, 2007].

Other sustainable alternatives include reducing congestion and improving the performance of the current transportation system. An effort called connected vehicle is working to establish communication between vehicles and between vehicles and roadside infrastructure. This effort can improve the system performance and increases safety [AASHTO-c, 2007], impacting the economic and social pillars of sustainability.

The concepts of transportation sustainability can be achieved most effectively by integrating all the transportation-related sectors. Looking to all business units, departments and policies to understand how they interact with each other for creating an agency-wide sustainability program. Each business unit and department's function and policies are put into that direction and completely integrated. In this way, the objective of regional sustainable program will be achieved [LACMTA, 2008].

Sustainable transportation is necessary due to its impact on fuel. The use of petroleum by the transportation sector is increasing dramatically, while the production of petroleum by the United States is decreasing. The entire petroleum production by the U.S. has not been enough to cover the consumption of the transportation sector since the end of 1980s. Keeping within current gross in transportation consumption and current trend in production, the petroleum produced by the U.S. will be only sufficient to support the country's cars and light trucks by 2035 [Stacy, 2011].

Materials used for controlling snow and ice are varied, and they have different impacts on the environment. The selection of these materials was based on cost and performance, while environmental impacts were not considered in this selection, the report by National Cooperative for Highway Research Program (NCHRP) is to include the environmental impacts in the procedure of selecting the materials. Due to the need for rational guidelines to assist DOTs in selecting snow and ice control materials, the report focused on developing guidelines for this selection. The guidelines will be based on the composition of the material, performance, and potential environmental effects. Many other factors will be considered also based on the site specific conditions [NCHRP, 2007].

A study comparing the transportation sector in Germany and the U.S. shows a significant similarity in both countries from car use growth and vehicle manufacturing.

> *"The result is a transportation system in the United States that is less sustainable than in Germany. The per capita carbon footprint of passenger transportation in the United States is about three times larger than in Germany. Although gas prices in the United States are half those in Germany, Americans spend five percent more of their budgets on transportation than Germans. In government outlays as well (federal, state and local), Germany spends less per capita on transportation than the United States"* [Ralph, 2009].

The report addresses the German transportation policies that could ultimately lead to a more sustainable U.S. transportation system. The focus of the report is more on changing the driver behavior, increasing gas prices and integrating the transit, cycling and walking as viable alternatives to the car. The German transportation system is safer than in the U.S. due to fewer fatalities per capita, per trip and per miles traveled.

To motivate people to use public transit, a report by Transit Cooperative Research Program (TCRP) on reducing GHG emissions from transit gives details on reducing the carbon footprint from transportation. The focus is on improving the public transit to encourage drivers to shift from private to public modes that lead to less congestion, decrease VMT and, at same time work on decreasing the emission from the public transit itself.

METHODS TOWARD ACHIEVING SUSTAINABLE TRANSPORTATION

As can be seen from the literature review, adopting sustainable transportation initiatives can be implemented in different ways by different agencies. Most of the practices are interconnect with each other directly or indirectly. For example, the production of fuel efficient vehicles reduces the GHG emission from transportation. Improving public transit can reduce congestion, lowering travel time, and managing demand better. Better demand management reduces the need for new construction, so less energy and materials are needed. Although some of the decisions can be made by individuals, such as choosing to use public transit, other solutions must be implemented by engineers in different stages of design, construction, operation and/or maintenance. The departments of transportation also can mitigate policies to achieve broader influence that reflects on most components of the community. The efforts for stepping toward sustainable transportation can be any one or a combination of the following:

Intelligent Transportation System

Using Intelligent Transportation Systems (ITS) can be great tools in reducing the environmental impact of our existing transportation system. Reducing congestion, improving public transit ridership, providing alternative routes during congestion, communicating with drivers better, roadway and traffic data collection devices will assist in decreasing the overall vehicle miles travelled, shorter trips and fewer emissions from a transportation system.

ITS technologies lead to better management during traffic incidents. Effective communication between the drivers from incident scene from one side and traffic management center and incident responders from the other side will assure faster detection. The surveillance cameras and traffic detectors make the process of detection, verification and response time much more efficient. Traffic Management Centers (TMC) can direct responders to faster routes by monitoring data for travel times.

Many ITS tools can be used during incident management, including closed circuit television, traffic detectors, and variable message signs. All of these tools seek to gather information about the traffic flow and/or provide travelers with information about their expected trips [FHWA, 2010].

Improving Public Transit

Public transit improvements can reduce the impacts of transportation on the environment in different ways.   Widespread use of public transit by citizens will help to reduce congestion by limiting the number of vehicles on the roadway. Fewer vehicles on the roadway make roadways less congested and cause less fuel consumption, less vehicle miles traveled and less emission from idling vehicles stuck in the congestion. Studies show a significant reduction of GHG emissions from transportation if public transit is used as a strong alternative to private auto, and especially when all seats of public transit are occupied, as shown in Figure 2. . Public transit can also reduce the GHG emissions by improving its fleet and using more efficient fuels, using renewable energy, optimizing the time and routes, changing their drivers behavior to drive more efficiently and improving the energy use in their facilities [TCRP, 2010].

