Spring 5-13-2016

Cumulative Impact of Shortest Path, Environment and Fuel Efficiency on Route Choice: Case Studies with Real-Time Data

Syed R. Islam
srislam@uno.edu

Cumulative Impact of Shortest Path, Environment and Fuel Efficiency on Route Choice: Case Studies with Real-Time Data

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Urban and Regional Planning

by

Syed Rezwanul Islam

BURP Bangladesh University of Engineering and Technology, 2013

May, 2016

Acknowledgement

I would like to express my sincerest gratitude to all the professors who encouraged and guided me to complete this thesis. I would like to convey my heartiest gratitude to Dr. Bethany Stich. She has helped me in every aspect of this research. I have received much needed support, guidance and encouragement throughout the preparation of this research work from her. I thank my committee members Dr. Gladstone and James Amdal to kindly attend my thesis defense. I have received some great suggestions from both of them to improve the quality of this research. I also thank Dr. Nelson for inspiring me to choose thesis. I have received help from David Lambour in every step of the way throughout my stay in this program. I would like to thank him for his generosity.

Without the help of my family, I would not have been able to accomplish all this. I thank my family for all their support.

Table of Contents

List of Abbreviations

ACS- American Community Survey

GPS- Global Positioning System

ITS- Intelligent Transportation System

VMT- Vehicle Miles Traveled

ISTEA- Intermodal Surface Transportation Efficiency Act

TEA-21- Transportation Equity Act for 21st Century

FHWA- Federal Highway Administration

List of Tables

List of Figures

Abstract

Intelligent Transportation System (ITS) provides a great platform for the planners to reduce environmental externalities from auto. We now have access to real time data. We have been using shortest path to provide route choice to the user. But we have the potential to add more variables in choosing routes. Real time data can be used to measure carbon di-oxide emission during a trip. Also, fuel efficiency can be measured using the real time data. Planners should use this potential of ITS to reduce the environmental impact. This paper thus try to evaluate if considering three variables shortest path, environmental impact and fuel efficiency together instead of only shortest path will change the route choice or not. It provides case studies on different types of routes and between different sets of origin/destination to evaluate the combined influence of these three variables on route choice.

Keywords: Intelligent Transportation System, Eco Friendly Route, Fuel Efficiency, GPS, Shortest Path, Route Choice

Chapter 1
Introduction

Automobile is widely used mode in the US. Flexibility and convenience are considered as reasons behind the popularity of auto over transit. Past policies and programs such as constructing federal highways, stagnant tax on fuel have favored the growth of auto. Sprawling cities, low density, preference of people to live in suburban areas have all contributed to the current inclination for auto. With growing spatial mismatch preference for auto has turned into necessities. An overwhelming 74.6 percent people use auto as their means of transport to work (ACS, 2014). The trend is no different for the state of Louisiana with 82.14% or the city of New Orleans with 69.89% (ACS, 2014).

Negative externalities involved with the auto are a big concern for the modern cities. The impact of auto on environment is irreversible and climate change is big growing concern all over the world. One element directly related to the climate change is the emission of carbon di-oxide from auto. However, in choosing route user can not consider the impacts that auto dependency brings. Planners and engineers have taken in account the detrimental impact of the auto dependency and focusing on policies to reduce the auto dependency. The process of moving people from auto dependency to transit is an arduous process. The process of implementing transit oriented development should also be simultaneous with reducing the negative externalities of auto.

Route choice can immensely reduce the impact of negative externalities. Congestion reduces the fuel efficiency and also increases the carbon di-oxide emission. With the advent of real time data the route can be chosen instantaneously. While choosing route people do use technology in forms of Global Positioning System (GPS), but technology provides them with only shortest path to the destination. Real time data can also be used to measure the impact on the environment by measuring the amount of carbon di-oxide emission. Thus, real time data can be used to provide people with option to consider the environment while driving. This data then can be used by the user to choose route that will be more benign to the environment.

Intelligent Transportation System (ITS) takes advantage of available data sources that are now available due to the technological improvements. ITS uses the information network created by the widespread use of internet, enabling users to share their experiences. ITS makes decision based on those shared experiences. The biggest advantage of ITS is that the data sharing can be done in real time as opposed to traditional process of collecting data through surveys. Second advantage of ITS is that it allows planners/engineers to create models that can account for uncertainties of real world. For example, a small incident can cause hours of congestion. ITS can help user to avoid congestion by disseminating the data.

ITS can be defined as "application of advanced information and communications technology to surface transportation in order to achieve enhanced safety and mobility while reducing the environmental impact of transportation" (USDOT, 2015). ITS brings whole new dimension to the route choice with its ability to create wireless communication between vehicles. We now have access to the real time database. Therefore it is necessary that the database collected can be used to improve the existing traffic situation. In recent years ITS has opened the opportunity to use the real time data to provide guidance to the users. For example, signal system at intersections could be adjusted with the use of the real time data. Depending on the traffic density at each intersection the signal timing can be varied. In conventional way it would have taken days of data collection and research before adjusting the signal timing. ITS can provide faster and also adapt to the changing condition.

One of the biggest challenges for planning profession is the time period required to bring changes. Changes in community take place rapidly and that can impact the transportation system. We need to focus on adaptable system that can cope with the changes. ITS comes up with adaptable system that can automatically adjust to the changing condition.

This research is focused on providing user with route based on environment, fuel efficiency and shortest path. It is important to strike balance between all these variables. These variables in many ways depend on each other. Same independent variables can drive these factors. The research purpose thus is to find a common ground between all these factors which can immensely reduce the negative environmental externalities.

Although the research is intended to reduce the environmental effect of auto but it can only provide temporary solution. In the long run the Vehicle Miles Traveled (VMT) will have to be reduced. Incorporation of more active mode of transport will have to be introduced. Until that transition takes place or people switch to the alternative fuel this model can help in keeping down the pollution by reducing emission of carbon di-oxide. Another important factor is the behavior of the user. Driving behavior of the people can impact the environment. People still have to be willing to reduce the impact of the auto on environment.

In recent years, focus has been on the smart growth to reduce the impact of the auto by reducing VMT. This research should not be considered as the alternative to that option. It is rather should be incorporated into those research working towards reducing VMT. This research focuses on reducing negative impact not the reduction of the VMT. Reduction of VMT depends on other factors that route choice can use but that is beyond the capacity of this research.

Technological improvement is also focusing on reducing the environmental impact by improving the fuel efficiency of the auto. Alternative fuel has also been proposed to stop the impact on the ecology. The trend of people moving from the traditional fuel to the alternative option has been slow. With low gas price and stagnant tax on the gas price make it even harder for the alternative fuel to achieve popularity among users.

Moving people from auto to transit is another way to reduce the VMT and carbon di-oxide emission. But transit lacks the connectivity desired by the user. Low density and scattered development pattern of the US makes it harder for transport planner to promote transit as an alternative to the auto.

Researchers still will have to work towards making transit better alternative to the auto. In the meantime, technology has given planners some much needed tools to reduce impacts of the auto on environment.

Objective

This research is focused on three objectives. Research is focused on identifying variables that will drive towards better route choice-

1. Finding out independent variables that are important for the environment, fuel efficiency and shortest path variables.
2. Finding a common ground between all these three variables.
3. Test the impact of real time data on route choice.

At the beginning, the research tries to identify important independent variables for each of these three variables: shortest distance, fuel efficiency and environment. Environmental impact will be judged by the emission of carbon di-oxide. There are several other pollutants that are involved with auto. But this research only focuses on one pollutant. Literature reviews are done to identify the independent variables for each of these variables. Real time data will be used for these independent variables to evaluate each of the variables for all possible routes between origin and destination.

These variables can be in conflict with each other. In that case, the goal will be to achieve a common ground among them by making compromise. Finally, the data have to be real time data so that the model can adjust to the changing conditions.

Broader goal of the research is to see if considering the variables like environment and fuel efficiency can reduce the environmental cost. At this point user is not paying for the pollution he/she is creating. But environmental impact will hurt everybody. In global scale, the US is ranked second among all other countries of world in producing carbon di-oxide (EPA, 2011). Transportation contributes a large share of that carbon di-oxide. About 31% of carbon di-oxide comes from the transportation sector (EPA, 2011). Though the US producing large share of carbon di-oxide, but the burden of the climate change will have to be borne by all the countries. More than the question of the equity it is hurting global climate and at some point consequences will be detrimental for everyone.

Chapter 2

Literature Review

This research paper works mainly with the three variables: environment, fuel efficiency and shortest path. One goal of the research is to test the efficacy of ITS. Thus the literature review will focus on transport agencies vision on ITS. Then we will move onto the three variables that are core to this research. The goal of this chapter is to take guidance from studies done on each of these variables and come up with a list of independent variables.

Intelligent Transportation System

Stephen Ezell argues in favor of Intelligent Transportation System. He describes ITS as having far more benefits compared to the highway investment (Ezell, 2010). ITS is now covering wide range of aspects through innovative applications. Stephen Ezell mentioned some of the broad aspects in transportation and specific applications that are serving those broad categories of transport planning.

Table 2.1: Broad ITS categories and applications under each categories

ITS Category	Specific ITS application
Advanced Traveler Information System	Real-time Traffic Information Provision Route Guidance/Navigation Systems Parking Information Roadside Weather Information Systems
Advanced Transportation Management Systems (ATMS)	Traffic Operations Centers (TOCs) Adaptive Traffic Signal Control Dynamic Message Signs (or “Variable” Message Signs) Ramp Metering

ITS Category	Specific ITS application
ITS-Enabled Transportation Pricing Systems	Electronic Toll Collection (ETC) Congestion Pricing/Electronic Road Pricing (ERP) Fee-Based Express (HOT) Lanes Vehicle-Miles Traveled (VMT) Usage Fees Variable Parking Fees
Advanced Public Transportation Systems (APTS)	Real-time Status Information for Public Transit System (e.g. Bus, Subway, Rail) Automatic Vehicle Location (AVL) Electronic Fare Payment (for example, Smart Cards)
Vehicle-to-Infrastructure Integration (VII) and Vehicle to-Vehicle Integration (V2V)	Cooperative Intersection Collision Avoidance System (CICAS) Intelligent Speed Adaptation (ISA)

Source: Stephen Ezell, 2010. Intelligent Transportation Systems

ITS is also capable of increasing road safety. Driverless car is also a step towards achieving safer environment for the pedestrian. It can take out some of the user errors and making roads safer for pedestrian movement.