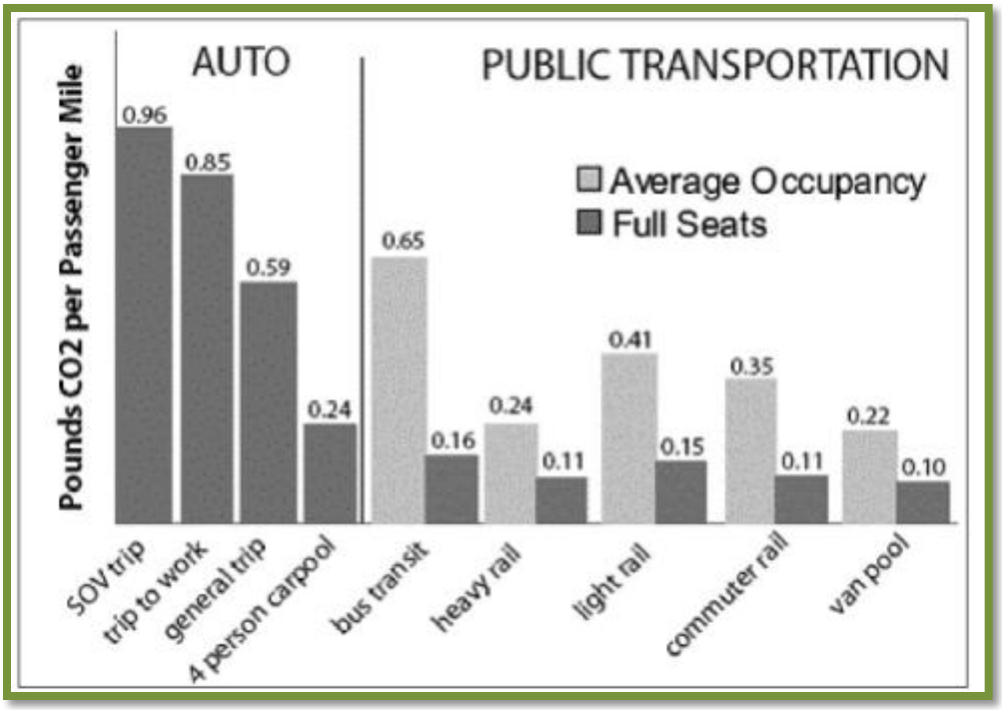

Figure 2: Reduction in CO_2 emissions comparing to Single Occupant Vehicles (SOV) (Source: Hodges, Federal Transit Administration, Jan. 2009).

Driver Behavior

Although driver behavior is difficult to change, some changes can improve sustainability of transportation. The choice of car purchase and good maintenance has a significant impact. Educating drivers to own smaller vehicles that cover their needs will reduce the fuel consumption and GHG emissions for the same trips. The selection of alternative routes by the drivers may reduce congestion and sometimes reduce miles traveled comparing to routinely used routes. Drivers can reduce fuel consumption and increase the life of their vehicles by using techniques such as avoiding fast acceleration. Using different modes of transportation, such as walking, biking, and using public transit for some of the daily trips, will reduce the footprint of transportation on the environment [AASHTO, 2008].

Fuel Efficient Vehicles and Vehicle Miles Travelled

Fuel efficiency has been significantly improved among the vehicle manufacturers. The goal to reduce GHG emission focuses on fuel efficient vehicles within the next decades. The improvements achieved and the projection of fuel economy is shown in Figure 3. One of the efforts by AASHTO is to "*support the president's goal to reduce oil consumption 20 percent in 10 years. Double the fuel efficiency of passenger cars and light trucks*" [AASHTO, 2008]. To support this goal, AASHTO uses the term mpg-ge (mile per gallon-gasoline equivalent) to compare vehicles with various fuel types. The GHG emission related with fuels will be measured based on the overall emissions from producing the fuel type up to the emission from tailpipe. For example, the vehicle powered by hydrogen does not produce any GHG emission from the tailpipe, but the production of hydrogen itself requires natural gas which produces GHG emissions.

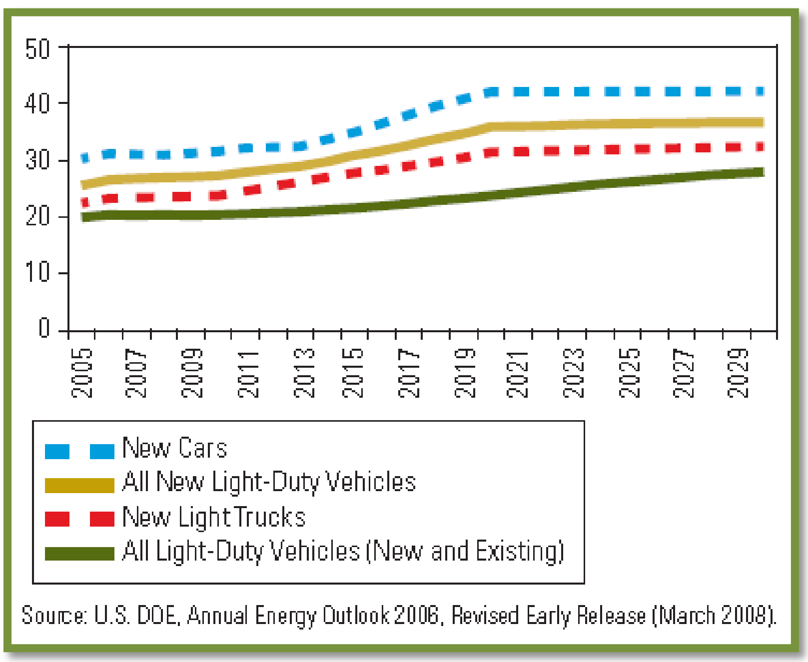

Figure 3: Average Fuel Economy 2006-2030

The study found that fuel efficiency of the vehicles has a significant impact on the economic aspect of sustainability. Based on the projected calculations, the gap between U.S. petroleum domestic supply and consumption will increase by about six million barrels per day on 2030 (62% of total consumption) as shown in Figure 4. The transportation part of oil consumption is about a quarter of overall U.S. consumption [AASHTO-c, 2007].

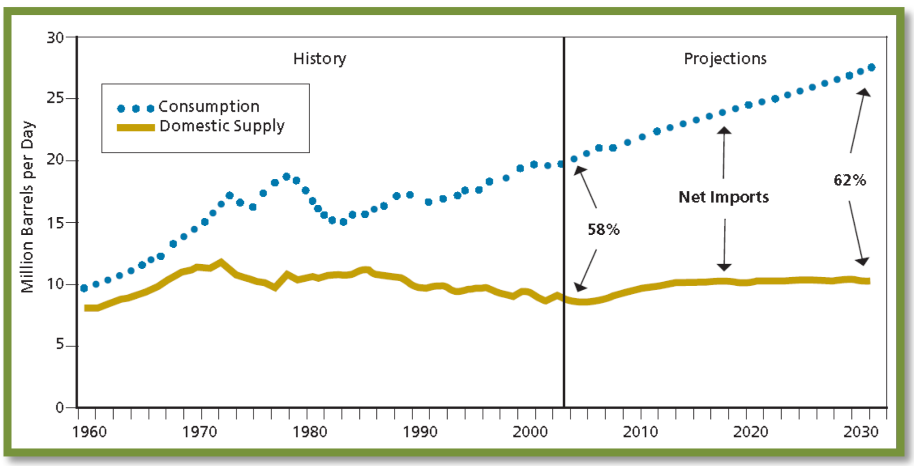

Figure 4: U.S. Petroleum Supply, Consumption, and Net Imports, 1960-2030
(Source: Annual energy outlook, 2006)

Population increase and the nature of long commute trips caused a dramatic increase in vehicle miles travelled (VMT) in the U.S. The expected increase in VMT for 2055 will be seven trillion miles if the trend remained with the current growth. The fuel efficiency development is within (40 mpg); however, if the fuel efficiency revolution reaches 100mpg and the VMT growth rate decreased by 1% annually (half by 2055) the emission of CO_2 will be reduced by 68%. The projected VMT is shown in Figure 5. [AASHTO, 2008]

Figure 5: The increase of VMT by 2055 –two scenarios
(Source: Transportation, Invest in our future by AASHTO- July 2007)

Green Roads

Greenroad is a rating system which considers if a sustainable approach was taken in all stages and for all contributing parts to a roadway's lifecycle. "*A Greenroad is defined as roadway project that has been designed and constructed to a level of sustainability that is substantially higher than current common practice*" [University of Washington, 2011]. The design stage should cover the concepts of sustainability by using untraditional methods to support low intensity energy use, less use of resources, and a more durable design life as known by Design for Environment and Sustainability (DfES). The procedures and recommendations from the designer will effect on the upcoming stages. Construction stages might focus on recycled materials, waste management, land use, livability, using methods that require less energy (warm-mix asphalt rather than hot-mix asphalt). To achieve the goals for constructing a green road, it is required to include the community in the process because they will be a great support during construction stages, if they have been involved and informed about the prospective of sustainability. To keep the community as continuous support, it is required to provide them with tools for measurements. The benefits from adopting these approaches in long and short terms will encourage the community to be more supportive in future sustainable projects, supporting the social pillar of sustainability [University of Washington, 2011].

Selecting Materials

The resources on the planet are limited. If the trend of extracting raw materials remains with the same current pattern, the planet will be out of many major elements in the near future. The selection of materials has three major impacts on the sustainability of the project: 1) the amount of availability of the material in nature, 2) the energy used for extracting and processing the material, and 3) the impacts of using the material on environment. By combining these three factors for material selection, the best available material with least possible impact will be chosen. For example, for comparing use of steel or concrete to construct a bridge, the first point will be the availability of steel or cement in nature, then comparing the energy required for extracting them, etc. Finally considering the impact of using these materials on the environment, by considering the life cycle assessment and consideration of recycling after design life has been over. Based on the material selection criteria, the availability of alternatives will be always an option to reduce impact on the environment and achieve sustainable production.

Non-Traditional Pavement

As a major component of roadway construction, pavement types and process will affect the cost and the environmental impacts. "*As of 2001, there are about 2 .5 million miles of paved roads in the United States, of which 94% are asphalt surfaced*" [Huang, 2001]. The proper selection of material has been addressed for less impact on environment. The process of pavement preparation, transportation and laying the selected type of pavement is an important area for improvement. Using new rather than conventional techniques will reduce the use of raw materials, consume less energy, and provide longer design lives.

Many new types of pavements have been invented in recent decades. The goal is to produce a pavement with less material use, lower energy requirements (this will cause lower GHG emissions), and longer life. Considering these three aspects for any pavement, the life cycle assessment will give better results than traditional pavements.

METHODOLOGY

Using ITS tools will assist in managing the traffic incidents on the roadways more effectively. The positive impacts from using these tools can be calculated in different ways. A previous study calculated the fuel consumption during each incident using ITS technologies including: traffic cameras, incident reporting hotlines, freeway service patrols (FSPs) and a traffic management center (TMCs), and without using any ITS tools [Ma et al., 2009]. The results from the study are shown in Table 1.