Lethitha vajanakshi et. al. (2010) describes the process of the ITS as acquiring data, analyzing data and provide user the data in a way so that it can guide the user. User therefore does not need to rely on the memory or experience. Existing situation of route can change due to unforeseen circumstances. ITS thus provide the opportunity to user to adapt to the changing condition. Relying on experience of driving on a same route will not help because user is unaware of the recent events taking place on that route. In an event of accident traffic may slow down. ITS can impart that data to the user and user can change his/her route to save time and avoid waiting in long line. There is also environmental implication of that data. Congestion increases environmental impact by increasing emission of carbon di-oxide. By imparting data to the user, ITS can reduce potential congestion on a specific location and thus reduce environmental impact.

The US transport agencies have been using the ITS for improving transportation system. For a country like the US with massive road infrastructure having real time data can help in many ways. Someone unfamiliar with the road network depends heavily on the GPS to get guidance and navigation. ITS programs under Intermodal Surface Transportation Efficiency Act (ISTEA) had impressive outcomes. Based on that result Congress passed the Transportation Equity Act for the 21st Century (TEA-21) in 1998 (FHWA, 2011). The act renewed funding for the ITS Program and refocusing the program on adoption and deployment of ITS technologies.

Some of the goals described in Strategic Plan of FHWA for 2011-14 were as follows-

- A fully connected, information-rich environment to allowing users to gather full knowledge of all aspects of the transportation
- Introduction of wireless technologies that enable transformative change.
- Enhance communication by imparting accident data
- Coordinate action and response among vehicles an Travelers
- Collecting data on environmental impact for future use
- Vehicles of all types that can communicate with traffic signals to eliminate unnecessary stops and help and people drive in a more fuel-efficient manner.
- Vehicles that can communicate the status of on-board systems and provide information that can be used by users
- Help in informed choices about travel modes.

US DOT is planning to introduce ITS in better management of transportation system. They are focusing on some of the aspects such as connected vehicles, automation, interoperability etc. Connected vehicles are the way of sharing data among the vehicles. Shared information can play massive role in reducing accident rates. User can gather information about locations of potential accident. That same data can be used by transport planners/engineers to look into the design aspects or any other reason that is causing frequent accidents. Connected vehicles can provide knowledge about the route condition such as sharp turn, places with higher pedestrian density etc (USDOT, 2014).

Automation is focused on moving some of the driving aspect to the automated system to reduce driver errors. Sensor in car now being installed that can provide information about a car on the blind spot. Fully automated car is also in under research at present. Automated car is believed to be bringing a major change in transportation system.

One of the focuses of the DOT is to marketing the available applications. Although the applications and innovative ITS can change the transportation but user will still have to adapt to the changes that ITS is bringing. It is vital to make the applications user friendly. An application like connected vehicle will not be able to achieve best results unless most people start to use them (USDOT, 2014). So marketability of these applications is vital issue in improving transportation system using ITS.

Shortest Path

It is difficult to predict travel behavior of a driver. But the travel behavior factor does change transportation pattern in a big way. Aly Tawfik and Hesham Rakha (2012) describe four different ways to identify individual travel behaviors. They argue that driver heterogeneity can be addressed by models of driver perceptions of travel conditions: travel distance, time, and speed. Also, it can be addressed from the perspective of driver learning trends and models of driver-types. They found personal traits to be an important aspect in predicting the heterogeneity of travel behavior.

Aly Tawfik and Hesham Rakha (2012) employed three different variables such as a driving simulator experiment, an in situ driving experiment in real-world conditions, and a naturalistic real-life driving experiment. Deviations of real world pattern were found to be due to the personal habits of drivers rather than other transportation factors. Interesting findings from the research was that the people see speed and travel time as the more important factor than the actual distance. It shows that people tend to compare routes based on the travel time. User will chose a route that will give them lesser travel time than the other. Speed is something that can be perceived by the people as means to achieve better travel time. Therefore it makes sense to choose route that has the capacity to incorporate high speed traffic.

Among the traits of the driver experience and knowledge of the community plays vital role. People living and driving in the same locality are likely to have good idea about the road condition, intersections and factors that can change the travel time (Tawfiq and Hesham, 2012). For example, schools locations, peak hour, off peak hour can provide good idea to the user about route with least travel time. However, depending on the driver they may want to focus on the average speed of the route. Focusing on the speed can be misleading. A route with consistent speed can allow user to reach destination quicker than the route with high speed and frequent stops.

Frequent stopping is also highly detrimental to the environment. Carbon di-oxide emission increases on the events of stopping. A large share of the carbon di-oxide comes from the events of stopping and starting again.

Hainan Li, Randall Guensler, and Jennifer Ogle (2005) focuses on the work related travels. Work related travels are more likely to increase the VMT as people drive five days a week. It is a difficult choice for the user to choose between several alternative routes. The research paper argues the user have different choices based on factors like age, gender, personality, experience, familiarity etc.

The research has also identified some crucial factors in route choice. The socio-economic consideration is important for the user. Cutting down on the fuel consumption is one of them. That driving behavior in long run will save them some money. Fuel economy is a big factor when user is trying to choose from alternative routes (Li, Guensler & Ogle, 2005). If a model can guide user to fuel efficient route, the user will be attracted to use the model.

Hainan Li, Randall Guensler, and Jennifer Ogle (2005) also argues that people has a certain level of inertia when it comes to change their route. People choose a route that can satisfy their needs. Again, these needs change with the personal trait and also social environment. Once a user chooses a route it requires them to cross a certain threshold before they would consider choosing another route. Experience plays a vital role in this process. People will remember their experience of driving on certain route. While choosing between alternative routes he/she will depend on the past experience.

Introduction of GPS did make a big difference. It provides user the option to choose the route with least travel time among the available routes. GPS depends on the historical database. Incorporating real time data can change dynamic more favorably. GPS taking real time data in consideration will be able to provide even better prediction of the travel time.

Lei Zhang and David Levinson looked into the impact of the real time data on the user. ITS focuses on providing the user with data that can helpful for driver to make decision. The challenge for the ITS is to identify which data the user is more interested on. Experiment needs to be done to identify the valuable and useful data for the user.

The research by Lei Zhang and David Levinson (2008) measured the impact of the real time data on the user. Researchers provided the important real time data to the user. User took the data and changed their route based on the knowledge they received. It shows that even though there is a certain amount of reluctance among the user to change the route but given the real time data people will be interested in changing their route to save time.

That finding also proves that people will be interested in using real time data. That is also important from the point of view of the marketability. Collecting real time data can be expensive and the user need to be willing to use the data. As more people start using the available applications providing real time data researcher can also gather more important data by introducing connected vehicle.

The data needs to be relevant to the user before they start depending on the real time data. Relevant data is one difficult factor to identify. As we have seen in earlier studies that the need of the user varies greatly depending on the age, gender, income etc. Most importantly it can vary greatly with the personal traits of a person. There are some common needs among the people such as the shortest travel time, fuel efficient route. Other factors that real time data can predict might not seem very relevant to the user. Therefore, it is necessary to find common interest among general people before user can be exposed to new technology with real time data.

Evaluating a way to identify a best possible route is difficult. A study by Bekhor, Ben-Akiva and Ramming (2006) describes Logit and Probit models. These are more popular methods used by the researcher in route choice. In case of the best route choice these models can take into account several variables and analyze these data to provide appropriate route.

ITS is focused on using these data, and process these data to provide user with a guideline. GPS uses shortest path rule invented by Dijkstra. It can take into account variables such as the distance and allowed speed limit.

Gravity model is one of the other methods that widely used in transportation to identify the point of attraction for the user. It is important to know the travel pattern of the users. It helps predict the actual expected traffic on each of the route. That factor in the end can become the guidance for designing models. In order to come up with models that can be useful, we also need to know about the travel pattern. As discussed earlier it is also important that the model can be marketable. To achieve that marketability researcher need to know the demand and requirements of the user. Only pertinent models can attract user to use the application.

ITS has been preferred by user because it can function as the memory of the user. User no longer needs to rely on his/her experience. That dependence on the technology can lead to better use of the transportation system. ITS has not only helping the user to guide and choose routes it can also be employed in transport management (Ramming, 2002).

Nikhil Sikka (2012) conducted a research to identify the user behavior while driving on unknown route. Lei Zhang and David Levinson in their study showed that the route choice can differ based on the real time data. This research is a different method to evaluate importance of the route information.

This research by Nikhil Sikka (2012) does point towards the importance of the information about the route. Additionally, this research can identify the travel behavior of the user. That aspect is difficult to accumulate in a way to understand the broader underlying implications. But it is clear that the driving behavior of the individual has long term impact on the transportation system.

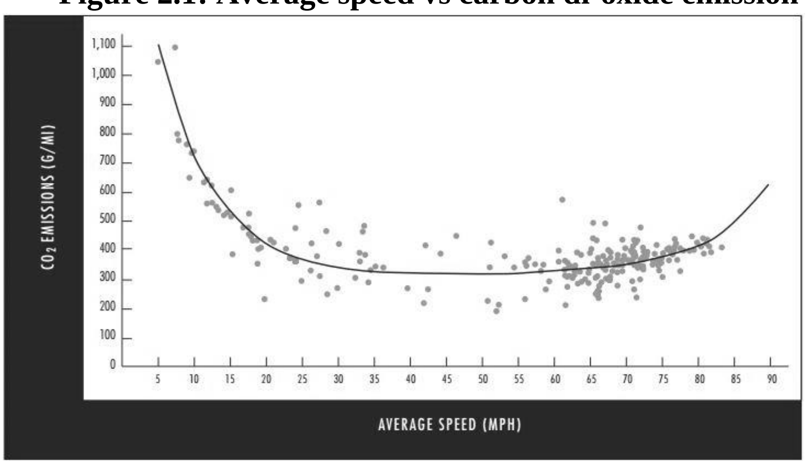
Environment

Auto has negative impact on the environment. But auto oriented development at this point is difficult to reverse and time consuming. With threat of climate change looming it is important that transport planner/engineers come up with a strategy to curb the negative impacts of the auto. New technology has in implementation to reduce that negative impact. Making car more environmental friendly is one way scientist is trying to reduce the negative environmental impact. It has been also realized that with better routing system environmental impact can be reduced.

Eco-friendly route is a concept that has been working towards providing route choice that can at least reduce some of the negative impacts of auto. With advent of Smart Phone the Smart Phone applications have started to gain popularity. A study conducted by Pereira et. al. (2014) describes the efficacy of SmartDecision app to make better route choices. The research found that the app can reduce the health and social cost by 17-35% by choosing the best possible route among the alternatives.