Table 1: Incident Management With/Without ITS

Incident Scenarios	**Fuel Consumption (unleaded) Gallon**	**Fuel Savings (Gallon)**	**Fuel Consumption (Diesel) Gallon**	**Fuel Savings (Gallon)**
1-lane 1-hour				
Using ITS	7731.7	63.1	3778.6	-2.5
Without ITS	7794.8		3776.1	
2-lane 2-hour				
Using ITS	11271.5	1279.8	5453.1	519.8
Without ITS	12551.2		5973.0	
3-lane 3-hour				
Using ITS	26774.0	1180.2	12138.5	426.8
Without ITS	27954.2		12565.2	

The study described herein uses this data to determine the total Carbon Dioxide Equivalent (CO_2eq) emissions for both cases (i.e. using ITS and without ITS). Four different methodologies have been used for the calculations including: (1) the emission calculator from U.S. Environmental Protection Agency's (EPA) website, (2) manual calculations, (3) the emission calculator from GHG protocol website, and (4) the emission calculator from the Carbon Neutral website. The assumptions from each model have been reviewed and the results from each method have been analyzed and compared.

DATA ANALYSIS AND FINDINGS

The emission calculator from EPA's website [EPA 2011] was used in method 1. This website was designed to calculate the emission from fuel use estimates. The CO_2eq emission results from this method are shown in Table 2.

Table 2: CO_2eq emission using EPA's calculator

Incident Scenarios	Fuel Consumption (Gasoline) Gallon	Fuel Consumption (Diesel) Gallon	Equivalent gasoline/diesel (Gallon)	Total Fuel Consumption (Gallon)	CO_2 Equivalent (Mton)
1-lane 1-hour					
Using ITS	7731.7	3778.6	4359.4	12091.1	108
Without ITS	7794.8	3776.1	4356.5	12151.3	108
2-lane 2-hour					
Using ITS	11271.5	5453.1	6291.3	17562.8	156
Without ITS	12551.2	5973.0	6891.0	19442.2	173
3-lane 3-hour					
Using ITS	26774.0	12138.5	14004.1	40778.1	363
Without ITS	27954.2	12565.2	14496.5	42450.6	378

The second method for estimating the CO_2eq emissions is manual calculation. The emission for gasoline is 19.6 lb. CO_2eq/gallon and for diesel is 22.4 lb. CO_2eq/gallon [Appendix A-Method 2]. The results from this method are shown in Table 3.

Table 3: CO_2eq emissions from manual calculation

Incident Scenarios	Fuel Consumption (unleaded) Gallon	Fuel Consumption (Diesel) Gallon	Carbon footprint from gasoline (Ib)	Carbon footprint from diesel (Ib)	CO2 Equivalent (Mton)
1-lane 1-hour					
Using ITS	7731.7	3778.6	151541.3	84640.8	107
Without ITS	7794.8	3776.1	152777.6	84584.5	108
2-lane 2-hour					
Using ITS	11271.5	5453.1	220920.9	122150.4	156
Without ITS	12551.2	5973.0	246004.3	133794.3	172
3-lane 3-hour					
Using ITS	26774.0	12138.5	524770.4	271901.3	361
Without ITS	27954.2	12565.2	547901.6	281460.6	376

The third method is from the GHG Protocol website. The website includes calculators for estimating GHG emissions for different service sectors including transportation. The calculator is an excel spreadsheet that allows user to input the type of vehicles, fuel and region. The results are displayed in CO_2, CH4 and N_2O, and then converted to metric-tonnes CO_2e as shown in Table 4.

Table 4: CO_2eq calculation from GHG protocol calculator

Calculation Method	Waste	Fossil Fuel Emissions		Biofuel CO_2 Emission (metric tonnes)
		Scope 1 (metric tonnes)	**Scope 3** (metric tonnes)	
Fuel Use	CO2	591.568	622.113	0
	CH4	0.016	0.017	
	N2O	0.009	0.010	
Total (metric tonnes CO_2e)		591.594	622.140	0

The fourth method used for calculating GHG emission is from the Carbon Neutral website. The website contains carbon calculator for different sectors including the vehicle and fuel use carbon calculator. The calculator allows user to select the fuel type, unit and the frequency. The results from this calculator are shown in Table 5. More details about the values and assumptions for all the four methods have been shown in Appendix A.

Table 5: Co_2eq emission using Carbon Neutral calculator

Incident Scenarios	Fuel Consumption (Gasoline) Gallon	Fuel Consumption (Diesel) Gallon	CO_2e from Gasoline (Mton)	CO_2e from Diesel (Mton)	CO_2 Equivalent (Mton)
1-lane 1-hour					
Using ITS	7731.7	3778.6	90.0	41.5	132
Without ITS	7794.8	3776.1	90.8	41.5	132
2-lane 2-hour					
Using ITS	11271.5	5453.1	131.3	59.9	191
Without ITS	12551.2	5973.0	146.2	65.6	212
3-lane 3-hour					
Using ITS	26774.0	12138.5	259.6	133.4	393
Without ITS	27954.2	12565.2	271.1	138.1	409

Due to the difference in input data, assumptions and calculations, varied results from each method are obtained. Each method has different approach in the calculation because the use of the results is varying based on the regional policies and its effects on the related activities. The results from all four methods are listed in Table 6.

Table 6: CO_2eq emissions results from all methods

CO2 Eq (Mton)				
Method	With ITS	Without ITS	% Reduction	Difference (Mton)
1	627	659	4.9	32.0
2	624	656	4.9	32.0
3	595	625	4.9	30.7
4	716	753	5.0	37.5

As Table 6 illustrates, the results from method one and method two are not significantly different. The results from method three is slightly lower than the two previous methods. The results from method four is higher than all of the other methods. The results from Table 6 have been plotted in the Figure 6.