Barth and Boriboonsomsin (2010) gather data to understand the relationship between the speed and carbon di-oxide emission. Average speed vs Carbon di-oxide emission forms a concave line. Figure 1 shows that at speed 35- 55 mph carbon dioxide emission drops to its lowest. But with increase/decrease from this range increase carbon di-oxide emission noticeably.

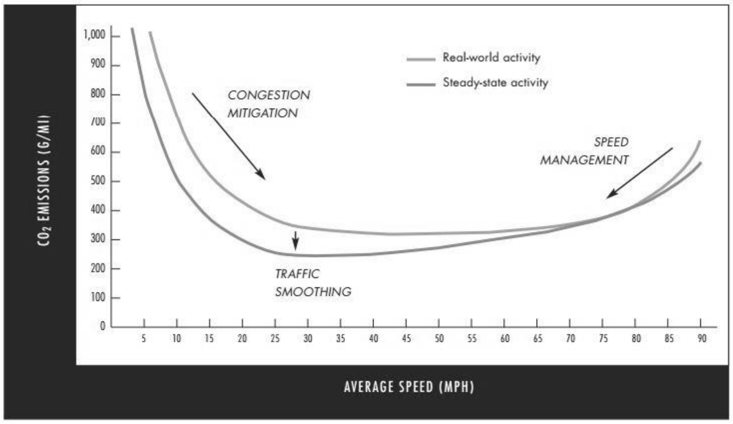
Figure 2.1: Average speed vs carbon di-oxide emission



Source: Matthew Barth & Kanok Boriboonsomsin (2010), Traffic Congestion and Greenhouse Gases

Barth and Boriboonsomsin (2010), in their study also mention importance of smooth traffic to reduce environmental impacts. Figure 2 shows the impact of consistent speed on carbon di-oxide emission. With the decrease of acceleration/deceleration/stopping events carbon emission can be reduced noticeably.

Figure 2.2: Average speed vs carbon di-oxide emission under real world condition



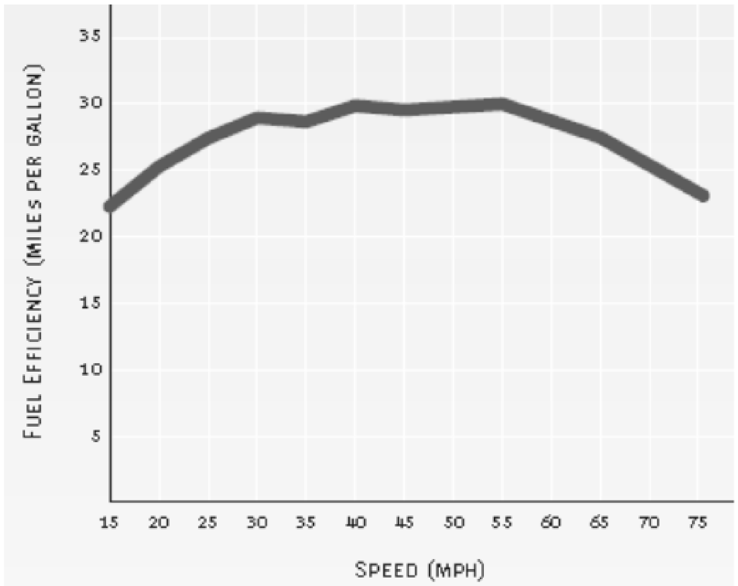
Source: Matthew Barth & Kanok Boriboonsomsin (2010), Traffic Congestion and Greenhouse Gases

Fuel Efficiency

Our other goal of the research is to find a route that will be more fuel efficient. Like the environment fuel efficiency gets impacted by the congestion. Speed also plays a role in case of fuel efficiency.

Frith and Cenek (2012) in their research established a relationship between the fuel efficiency and speed. They found that at 55 mph speed, a vehicle can achieve the best fuel efficiency. With the increase in speed the fuel efficiency is likely to drop. Again at speed higher than the 55 mph environmental impact in form of carbon di-oxide emission is also higher. Figure 3 shows the correlation between speed and fuel efficiency based on the data collected from 1988-95.

Figure 2.3: Average speed vs fuel consumption



Source: William Frith & Peter Cenek (2012). Standard metrics for transport and driver safety and fuel economy, Retrieved on from

Variables

Literature review gives an idea about the variables that can be used in choosing routes. These variables will impact the variables: environment, fuel efficiency and shortest path.

Table 2.2: Selected independent variables based on literature review

Variables	**Independent variables**
Shortest distance	Travel time
Environment	Number of intersections Physical infrastructure Congestion
Fuel Efficiency	Speed Congestion

Before moving into the modeling relationship among these variables needs to be identified. Shortest distance is generally the route the takes lowest time to arrive at the destination. This variable is measured based on the travel time. Shortest travel time is used by Global Positioning System (GPS) to provide the user with best route among all the alternatives. In most cases, taking highway will provide the shortest travel time. In case of the environmental variable the speed is an important factor. Speed vs carbon emission forms a concave graph. Speed lower than 35 mph and greater than 65 mph can increase the carbon dioxide emission significantly. Therefore, speed has been identified as one of the variables for the study.

Other two independent variables of intersection and physical infrastructure are also important. Event of acceleration, deceleration and stopping increases the carbon dioxide emission. Acceleration, deceleration and stopping events can depend on the number of signalized intersections. More signalized intersections increase the probability of acceleration, deceleration and stopping events. Poor physical infrastructure will also slow down the traffic and increase events of acceleration/deceleration. The prime factor that will reduce the speed of auto below speed limit is the congestion. Real time data do provide us the data on congestion at certain time of the day. That real-time data can be used with known physical infrastructure and signalized intersection of each route to evaluate the environmental impact.

Fuel efficiency increases with speed up to a certain level. At 55 mph most cars at its best in regards to fuel efficiency. Lower speed decrease fuel efficiency and speed greater than 80 mph will start reducing the fuel efficiency.

Best route will be the one that will provide auto mobile to have consistent speed with least interruptions on its way. However, the driving behavior of the individual will also have to conform to our assumption.

Assumption

The research assumes that people do believe in environmental impacts of auto and do not currently posses any option to avoid the environmental impacts. However, people will use the opportunity to curb the impact on the environment if they are given the option. Driving behavior of people plays a vital role in reducing negative impacts of the auto.

Apart from the variables this research is considering there are several other varaibales that can alter the outcome. Factors like driving behavior, car make and model, error of one user can change the result of the model. But the attempt of the research is to identify the individual impact of these factors in improving the overall transport system. For this research we are assuming a common set of origin and destination, same user and same car make and model. Therefore the result should be able to provide a good basis for the comparison.

Chapter 3

Methodology

The goal of the research is to identify the best route among alternatives. The variables as mentioned earlier are shortest distance, environment and fuel efficiency. Best route for this study is defined as the one that has least impact on environment and increase fuel efficiency. Lower environmental impact refers to least carbon di-oxide emission.

Shortest path is determined using the path length and defined speed limit. If the car could drive without any stopping/accelerating/decelerating then the path could be the most environment friendly route. As the number of signalized intersection reduces speed, negative impact on environment increases. We can assume the travel time for each route by comparing the recorded data from the past. But real-time data use can significantly reduce dependence on the historical data. In addition to that, the model can adjust to the changing situation and provide the user with better route option.

Fuel efficiency is dependent on the speed. Higher speed insures better fuel efficiency. User driving on freeway with speed of 55 mph will save more fuel than someone driving on city roads with 35 mph. If the national speed limit of the city roads could have been increased to 55 mph better fuel efficiency could have been achieved. But safety issue of the community would have been sacrificed to achieve that. Stake for that bargain is too high. Researches show that fuel efficiency at 35-35 mph level is also very compelling. So the issue that prohibits us from achieving better fuel efficiency is congestion.

All these factors point towards the fact that the consistent speed increases fuel economy and lesser event of acceleration/deceleration/stopping decreases the environmental impact. Although auto can have several different negative impact on the environment but we are only considering carbon di-oxide emission as the criteria to measure negative impact on the environment.

This research will rate each of the alternative route based on the shortest distance, eco friendliness and fuel efficiency. Each of these routes will be ranked according to these variables. Then finally, these ranking will be taken into consideration to provide best possible route.

Depending on literature review and Figure 1 and Figure 2, it is clear that the congestion free route will have less impact on the environment compared to the one with higher congestion. In real world, congestion will exist but using real time data we can avoid routes with high congestion and chose more environment friendly route. Thus the target of the research will be to find a route that has less congestion.

Another important factor influencing the congestion situation is the physical infrastructure. Due to aging infrastructure congestion is inevitable. Even in the events of maintenance traffic is likely to get slower causing congestion. Especially in case of the City of New Orleans congestion is created both because of the poor physical infrastructure and also during maintenance period. Maintenance takes long time which can worsen the congestion situation for months.

Real time data is also capable of providing incidence data. Accidents cause routes to slow down temporarily and contribute to congestion. In this research we are not focusing on the impact of the accident events.

At speed 55 mph, automobile can achieve both of our objectives. It can reduce the negative impact on the environment and also increase fuel efficiency. But the national speed limit on city roads is 35 mph. User will not be able to find highways with 55 mph speed routes from their origin to destination every time. For all the independent variables we come up with numeric points based on the ranking. Summation of independent variables gives numeric point for each of the three variables. Numeric point will decide the best possible route.

We have two different methodologies for this study. One is ideal or theoretical model other one is the real-world example model. Theoretical model includes physical infrastructure as an independent variable for the environmental variable. But in real world scenario infrastructure data was not available as a real-time data. Therefore, we did not include that independent variable in our final analysis. But physical infrastructure can have influence on speed of the traffic. Therefore, it has great impact on the environment and fuel efficiency. Having Level of Service data based on the infrastructure could have added more accuracy to the model. Figure 4 and Figure 5 shows the ideal methodology and methodology used for the case studies in this research paper.

Figure 3.1: Flow chart of ideal model

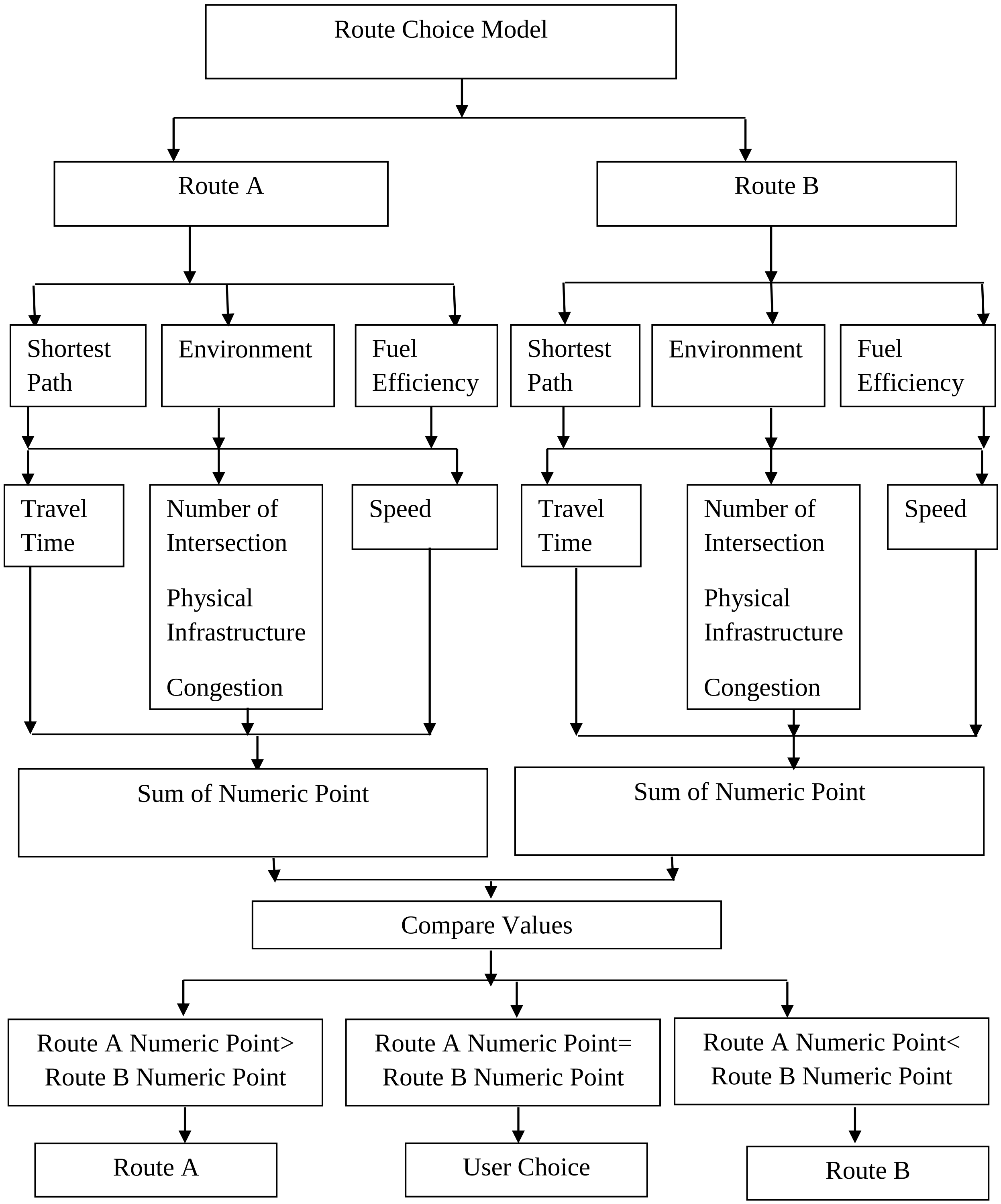
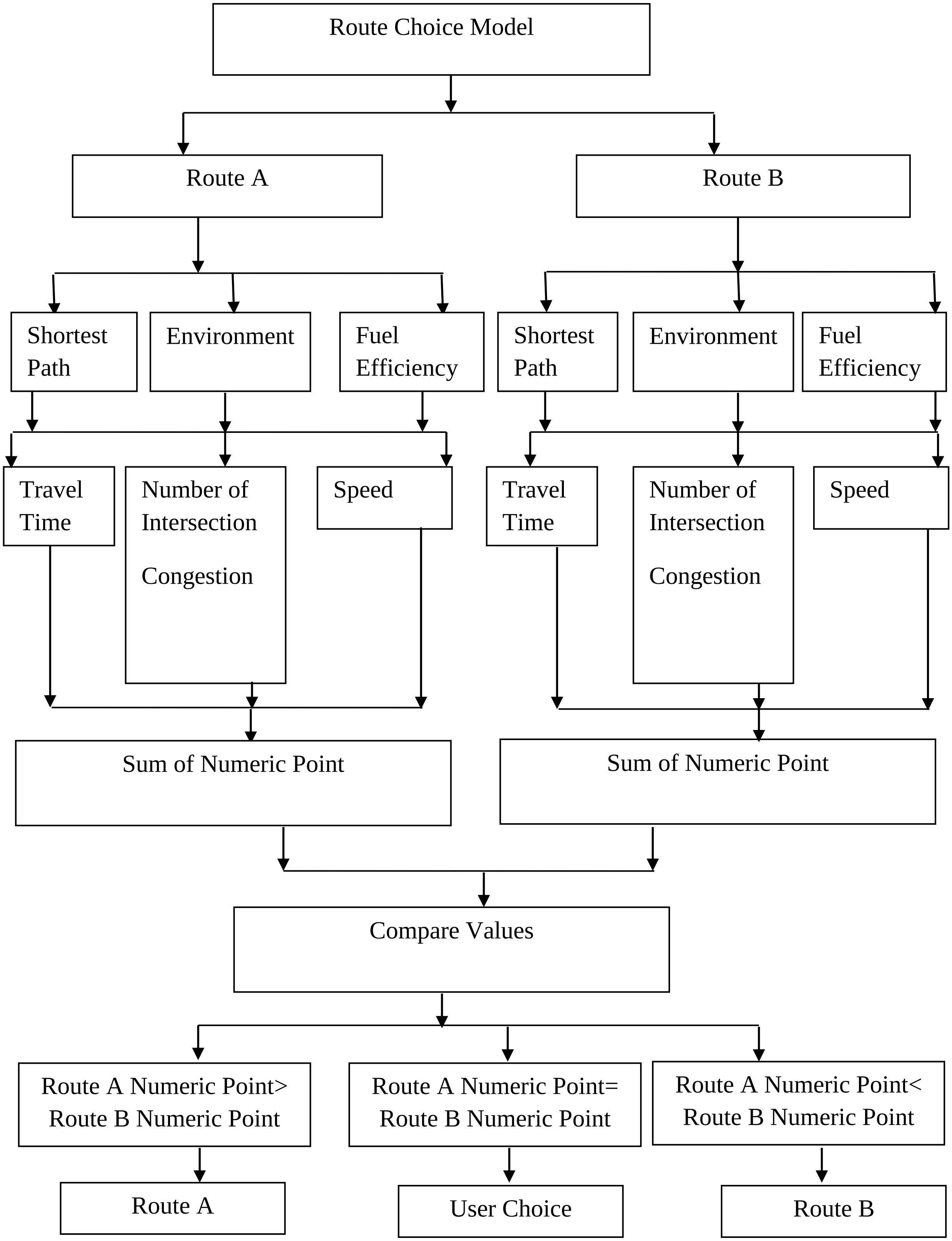


Figure 3.2: Flow chart of model used for case studies



The Figure 3.2 shows the flow of the work process to select the appropriate route. We will analyze all the available alternative routes and assign a numeric value according to the ranking. Sum of the ranking for each value will be compared. One with the higher value will be selected as the route. In case of a tie the user him/herself will be able to choose the route. It allows a bit more flexibility. User can in this case depend on his/her knowledge of the locality to select the appropriate route.

For the case studies, we have used the real time data provided by the Google maps. Google map provides data on congestion. Based on the speed of the traffic they symbolize the route with blue, orange and red color. Red symbolizes part of the route with slowest traffic and orange represents traffic slower than normal expected traffic. Traffic congestion thus point to the fact that the auto are moving slower than the speed limit.

To determine the speed range under each color on Google map, we drove on selected routes. In the case of the route represented with color orange, the speed of the auto has been found to be between 20-35 mph during observation. In case of the route colored red, speed of auto drops below the 20 mph.

Depending on the speed of the auto carbon di-oxide emission varies as we have seen from the average speed vs carbon emission graph (Figure 1). Although the carbon di-oxide emission varies within the speed range of 20-35 mph and also 0-20 mph, but we will consider the average carbon di-oxide emission taking place in each range.

Table 3.1: Average carbon di-oxide emission at different speed

Speed (mph)	**Carbon di-oxide emission (gram/mile)**
Above 55	400
35-55	350
20-35	400
Below 20	700

Our theoretical model considers the impact of the physical infrastructure. We have provided numeric point to the physical infrastructure of the route.

Table 3.2: Assigned numeric point to physical infrastructure

Physical Infrastructure condition	Numeric point
Good	2
Poor	1

These numeric points can be assigned based on the Level of Service (LOS) of each route. Routes with better LOS based on the quality of infrastructure will be assigned 2 numeric points and others will receive 1 numeric point. However, we are not going to include that in our case studies. Physical infrastructure data is not available as real time data. In case studies, we assigned every route same numeric point of 1 because we do not have real time data on physical infrastructure.

Number of events on each route will be considered also. It is important to notice that we have already considered the impact of congestion. So even though user on the congested route will experience events of acceleration/declaration/stopping, we will not consider that under this independent variable to avoid double count. We will consider the signalized intersection numbers as the potential source of acceleration/deceleration/stopping events.

We can use the similar breakdown of the speed to check the fuel efficiency. Miles driven at each of the speed range will be multiplied to find out fuel efficiency of each route. Route with lowest fuel consumption will be most fuel efficient route and will receive higher numeric points than other alternative routes.

Table 3.3: Average fuel consumption at different speed

Speed (mph)	Average Fuel Consumption (Liter/100 mile)
Above 55	11.2
35-55	12.8
20-35	15.2
Below 20	16.8

Finally, we need to consider the shortest distance between origin and destination. Length of the route and speed limit can give us idea about the shortest path but we also need to consider other aspects like signalized intersection and congestion. Real time data from Google map does provide the information of approximate travel time. We will use that real-time data for shortest path variable.

Chapter 4

Results

Five case studies have been completed as part of the research. The routes were chosen to test the model under different types of route. Some of the choices allowed comparison between city streets and highways. For one origin destination set all three alternative routes were highways. Even among highways there was difference in speed limits. The goal was to cover these different dynamics and find the efficacy of the model.

Case Study I

Route from University of New Orleans to French Quarter was chosen for the first case study. University of New Orleans was the origin and French Quarter was the destination. Map of the routes have been included in the Appendix.

Available Real Time Data

There are three possible routes from the origin to the destination. There can be more alternative routes but user will not be willing to use the one that provides significantly high travel time than the other. These three routes were selected based on the fact that they are very similar in length and travel time.