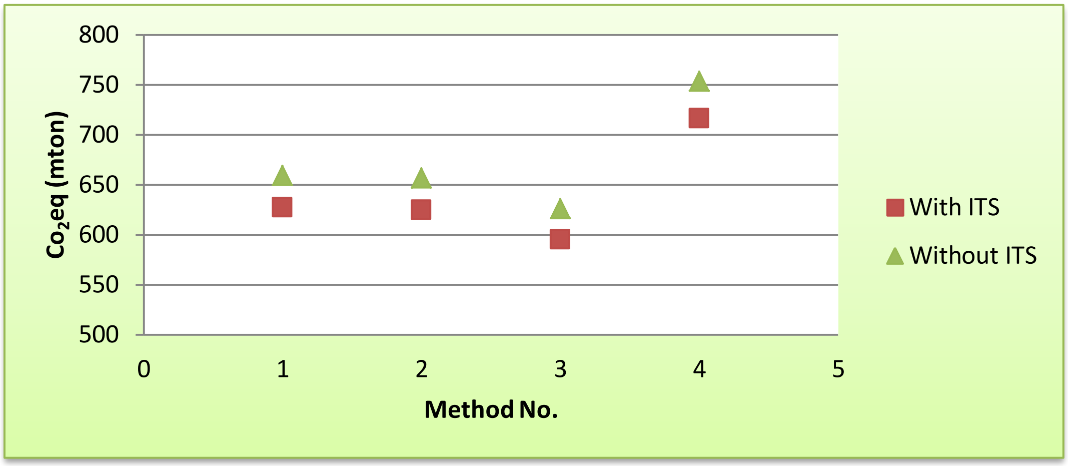

Figure 6: CO_2eq emission results from all methods

The calculator from method one (EPA) is very user friendly. The goal of the calculator is to assist in understanding the emission in easy units. The assumptions in this method and the second method include of 19.6 lbs. of carbon per gallon of gasoline and 22.4 lbs. of carbon produced per gallon of diesel. The only challenge noticed in method one is the lack of diesel in fuel type. The user needs to use a factor to convert diesel GHG emissions to gasoline.

The values and assumptions used by the method three are not clear and cannot be evaluated. The introduction part states that it uses default emission factors. These factors are varying between U.S., U.K. and other countries. The values for each country are not displayed for the user.

Method four calculates the emissions from the fuel burning, extraction, processing, and the transportation. The emission estimated from this method is much higher due to this reason as indicated in the Figure 6.

Using different methodologies and assumptions results in different amount of CO_2eq emissions but it can be noticed from Figure 7 that all four methodologies have almost the same values for reduction. The values are all approximately 5% from all four methods. This similarity is a good indicator that using ITS contributes in decreasing the GHG emission by 5%.

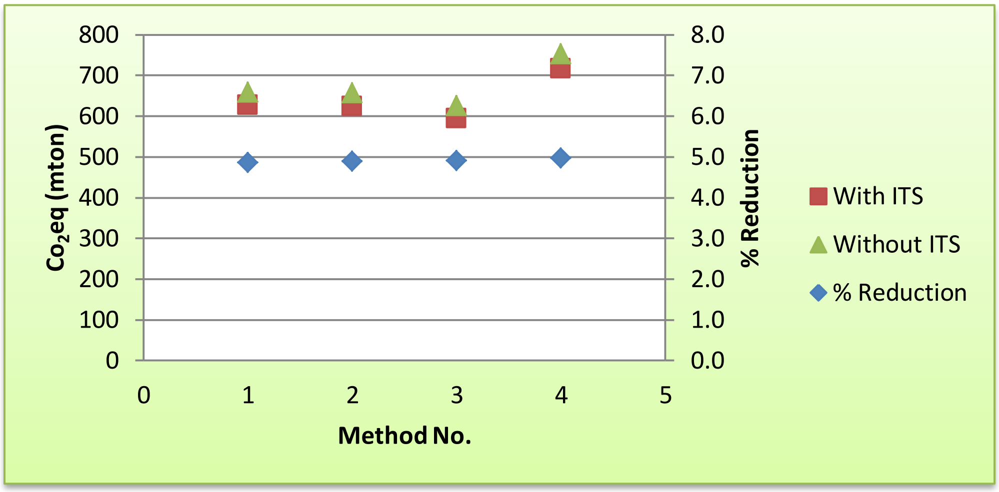

Figure 7: CO_2eq emission and % reduction for all the methods

The economic aspects from using ITS technologies during incident management are calculated in the same report used as reference in fuel consumption. The report found the ratio of 13/1 benefits-to-cost ratio if ITS tools has been used. The saving from fuel in each scenario has been represented to its equivalent US$ based on the price of fuel and CO_2eq. The economic savings are presented in Table 7.

Table 7: Cost Savings using ITS in incident Management

Economic Benefits				
	Saving	**Unit**	**Price/Unit ($)**	**Saving Cost ($)**
Unleaded	2523	gallon	3.623	9,141.84
Diesel	944	gallon	3.914	3,695.05
CO_2eq	32.00	Mton	21	672.00
Total Cost Savings ($)				**13,508.89**

Using ITS technologies contribute is less VMTs, fewer congestion, less VHT and fewer emissions. These benefits from saving time and consuming less amount of fuel are great factors in supporting social aspects. Societies with less congestion and cleaner air are more viable.