Table 4.1: Route length and approximate travel time for each route

Route	Length (mile)	Approximate travel time (min)
Route 1	5.2	19
Route 2	5.9	21
Route 3	5.6	22

Approximate travel time considers the historical data to predict the travel time. These routes will be analyzed based on each of the variables. To analyze each route the independent variables will be calculated. Each of the independent variables will require datasets. We will only use real-time dataset for the case studies.

Speed is one of the factors that are required to be used for both environment and also fuel efficiency. One of the assumptions of the research was that the people will be driving according to the posted speed limit. The aberrations are difficult to incorporate in the model. However, in case of people driving above the speed limit of 35 mph but below the 55mph tend to have the similar impact on the environment. Therefore, user driving higher than 35 mph will not have varied impact. Again, we assume that user will not be driving at speed of 55 mph on a route with posted speed limit of 35 mph. Similar argument cannot be made for the route with 55 mph allowable speed limit. With increase of speed above 55 mph environmental impact in form of carbon di-oxide emission increases severely. In measuring environmental impact and fuel efficiency, we consider the four speed limits for the three routes. Miles driven at each range of speed is registered to calculate the environmental impact. Again we assumed that the user will behave rationally and abide by the posted speed limit.

We calculated the miles driven under each range of speed limits mentioned earlier in Table 3.1.

Table 4.2: Miles driven at each speed range

Route	Miles driven above 55 mph	Miles driven at 35-55 mph	Miles driven at 20-35 mph	Miles driven at 0-20 mph
Route 1	0.00	4.88	0.32	0.00
Route 2	0.00	5.65	0.30	0.04
Route 3	0.00	5.02	0.52	0.08

Another factor is the potential stop/acceleration/deceleration events. These are the number of signalized intersections.

Table 4.3: Number of intersection on each route

Route	Number of Intersection
Route 1	10
Route 2	9
Route 3	13

Based on the information each of the independent variables now can be calculated to find out the variables. Environment variable will calculate how much carbon di-oxide emission will take place under each range of speed limit. Fuel efficiency variable will calculate amount of fuel used on each route to get to the destination.

Shortest Path

Based on the available approximate data route one has the shortest approximate travel time. The route with shortest travel time will receive the highest numeric point according to the ranking.

Table 4.4: Assigned numeric points based on the approximate travel time

Route	Length (mile)	Approximate travel time (min)	Numeric point
Route 1	5.20	19	3
Route 2	5.99	21	1
Route 3	5.62	22	2

Environmental Impact

For the calculation the research is using two independent variables: carbon di-oxide emission and the number of signalized intersection. Carbon di-oxide emission is calculated using the following equation:

Carbon di-oxide emission for Route A= ∑(Miles driven at a specific speed Limit (Table 4.2) × Average carbon di-oxide emission at that speed (Table 3.1))

Table 4.5: Assigned numeric points based on carbon di-oxide emission

Route	Carbon Di-oxide emission at different speed (gram)			Total carbon di-oxide emission (gram)	Numeric Point
	35-55 mph	20-35 mph	0-20 mph		
Route 1	1,708.00	128.00	0.00	1,836.00	3
Route 2	1,977.50	120.00	28.00	2,125.50	1
Route 3	1,757.00	208.00	56	2,021.00	2

We have the number of signalized intersection. Based on the number of signalized intersection we have assigned numeric points to each of the routes. Impact of the signalized intersection can sometime be even greater than the congestion itself.

Table 4.6: Assigned numeric points based on the number of intersection

Route	Number of Intersection	Numeric Point
Route 1	10	2
Route 2	9	3
Route 3	13	1

Now we can calculate the most eco-friendly route by summation of the numeric point achieved by each of the routes. We did not consider the physical infrastructure. We will assign all the routes same numeric point.

Table 4.7: Numeric points based on all three independent variables of environment

Route	Numeric point			Total numeric point
	Carbon Di-oxide emission	Signalized intersection	Physical infrastructure	
Route 1	3	2	1	6
Route 2	1	3	1	5
Route 3	2	1	1	4

Based on the real time data Route 1 is the most eco-friendly route with highest numeric points. Although the Route 1 has more signalized intersection than Route 2 but route 2 has higher carbon di-oxide emission.

Fuel Efficiency

Fuel consumption for the Table 4.8 has been calculated using the flowing equation-

Fuel Consumption for Route A= ∑(Miles driven at a specific speed Limit (Table 4.2) × Average fuel consumption at that speed (Table 3.3)/100)

Table 4.8: Assigned numeric points based on the fuel efficiency

Route	Fuel consumption at different speed (liter)				Total fuel consumption (liter)	Numeric point
	55+ mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	0.00	0.62	0.05	0.00	0.67	3
Route 2	0.00	0.72	0.05	0.01	0.78	1
Route 3	0.00	0.64	0.08	0.01	0.74	2

Overall numeric points can be calculated to find out the appropriate route. Table 4.9 shows the total numeric points for each of the route. Route 1 has higher numeric value than the others. Therefore the Route 1 is the best route.

Table 4.9: Total numeric points based on all three variables

Route	Shortest path	Environment friendliness	Fuel efficiency	Total numeric points
Route 1	3	6	3	12
Route 2	1	5	1	7
Route 3	2	4	2	8

Case Study II

Route chosen for the second case study starts from University of New Orleans and ends at Chalmette. University of New Orleans was again the origin and Chalmette was the destination in this case. Maps have been provided in the Appendix.

Available Real Time Data

There are three possible routes from the origin to the destination. Table 4.10 shows that the Route 1 is the longest of the all three. But according to the travel time Route 1 provides the shortest path from origin to the destination. The reason behind that is the presence of highway within that particular route.

Table 4.10: Route length and approximate travel time for each route

Route	Length (mile)	Approximate travel time (min)
Route 1	17.4	24
Route 2	10.6	29
Route 3	10.7	28

Each of the routes has been categorized into four speed ranges based on the allowable/posted speed limits. Miles driven under each speed limit have been recorded.

Table 4.11: Miles driven at each speed range

Route	Miles driven above 55 mph	Miles driven at 35-55 mph	Miles driven at 20-35 mph	Miles driven at 0-20 mph
Route 1	7.65	7.29	1.23	1.23
Route 2	0.00	9.45	1.06	0.09
Route 3	0.00	9.75	0.81	0.14

Table 4.12 shows that the route 3 has most number of intersections. Signalized intersections increase the potential of deceleration/acceleration/stopping events. So any driver driving on route 3 is likely to experience more deceleration/acceleration/stopping events.

Table 4.12: Number of intersection on each route

Route	Number of intersection
Route 1	15
Route 2	16
Route 3	24

Shortest Path

Based on the available approximate data route one has the shortest approximate travel time. The route with shortest travel time will receive the highest numeric point according to the ranking.

Table 4.13: Assigned numeric points based on the approximate travel time

Route	Length (mile)	Approximate travel time (min)	Numeric point
Route 1	17.4	24	3
Route 2	10.6	29	1
Route 3	10.7	28	2

Environmental Impact

Carbon di-oxide emission for Route A= ∑(Miles driven at a specific speed Limit (Table 4.11) × Average carbon di-oxide emission at that speed (Table 3.1))

Table 4.14: Assigned numeric points based on carbon di-oxide emission

Route	Carbon di-oxide emission at different speed (gram)				Total carbon di-oxide emission (gram)	Numeric Point
	55+ mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	3,060.00	2,251.00	492.00	861.00	6,964.50	1
Route 2	0.00	3,307.50	424.00	63.00	3,794.50	3
Route 3	0.00	3,412.50	324.00	98.00	3,834.50	2

Similar to the Case Study I we will use the number of intersections on each of these routes. Table 4.16 shows that Route11 has least number of intersections. So, Route one will get the highest numeric point of three.

Table 4.15: Assigned numeric points based on the number of intersections

Route	Number of intersection	Numeric point
Route 1	15	3
Route 2	16	2
Route 3	24	1

At this point, we have calculated all three factors for the environment variable. We can sum all these values to come with a basis to compare each routes based on their environment friendliness.

Table 4.16: Numeric points based on all three independent variables of environment

Route	Numeric point based on all factors			Total numeric point
	Carbon di-oxide emission	Signalized intersection	Physical infrastructure	
Route 1	1	3	1	5
Route 2	3	2	1	6
Route 3	2	1	1	4

Route 1 did poorly in carbon di-oxide emission. Despite shorter travel time Route 1 emits more carbon di-oxide than the other two. Even though it had less number of signalized intersections but carbon di-oxide emission was much larger. Comparing to the other two routes Route 1 has longer path to travel. Route 1 would have been the best route due to shortest travel time if we had not considered other variables. It also proves that least amount of travel time does not mean anything in context of environment. VMT is an important aspect that was missing from route choice. Environmental impact variable brings that factor back into the consideration.

Fuel Efficiency

Fuel consumption will be calculated by using Table 4.11 and Table 3.3. Following is the equation to calculate the fuel consumption.

Fuel Consumption for Route A= ∑(Miles driven at a specific speed Limit(Table 4.11) × Average fuel consumption at that speed (Table 3.3)/100)

Table 4.17: Assigned numeric points based on the fuel efficiency

Route	Fuel consumption at different Speed (liter)				Total fuel consumption (liter)	Numeric point
	60 mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	0.86	0.93	0.19	0.21	2.18	1
Route 2	0.00	1.21	0.16	0.02	1.39	2
Route 3	0.00	1.25	0.12	0.02	1.39	2

Route 2 and Route 3 has the same level of fuel consumption. Therefore they both were assigned same numeric points.

Now we consolidate all three variables to identify the best route among them. Route 1 and Route 2 achieves same numeric points. But in this case if user focuses on the environment then Route 2 becomes the best route among three alternatives.

Table 4.18: Total numeric points based on all three variables

Route	Shortest path	Environment friendliness	Fuel efficiency	Total numeric points
Route 1	3	5	1	9
Route 2	1	6	2	9
Route 3	2	4	2	8

Case Study III

For this case study origin was the Waldo Dr. and the destination was Walmart at the Veterans Blvd. We came up with three alternative routes based on their similarity in length and travel time. Maps for this set of origin destination have been provided in the Appendix.

Available Real Time Data

Table 4.19 shows that Route 1 is the shortest path based on the approximate travel time. Length of the each route is similar in this case. Path with least length has the highest travel time.

Table 4.19: Route length and approximate travel time for each route

Route	Length (mile)	Approximate travel time (min)
Route 1	14.1	23
Route 2	13.4	26
Route 3	11.9	33

Miles driven under each posted/allowable speed limit within the routes has been shown in the Table 24. Route 3 does not have highway segment. That is one of the reasons of longer travel time despite shorter distance.

Table 4.20: Miles driven at each speed range

Route	Miles driven Above 55 mph	Miles driven at 35-55 mph	Miles driven at 20-35 mph	Miles driven at 0-20 mph
Route 1	9.01	2.51	1.07	1.51
Route 2	7.50	3.38	1.01	1.51
Route 3	0.00	9.67	1.91	0.32

Route 3 also has higher number of signalized intersections. That is also a reason for longer commute time.

Table 4.21: Number of intersection on each route

Route	Number of Intersection
Route 1	7
Route 2	9
Route 3	25

Shortest Path

Based on the available approximate travel time data route one has the shortest approximate travel time. Route 1 thus receives highest numeric points among all three routes.

Table 4.22: Assigned numeric points based on the approximate travel time

Route	Length (mile)	Approximate travel time (min)	Numeric point
Route 1	14.1	23	3
Route 2	13.4	26	2
Route 3	11.9	33	1

Environmental Impact

Carbon di-oxide emission is highest for the route 3. Equation used for the calculation is- Carbon di-oxide emission for Route A= ∑(Miles driven at a specific speed Limit (Table 4.20) × Average carbon di-oxide at that speed (Table 3.1))

Table 4.23: Assigned numeric points based on carbon di-oxide emission

Route	Carbon di-oxide emission at different speed (gram)				Total carbon di-oxide emission (gram)	Numeric Point
	55+ mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	3,604.00	878.50	428.00	1,057.00	5,967.50	1
Route 2	3,000.00	1,183.00	404.00	1057.00	5,644.00	2
Route 3	0.00	3,384.50	764.00	224.00	4,372.50	3

Route 1 has least number of signalized intersections. Route 3 is worst among all three in context of signalized intersection. It has significantly higher number of signalized intersections compared to other two.

Table 4.24: Assigned numeric points based on the number of intersections

Route	Number of Intersection	Numeric Point
Route 1	7	3
Route 2	9	2
Route 3	25	1

Based on all three factors route 3 has advantage over the other two. Important thing to notice is that the highways with speed limit of 60 mph or above is not helping the environment. Carbon di-oxide emission at 60 mph is same as that of speed below 35 mph.

Table 4.25: Numeric points based on all three independent variables of environment

Route	Numeric Point			Total numeric point
	Carbon di-oxide emission	Signalized intersection	Physical infrastructure	
Route 1	1	3	1	5
Route 2	2	2	1	5
Route 3	3	1	1	6

Fuel Efficiency

Fuel consumption for the Table has been calculated the flowing equation

Fuel Consumption for Route A= ∑(Miles driven at a specific speed Limit(Table 4.20) × Average fuel consumption at that speed (Table 3.3)/100)

Table 4.26: Assigned numeric points based on the fuel efficiency

Route	Fuel consumption at different speed (liter)				Total fuel consumption (liter)	Numeric point
	55+ mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	1.01	0.32	0.16	0.25	1.75	1
Route 2	0.84	0.43	0.15	0.25	1.68	2
Route 3	0.00	1.24	0.29	0.05	1.58	3

Accumulation of numeric points based on all three variables provides Route 3 as the preferred route. Despite longer ravel time the environmental impact was lesser in case of Route 3.

Table 4.27: Total numeric points based on all three variables

Route	Shortest path	Environment friendliness	Fuel efficiency	Total numeric points
Route 1	3	5	1	9
Route 2	2	5	2	9
Route 3	1	6	3	10

Case Study IV

For this case origin was the Waldo Dr. and the destination is Louis Armstrong New Orleans International Airport. Again three alternative routes were chosen for this case. Map for this case study has been included in the Appendix.

Available Real Time Data

Route 1 has the shortest travel time and the length of each route is very similar to each other. Route 1 and Route 2 has highway segments in its route. Route 3 has significantly higher travel time than the other two.

Table 4.28: Route length and approximate travel time for each route

Route	Length (mile)	Approximate travel time (min)
Route 1	15.1	22
Route 2	15.3	24
Route 3	14.2	37

Table 33 shows the amount of miles driven under each of the posted/allowable speed limits. Route 1 and Route 2 are very similar. They both use the highway but enter the highway from two different entrances.

Table 4.29: Miles driven at each speed range

Route	Miles driven above 55 mph	Miles driven at 35-55 mph	Miles driven at 20-35 mph	Miles driven at 0-20 mph
Route 1	9.84	1.98	3.28	0.00
Route 2	8.30	4.65	2.35	0.00
Route 3	0.00	11.96	2.24	0.00

Route 3 has higher signalized intersections as it does not have any highway segment in its route. That also is reason for higher travel time.

Table 4.30: Number of intersection on each route

Route	Number of Intersection
Route 1	7
Route 2	9
Route 3	28

Shortest Path

Based on the available approximate data route one has the shortest approximate travel time. So based on the travel time Route 1 gets the highest numeric point.

Table 4.31: Assigned numeric points based on the approximate travel time

Route	Length (mile)	Approximate travel time (min)	Numeric point
Route 1	15.1	22	3
Route 2	15.3	24	2
Route 3	14.2	37	1

Environmental Impact

Route 3 receives highest numeric point among all three variables. Route 1 requires driver to drive longer at 60 mph. Therefore the carbon di-oxide emission is highest for route 1. Carbon di- oxide emission has been calculated using the following equation

Carbon di-oxide emission for Route A= ∑(Miles driven at a specific speed Limit (Table 4.29) × Average carbon di-oxide at that speed (Table 3.1))

Table 4.32: Assigned numeric points based on carbon di-oxide emission

Route	Carbon di-oxide emission at different speed (gram)				Total carbon di-oxide emission (gram)	Numeric point
	55+ mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	3,936.00	693.00	1,312.00	0.00	5,941.00	1
Route 2	3,320.00	1,627.50	940.00	0.00	5,887.50	2
Route 3	0.00	4,186.00	896.00	0.00	5,082.00	3

Route 3 has the highest number of signalized intersections. Potential scenario of deceleration/acceleration/stopping is significantly higher in the case of Route 3 than on the other two alternative routes.

Table 4.33: Assigned numeric points based on the number of intersections

Route	Number of intersection	Numeric point
Route 1	7	3
Route 2	9	2
Route 3	28	1

All these routes have similar impact on the environment. Carbon di-oxide emission was lower for than Route 3 but has lot of signalized intersection. In this case, physical infrastructure data could have played vital role in determining the best route.

Table 4.34: Numeric points based on all three independent variables of environment

Route	Numeric Point			Total numeric point
	Carbon Di-oxide emission	Signalized intersection	Physical infrastructure	
Route 1	1	3	1	5
Route 2	2	2	1	5
Route 3	3	1	1	5

Fuel Efficiency

Fuel consumption for the Table has been calculated using the flowing equation

Fuel Consumption for Route A= ∑(Miles driven at a specific speed Limit(Table 4.29) × Average fuel consumption at that speed (Table 3.3)/100)

Table 4.35: Assigned numeric points based on the fuel efficiency

Route	Fuel Consumption at Different Speed (liter)				Total fuel consumption (liter)	Numeric point
	55+ mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	1.10	0.25	0.50	0.00	1.85	3
Route 2	0.93	0.60	0.36	0.00	1.88	1
Route 3	0.00	1.53	0.34	0.00	1.87	2

Route 1 becomes the best route. It had higher carbon di-oxide emission but lower events of deceleration/acceleration/stopping events. In this case, environmental impact was tied based on the numeric points. Shortest path therefore played important role in deciding the preferred route.

Table 4.36: Total numeric points based on all three variables

Route	Shortest path	Environment friendliness	Fuel efficiency	Total numeric points
Route 1	3	5	3	11
Route 2	2	5	1	8
Route 3	1	5	2	8

Case Study V

For Case Study V the origin was the Waldo Dr. and the destination was the World War Museum at Magazine Street. All three routes selected for this case study had highway segments in its route. Maps have been included in the Appendix.

Available Real Time Data

Each of the routes in this case had very similar travel despite variation in their length. Table 4.37 shows the route length and approximate travel time.

Table 4.37: Route length and approximate travel time for each route

Route	Length (mile)	Approximate travel time (min)
Route 1	7.20	18
Route 2	10.40	20
Route 3	9.76	21

Table 4.38 shows the amount of miles driven under the posted/allowable speed ranges on each of these routes

Table 4.38: Miles driven at each speed range

Route	Miles driven Above 55 mph	Miles driven at 35-55 mph	Miles driven at 20-35 mph	Miles driven at 0-20 mph
Route 1	2.22	4.02	0.75	0.21
Route 2	6.14	3.60	0.63	0.03
Route 3	4.27	4.51	0.42	0.56

Route 2 has the higher potential stop/acceleration/deceleration events. Table 4.39 shows the number of signalized intersections on each route.

Table 4.39: Number of intersection on each route

Route	Number of intersection
Route 1	9
Route 2	10
Route 3	7

Shortest Path

Route 1 has the least travel time and also shorter length compared to the other routes. Route 1 thus achieves the highest numeric point.

Table 4.40: Assigned numeric points based on the approximate travel time

Route	Length (mile)	Approximate travel time (min)	Numeric point
Route 1	7.2	18	3
Route 2	10.4	20	2
Route 3	9.7	21	1

Environmental Impact

Route 1 has the lower carbon di-oxide emission. Following equation has been used for the calculation of carbon di-oxide emission-

Carbon di-oxide emission for Route A= $\sum$(Miles driven at a specific speed Limit (Table 4.38) $\times$ Average carbon di-oxide at that speed (Table 3.1))

Table 4.41: Assigned numeric points based on carbon di-oxide emission

Route	Carbon Di-oxide emission at different speed (gram)				Total carbon di-oxide emission (gram)	Numeric Point
	55+ mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	888.00	1,407.00	300.00	147.00	2,742.00	3
Route 2	2,456.00	1,260.00	252.00	21.00	3,989.50	1
Route 3	1,708.00	1,578.00	168.00	392.00	3,846.00	2

Based on the number of signalized intersections Route 3 achieves highest numeric points.

Table 4.42: Assigned numeric points based on the number of intersections

Route	Number of Intersection	Numeric Point
Route 1	9	2
Route 2	10	1
Route 3	7	3

Route 1 has the lowest environmental impact among all three variables. Based on all three factors Route 1 has lower environmental impact as well as lower carbon di-oxide emission.