CONCLUSIONS

Moving toward transportation sustainability is a necessary action for reducing the damages from transportation on the environment. From one side, the transportation applications affect the balance of environment, from the other side, the climate change and the global warming affects the function and development of the transportation system. The impact of transportation on the environment will increase if sustainable policies are not adopted

Since this goal will not be reached if the efforts are not made within a wide range policy, each transportation agency needs to contribute towards achieving sustainable transportation. In the United States, sustainable approaches can be considered rather new. Efforts from main agencies are continuous, and many studies and publications are conducted in this field. AASHTO, as one of major contributors is this direction, published many references for identifying the areas that transportation sustainability can be implemented, fostering the DOTs to move from only adopting the concepts to the practical projects. Some of AASHTO's publications provide useful tools for measuring and evaluating these approaches.

Intelligent Transportation System (ITS) is one of the major contributors in achieving sustainable transportation. ITS technologies help in managing the roadways more efficiently. The traffic incident managers are significantly using ITS to detect, verify, and respond to the incidents more effectively. Better management of traffic incidents leads to fewer emissions because traffic incidents are considered as major contributors in congestion in the U.S. Specifically, this study found that 5% less GHG CO_2eq emission were produced when ITS was utilized in managing traffic incidents, supporting the first aspect of sustainability, environment.

The effects of using ITS during incident management on decreasing the vehicle hours traveled due to less congestion will results in less emission, less fuel consumption, and less delay. All three of these indicators support the economic aspect of sustainability.

Any community with better managed roadways, less GHG emissions from incidents, fewer secondary crashes, and less congestion will be a vibrant and more attractive place to live. This type of society will develop faster and healthier, illustrating the social aspect of sustainability which. Thus, using ITS to support traffic incident management operations can have positive impacts on all three aspects of sustainability.

The calculator from the U.S. EPA is updated frequently and all the data used are available for the users to consider. The website as a whole, and the particularly the calculator, is user friendly with availability of various input and output values. This calculator is recommended and can be considered the best. Because of these features, this tool was found to be the best for transportation application, among those reviewed.

Because the data used for this analysis was collected during just one year, future studies might find benefits for more years. Also, the first three methodologies calculate the CO_2eq only focus on the combustion of the fuel without including the emission and energy use during extraction, transportation, and production as calculated in method four. More studies could investigate the concept of each methodology for identifying the most reliable result for transportation applications.

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APPENDIX A

Method 1- EPA

Revision History

This page describes the revisions and updates made to the Greenhouse Gas Equivalencies Calculator since it was originally posted on EPA's website in February 2008.

November 20, 2009

- **Passenger vehicles per year:** Updated fuel economy and vehicle miles traveled figures to reflect 2007 data; previous figures were for 2005. Also adjusted the ratio of carbon dioxide emissions to total emissions based on 2007 data. Result is now slightly lower (5.23 metric tons CO_2 equivalent per vehicle per year, compared with 5.46 previously).
- **Gallons of gasoline consumed:** Revised the methodology used to calculate emissions per gallon of gasoline; the new methodology yields a slightly different result ($8.89*10^{-3}$ metric tons CO_2/gallon compared with $8.81*10^{-3}$ metric tons CO_2/gallon previously).

February 28, 2011

- **Electricity use:** Updated the electricity use calculation when converting reductions of kilowatt-hours into avoided units of carbon dioxide emissions: the Emissions & Generation Resource Integrated Database (eGRID) U.S. annual non-baseload CO_2 output emission rate was updated from eGRID2007 Version 1.1 to eGRID2010 Version 1.0.
- **Passenger vehicles per year:** Updated the amount of carbon dioxide emitted per gallon of motor gasoline burned from 8.89 to $8.92*10^{-3}$ metric tons to reflect latest U.S. EPA Greenhouse Gas Inventory data. This gives a result of 5.1 metric tons of carbon dioxide equivalent per vehicle per year, consistent with EPA figures provided in the 2011-2016 light-duty fuel economy standards analysis.
- **Gallons of gasoline consumed:** Updated the amount of carbon dioxide emitted per gallon of motor gasoline burned from 8.89 to $8.92*10^{-3}$ metric tons to reflect latest U.S. EPA Greenhouse Gas Inventory data.

May 20, 2011

- Electricity use, Home electricity use, Home energy use: Updated the CO_2 emissions factor to reflect the updated eGRID2010Version 1.1.

November 1, 2011

- Home energy use: Corrected a typographical error in the final equation; the correct value for liquid propane is 0.34 metric tons CO_2 (not 0.32 as previously shown), and the total emissions per household per year are 11.55 metric tons CO_2 (not 11.53 as previously shown).
- Coal-fired power plant emissions for one year: Deleted the conversion to metric tons, which is not needed in the final equation and was inadvertently retained in the text from a previous version of the calculator. The result shown was correct and has not been changed.

Source: http://www.epa.gov/cleanenergy/energy-resources/calc-rev-history.html

Calculations and Assumptions:

Carbon Dioxide Equivalent

A metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). Carbon dioxide equivalents are commonly expressed as "million metric tons of carbon dioxide equivalents (MMTCO2Eq)." The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by the associated GWP. The use of carbon equivalents (MMTCE) is declining.