Table 4.43: Numeric points based on all three independent variables of environment

Route	Numeric Point			Total numeric point
	Carbon di-oxide emission	Signalized intersection	Physical infrastructure	
Route 1	3	3	1	7
Route 2	2	1	1	4
Route 3	1	2	1	4

Fuel Efficiency

Fuel Consumption for Route A= ∑(Miles driven at a specific speed Limit(Table 4.38) × Average fuel consumption at that speed (Table 3.3)/100)

Table 4.44: Assigned numeric points based on the fuel efficiency

Route	Fuel consumption at different speed (liter)				Total fuel consumption (liter)	Numeric point
	55+ mph	35-55 mph	20-35 mph	0-20 mph		
Route 1	0.25	0.51	0.11	0.04	0.91	3
Route 2	0.69	0.46	0.10	0.01	1.25	1
Route 3	0.48	0.58	0.06	0.09	1.21	2

Table 49 shows the accumulated value for each of the three routes. Route 1 achieves highest point. Route 1 does better in all the regards.

Table 4.45: Total numeric points based on all three variables

Route	Shortest path	Environment Friendliness	Fuel Efficiency	Total Numeric Points
Route 1	3	7	3	13
Route 2	2	4	1	7
Route 3	1	4	2	7

Chapter 5

Analysis

Shortest distance is not necessarily the best route when we consider the environmental impact. In our case studies, we found results that prove that high speed route is not always provide the least amount of environmental impact. At speed higher than the 55 mph, carbon di-oxide emission increases and also the fuel efficiency decreases. On the other hand with higher speed travel time can get shorter. Often user chooses the route with lesser travel time. Apparently, it seems that shorter travel time will be better for the environment. This research finds result in contradiction to that assumption. So it is important that we use the available real-time data and indentify the environmental impact besides looking into the shortest path. Considering all these three variables together brings a new dynamic and can considerably change the route choice.

Marketability of the ITS based applications is an important factor. More people use these applications more improvement can be made to the models. So it is important to make sure that people use these applications. To ensure marketability we needed to introduce options that most people will be willing to use. People chose routes based on the fuel efficiency and shortest travel time. So we include both of these two options and create a model that can also consider environment beside these two factors.

Limitations

The research did not focus on the active mode of the travel. The health and environmental benefit attached with the active mode cannot be denied. Introduction of the model in transportation system can never achieve the same level of health and environmental benefit that active mode of transportation can achieve. The model should not give the user an impression that using the model will be justification for more auto driving. Purpose of the model is just to let the user know that he/she can reduce the environmental impact by following the model.

One of the biggest limitations of the model is the failure to predict the user behavior. Firstly, user will have to be interested in using environment friendly routes. Instead of that the user might be more interested in fuel economy. Our assumption is that people will consider reducing environmental impact. This assumption that people are considerate about environment will have to hold true to be able to reduce the environmental impact.

Secondly, the accidents and physical infrastructure will have to be considered in trying to figure out best possible routes. It is often difficult to predict how much these factors will reduce the speed of the traffic or how much congestion will be created due to these factors. May be looking into the historic data is one of the way to predict that. But approximation will require lot more data analysis.

Thirdly, make and model of the car have impact on these factors. It was difficult to consider all different makes and models of auto for our study. But the model can easily incorporate that aspect. Again, there are several other factors that can influence the fuel efficiency and environmental impact. We have only considered carbon di-oxide to measure environmental impact.

Finally, the land use factors have strong influence on the environment. If the route is situated in a densely populated corridor even with reduced carbon di-oxide emission it might impact more people than the route in an isolated area with higher emission. That impact is more related to the land use option. As we were considering carbon di-oxide as the only pollutant so population density will not affect the model. Carbon di-oxide is not a kind of pollutant that stays on the location like many other air pollutants. Again other environmental impacts such as the sound pollution are not considered in this research. Land use pattern is important because that can answer how many people will be impacted by the negative externalities. It is also a question of equity. This model might direct user to drive on routes that has comparatively less traffic but may not direct user away from the densely populated neighborhood.

Future Research

The research opens up the opportunity to work with real time data. Data used for the model is quantitative in nature and does not include the option of introducing land use and driver behavior data. Including those aspects can increase the usefulness of the model. Another aspect that can be introduced in the model is the physical infrastructure. The model is prepared based on the prediction system. Therefore data that can predict the outcome of the physical infrastructure can greatly improve the model.

We can also work on the numeric point system. In some cases, carbon di-oxide emission on different route was very similar. But we provided them different numeric number. That can make the model biased and favor a particular route. We can come up with a range to avoid that issue. To determine that threshold we would require extensive research.

One of the easier improvements can be the introduction of make and model of the car. Another option for the model is to introduce emergency routes. Especially for flood prone area like New Orleans, having alternative safe route in the system can be very helpful. Model can use weather prediction to provide user with alternative route to avoid flooded routes.

Bibliography

American Community Survey (2010-14), Demographic and housing estimates, Table DP05, 5 year estimates, Retrieved on Sep 07, 2015 from http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_14_5YR_DP05&prodType=table

American Community Survey (2010-14), Means of transportation to work by age, Table B0810, 5 year estimates, Retrieved on Sep 07, 2015 from http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_14_5YR_B08101&prodType=table

Barth, M. & Boriboonsomsin, K. (2010), Traffic Congestion and Greenhouse Gases, *Transportation Research Board*, Retrieved on Jan 10, 2016 from http://www.uctc.net/access/35/access35_Traffic_Congestion_and_Grenhouse_Gases.pdf

Bekhor, S., Ben-Akiva, M., E., & Ramming, M. S. (2006). Evaluation of choice set generation algorithms for route choice models, Retrieved on Feb 18, 2016 from http://web.mit.edu/rama/Public/papers/paper7.pdf

Ezell, S. (Jan, 2010). Intelligent Transport System, *The Information Technology and Innovation Foundation*, Retrieved on Sep 16, 2015 from http://www.itif.org/files/2010-1-27-ITS_Leadership.pdf

Federal Highway Administration (April, 2011). Intelligent Transportation Systems (ITS) Standards Program Strategic Plan for 2011—2014 final report, Retrieved on Dec 15, 2015 http://www.its.dot.gov/standards_strategic_plan/stds_strat_plan.pdf

Frith, W., & Cenek, P. (Nov, 2012). Standard metrics for transport and driver safety and fuel economy, Retrieved on Dec 16, 2015 from https://www.aa.co.nz/assets/about/Research-Foundation/Ecodrive/Opus-AA-ecodriving-Final Report.pdf?m=1359596615%22%20class=%22type:%7Bpdf%7D%20size:%7B483%20KB%7D%20file

Li, H., Guensler, R., & Ogle, J. (2005). Analysis of Morning Commute Route Choice Patterns Using Global Positioning System–Based Vehicle Activity Data. *Transportation Research Record: Journal of the Transportation Research Board*, 1926, 162-170, Retrieved on Sep 16, 2015 from, Retrieved on from http://commuteatlanta.ce.gatech.edu/Resources/05-2178.pdf

Pereira, S.R., Fontes, T., Bandeira, J. M., Fernandes, P., & Coelho, M.C. (July, 2014). SmartDecision: a route choice app based on eco-friendly criteria, Retrieved on Jan 6, 2016 from http://docs.trb.org/prp/15-2209.pdf

Ramming, M. S. (2002). Network Knowledge and Route Choice, Retrieved on Feb 18, 2016 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.457.5449&rep=rep1&type=pdf

Sikka, N. (2012). Understanding travelers' route choice behavior under uncertainty, Retrieved on Feb 15, 2016 from http://ir.uiowa.edu/cgi/viewcontent.cgi?article=3135&context=etd

Vajanakshi, L., Ramadurai, G., & Anand, A. (Dec, 2010). Synthesis report on ITS including issues and challenges in India, Retrieved on Sep 16, 2015 from https://coeut.iitm.ac.in/ITS_synthesis.pdf

US Department of Transportation (2011). Intelligent Transportation Systems (ITS) Standards Program Strategic Plan for 2011–2014, Retrieved on Nov 12, 2015 from http://www.its.dot.gov/standards_strategic_plan/

US Department of Transportation (2014). ITS Strategic Plan 2011-15, Retrieved on Nov 12, 2015 from http://www.its.dot.gov/strategicplan/

https://vtechworks.lib.vt.edu/bitstream/handle/10919/55070/3857.pdf?sequence=1&isAllowed=y

US Environmental Protection Agency (2010). Overview of Greenhouse Gases, Retrieved on Nov 12, 2015 from https://www3.epa.gov/climatechange/ghgemissions/gases/co2.html

Zhang, L., Levinson, D., (2008). Determinants of Route Choice and Value of Traveler Information, *Transportation Research Record: Journal of the Transportation Research*

Board, 2086, 82-92, Retrived on Feb 08, 2016 from
http://www.nexus.umn.edu/papers/DeterminantsOfRouteChoice.pdf