MMTCO2Eq = (million metric tons of a gas) * (GWP of the gas)

Global Warming Potential (GWP)

Global Warming Potential (GWP) is defined as the cumulative radiative forcing effects of a gas over a specified time horizon resulting from the emission of a unit mass of gas relative to a reference gas. The GWP-weighted emissions of direct greenhouse gases in the U.S. Inventory are presented in terms of equivalent emissions of carbon dioxide (CO2), using units of teragrams of carbon dioxide equivalents (Tg CO2 Eq.).

Conversion: Tg = 10^9 kg = 10^6 metric tons = 1 million metric tons

The molecular weight of carbon is 12, and the molecular weight of oxygen is 16; therefore, the molecular weight of CO2 is 44 (i.e., 12+[16 x 2]), as compared to 12 for carbon alone. Thus, carbon comprises 12/44ths of carbon dioxide by weight.

Global Warming Potentials (100 Year Time Horizon)

Gas	GWP	
	SAR[a]	TAR[b]
Carbon dioxide (CO_2)	1	1
Methane (CH_4)*	21	23
Nitrous oxide (N_2O)	310	296
HFC-23	11,700	12,000
HFC-125	2,800	3,400
HFC-134a	1,300	1,300
HFC-143a	3,800	4,300
HFC-152a	140	120
HFC-227ea	2,900	3,500
HFC-236fa	6,300	9,400
HFC-4310mee	1,300	1,500
CF_4	6,500	5,700
C_2F_6	9,200	11,900
C_4F_{10}	7,000	8,600
C_6F_{14}	7,400	9,000
SF_6	23,900	22,200

[a] *IPCC Second Assessment Report* (1996)
[b] *IPCC Third Assessment Report* (2001)

* The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

Note: GWP values from the *IPCC Second Assessment Report* are used in accordance with UNFCCC guidelines.

Metric Ton

Common international measurement for the quantity of greenhouse gas emissions. A metric ton is equal to 2205 lbs. or 1.1 short tons. See short ton.[7]

- EPA's website contains detailed information about their calculations and assumptions
- In this method there is no calculation for Diesel. To convert diesel to gasoline, the factor of 1.1537 used:

  Emission from 1 gal. of Diesel= 1.1537 emission from gasoline

  The amount of diesel consumed has been converted to its equivalent gasoline and added to the gasoline amount to be used as total input value in the calculator.

This ratio is obtained from:

1. Dividing the emission from diesel by gasoline (Sources from Method 2)

   22.4 lb. carbon for diesel/19.6 lb. carbon for gasoline= 1.142857

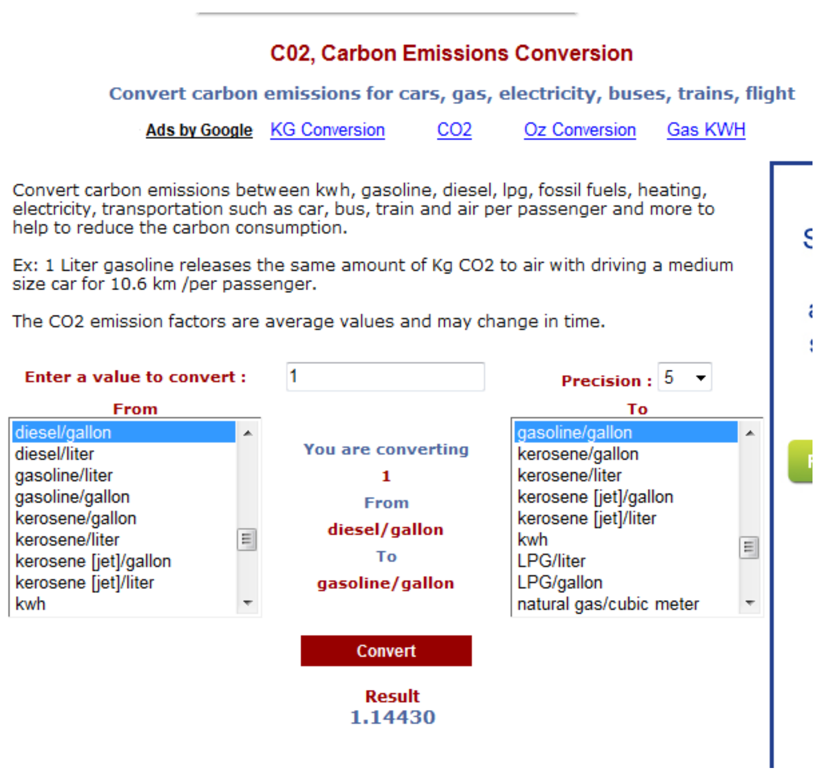
2. Using the values of CO_2 emissions from equal units of gasoline and diesel from different sources to find the conversion factor:

CO_2 Tailpipe Emissions/Litre of Fuel Consumed	
Fuel Type	**CO_2 Emissions**
Petrol	2.3 kg
LPG	1.6 kg
Diesel	2.7 kg

http://www.environment.gov.au/settlements/transport/fuelguide/environment.html

   The ratio can be obtained from table above (2.7/2.3=1.1739)

3. Using an online calculator for converting the CO_2 emission from Diesel to gasoline



http://www.asknumbers.com/CarbonEmissionConversion.aspx

4. Taking an average from above values:

   (1.142857+1.1739+1.1443)/3=1.15368

Method 2- Manually

1. **The data below is from** **http://www.zeroghg.ca/howto_calculate_carbon_footprint.html**

   Calculating carbon emissions from your cars

- Car emissions are directly related to the quantity of fuel burned which is in turn related to the fuel efficiency of your car.
- Fuel efficiencies vary from model to model but also depend on driving conditions (eg. highway versus city driving). Be sure to use a fuel efficiency factor that reasonably reflects your driving patterns.
- Your carbon footprint is calculated using an assumption of 19.6 lbs./gal of gasoline and 22.4 lbs./gal of diesel
- Although the combustion of 1 lb. of diesel results in the release of more emissions that 1 lb. of gasoline, a pound of diesel typically translates into a larger travel distance. Overall emissions effectiveness thus depends on fuel efficiency.