Appendix

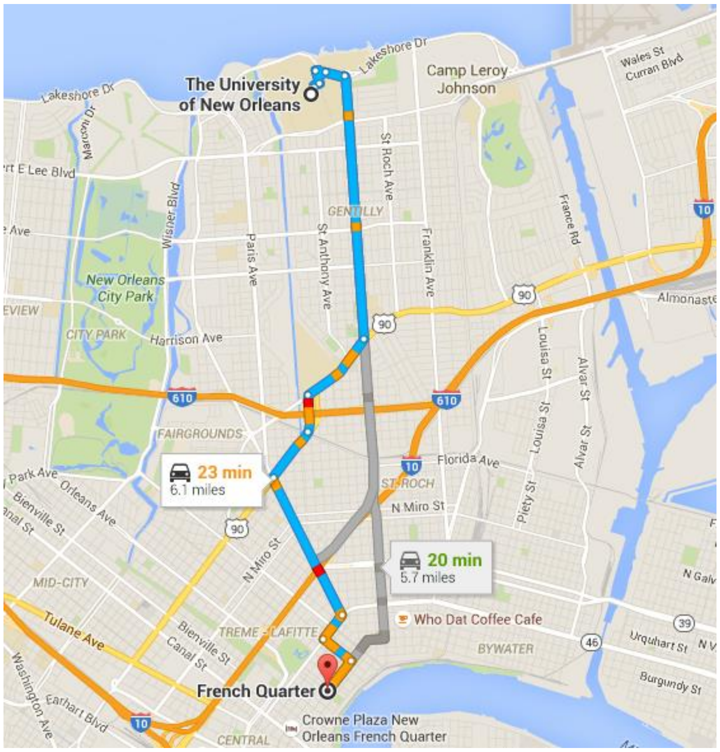


Figure: Origin/destination set for Case Study I Source: Google Map, 2011

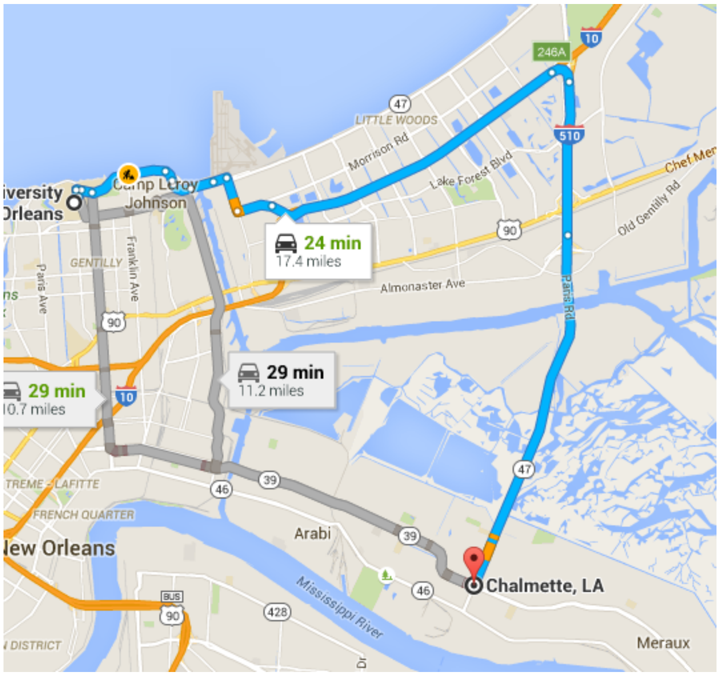


Figure: Origin/destination set for Case Study II Source: Google Map, 2011

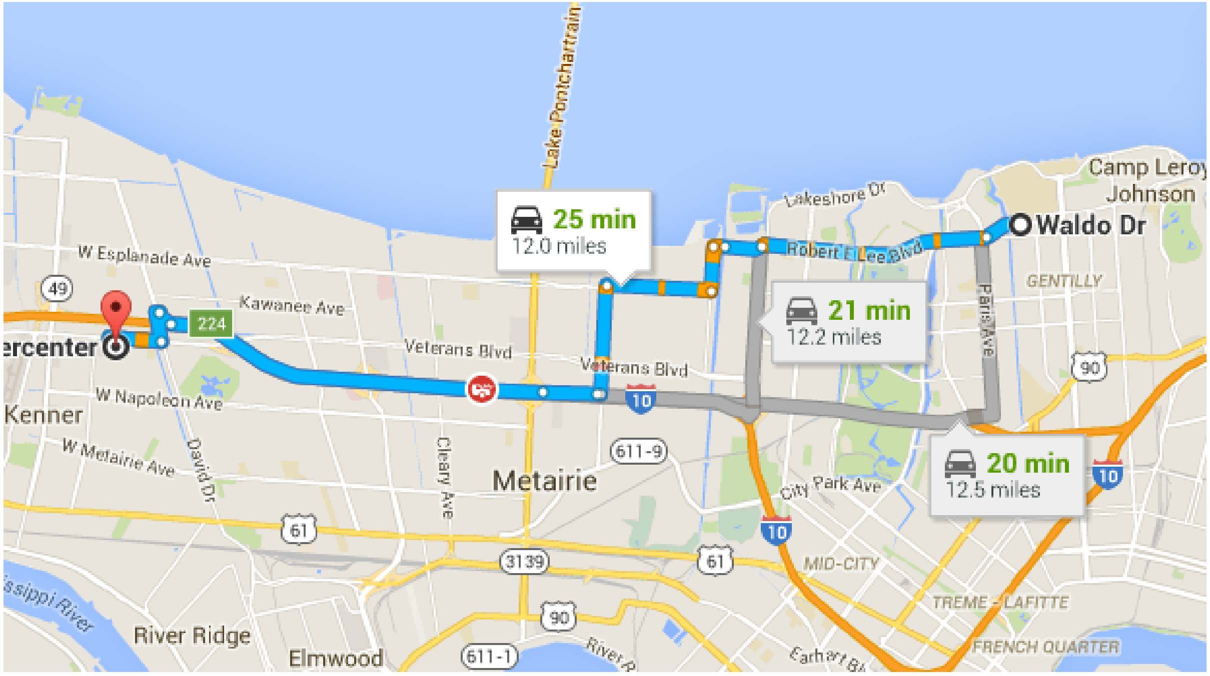


Figure: Origin/destination set for Case Study III Source: Google Map, 2011

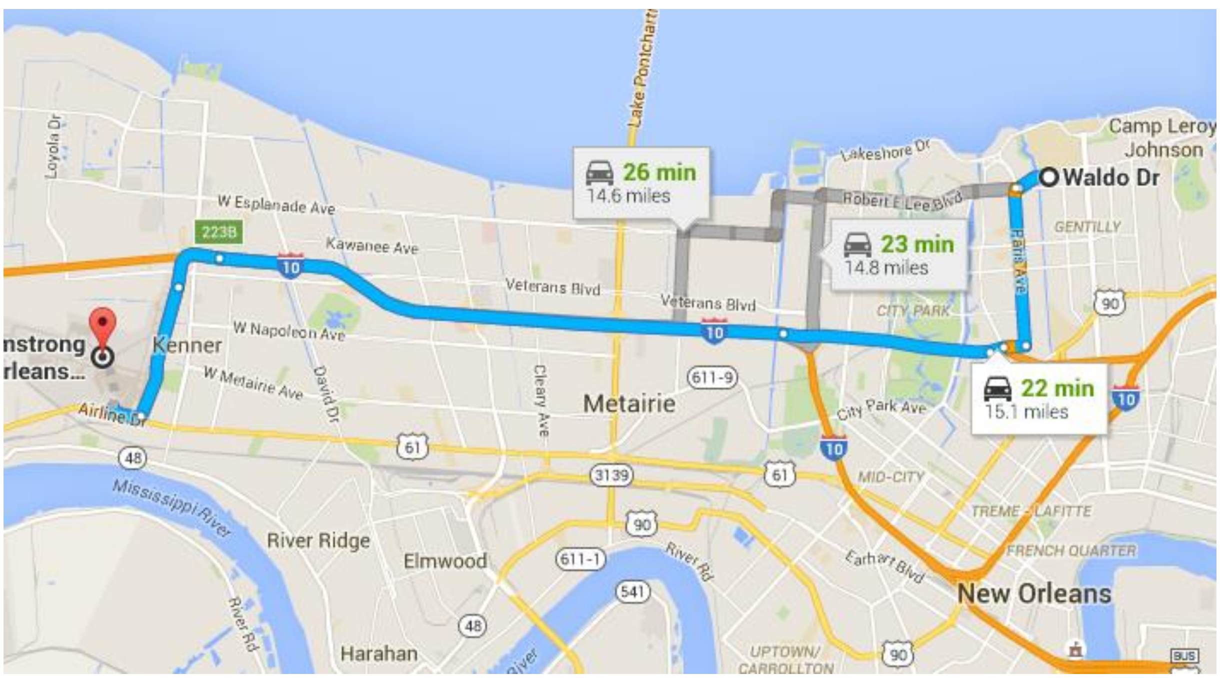


Figure: Origin/destination set for Case Study IV Source: Google Map, 2011

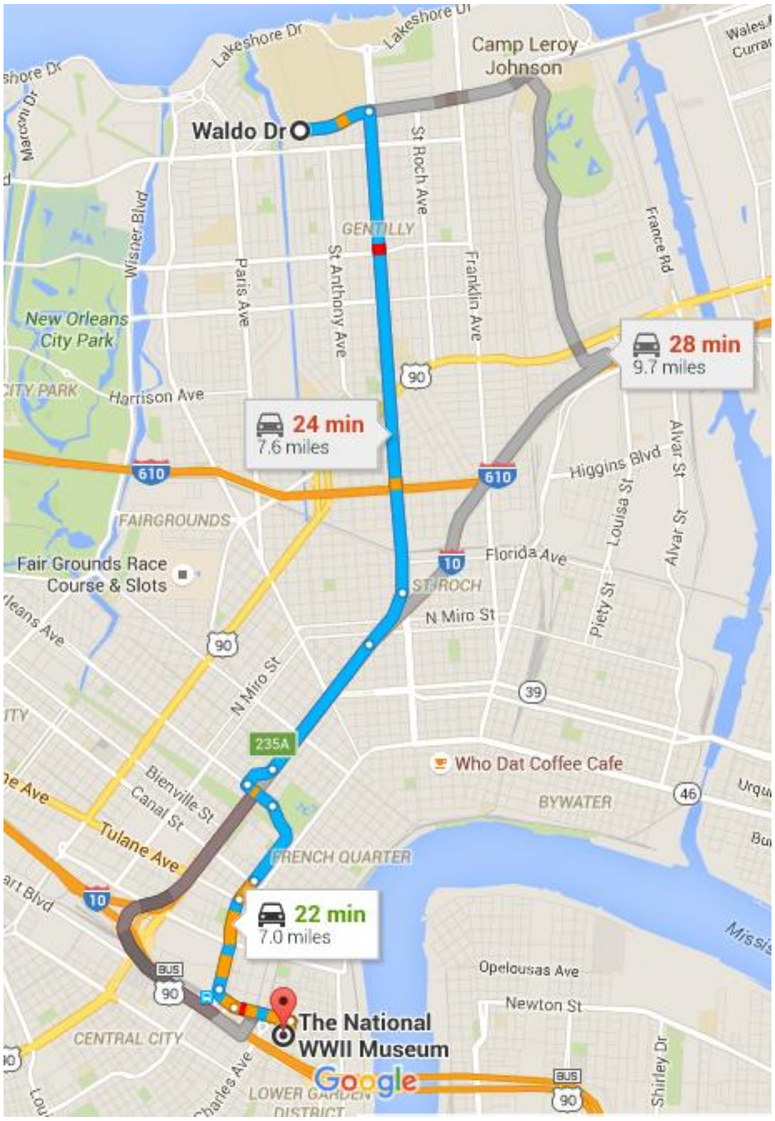


Figure: Origin/destination set for Case Study V Source: Google Map, 2011

Vita

The author was born in Dhaka, the capital of Bangladesh. He completed his bachelor degree in Urban and Regional Planning from Bangladesh University of Engineering and Technology in 2013 from Bangladesh. He joined Master of Urban and Regional Planning (MURP) program at the University of New Orleans in fall of 2014. He has worked as an Intern for Jefferson Parish Planning Department from August 2015- May 2016. He had also worked with UNO-CHART as a Graduate Research Assistant in 2015.