The calculation from lb. to metric ton is:

1 tonne (metric ton) t= 2204.623 lb.

Compared to EPA (method 1):

$19.6 / 2204.623 = 8.89 \times 10^{-3}$

Another Source for these values is:

http://www.uitp.org/advocacy/climate_change_docs/Calculating_carbon_emissions.pdf

Method 3-GHG Protocol

There are no details about the calculations and standards used. This organization is a combination from agencies and organizations from more than 20 countries (including US). The detailed GHG protocol is focusing more on using the available calculators by different service sectors (including transportation) to report the GHG emissions. The organization is well trusted and many data and personnel from USEPA participated in the preparation of the protocol, but the variation of the results from first two methods cannot be judged due the lack of calculation standards and steps. The tools will be more suitable for manufacturing companies and small businesses.

The following comparison shows similar factor (10.156/8.838=1.149) between gasoline and diesel. While the calculation of CO2 from each of gasoline and diesel in not known.

Activity Data				**GHG Emissions**			
Vehicle Type	**Fuel Used**	**Fuel Amount**	**Unit of Fuel Amount**	**Fossil Fuel CO2** (metric tonnes)	**CH4** (kilograms)	**N2O** (kilograms)	**Emissions, exclude Biofuel CO2** (metric tonnes
Bus - Gasoline	Gasoline/Petrol	1000	US Gallon	8.810	0.105	0.085	8.838
Bus - Diesel	On-Road Diesel Fuel	1000	US Gallon	10.15	0.019	0.018	10.156

http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf

http://www.ghgprotocol.org/calculation-tools/service-sector

Method 4-Carbon Neutral

The following values were used in this calculator:

Scope 1 Fuel use extract (page 17):

Table 4: Fuel combustion emission factors -fuels used for transport energy purposes

Transport equipment type	Fuel combusted	Energy content factor (GJ/kL unless otherwise indicated)	Emission factor kg CO_2–e/GJ (relevant oxidation factors incorporated)		
			CO_2	CH_4	N_2O
General transport					
	Gasoline (other than for use as fuel in an aircraft)	34.2	66.7	0.6	2.3
	Diesel oil	38.6	69.2	0.2	0.5
	Gasoline for use as fuel in an aircraft	33.1	66.3	0.04	0.7
	Kerosene for use as fuel in an aircraft	36.8	68.9	0.01	0.7
	Fuel oil	39.7	72.9	0.06	0.6
	Liquefied petroleum gas	26.2	59.6	0.6	0.6
	Biodiesel	34.6	0.0	1.2	2.2
	Ethanol for use as fuel in an internal combustion engine	23.4	0.0	1.2	2.2

Scope 3

Table 39: Scope 3 emission factors – liquid fuels and certain petroleum based products

Liquid Fuels combusted	EF for scope 3 kg CO2-e/GJ
Petroleum based oils (other than petroleum based oil used as fuel, eg lubricants)	5.3
Petroleum based greases	5.3
Crude oil including crude oil condensates	5.3
Other natural gas liquids	5.3
Gasoline (other than for use as fuel in an aircraft)	5.3
Gasoline for use as fuel in an aircraft (avgas)	5.3
Kerosene (other than for use as fuel in an aircraft)	5.3
Kerosene for use as fuel in an aircraft (avtur)	5.3
Heating oil	5.3
Diesel oil	5.3
Fuel oil	5.3
Liquefied aromatic hydrocarbons	5.3
Solvents if mineral turpentine or white spirits	5.3
Liquefied Petroleum Gas	5.0
Naphtha	5.3
Petroleum coke	5.3
Refinery gas and liquids	5.3
Refinery coke	5.3
Petroleum based products other than mentioned in items above	5.3
Biofuels	NE

Values are relatively higher because the calculation will include all the emissions from extraction, processing and transport of the fuel beside the emission from combusting the fuel itself.

For example the calculation made for gasoline is as follows:

Scope 1:

Adding the emission factors from each of CO_2, CH4, and N2O

66.7+0.6+2.3=69.6 kg CO_2e/GJ

Multiply it by the energy content factor

34.2 GJ/kL x 69.6 kg CO_2e/GJ = 2380.32 kg CO_2e /kL =2.38032 T CO_2e/kL

To convert to standard units

2.38032 T CO_2e/264.1721= $9x10^{-3}$ T CO_2e/gallon

This is greater than the values used by EPA (8.92x10-3).

Scope 3:

Following same steps the emission factor petrol is 5.3 kg CO_2e/GJ

5.3x34.2/1000 =0.18126 T CO_2e/kL= 6.86 x 10^{-4} T CO_2e/gallon

This amount of emission has not been included in any other methods used in this paper.

The factor between gasoline and diesel:

Total emission for gasoline = 2.56158 T CO_2e/kL

Total emission for diesel=2.90272 T CO_2e/kL

The factor =1.13317 which is slightly smaller than used factor in this study

http://www.carbonneutral.com.au/carbon-calculator/research-and-references/127-fuel-use-calculation-methodology.html

http://www.carbonneutral.com.au/carbon-calculator/vehicles-and-fuel-use.html