Using Traffic Modeling to Explore How Congestion Information Affects Traffic

by

Jennifer L. Smith
A Thesis
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Master of Science
Geoinformatics and Geospatial Intelligence

Committee:

___________________________ Dr. Kevin Curtin, Thesis Director
___________________________ Dr. Anthony Stefanidis, Committee Member
___________________________ Dr. Sven Fuhrmann, Committee Member
___________________________ Dr. Anthony Stefanidis, Department Chair
___________________________ Dr. Donna M. Fox, Associate Dean for Student Affairs, College of Science
___________________________ Dr. Peggy Agouris, Dean, College of Science

Date: ________________________ Spring Semester 2016
George Mason University
Fairfax, VA
Using Traffic Modeling to Explore How Congestion Information Affects Traffic

A Thesis submitted in partial fulfillment of the requirements for the degree of Master at Science at George Mason University

by

Jennifer Smith
Bachelor of Science
The University of Maryland, 1990

Director: Kevin M. Curtin, Associate Professor
Department of Geography and GeoInformation Science

Spring Semester 2016
George Mason University
Fairfax, VA
This work is licensed under a creative commons attribution-noderivs 3.0 unported license.
DEDICATION

This thesis is dedicated to Darryl, my husband, for his love and support!!! Thank you for all your gifts! Because of you, I am happier than I’ve ever been!
ACKNOWLEDGEMENTS

I would like to thank the leadership at the Army Geospatial Center (AGC) and Geospatial Research Laboratory (GRL) who have made this happen. I would also like to thank Drs. Stefanidis, Curtin, Furhmann, and the George Mason University professors who taught the students of the geospatial intelligence program at AGC. And especially, the AGC and GRL students of the geospatial intelligence program who participated in the program with me. Their inspiration kept me going!
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>vi</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vii</td>
</tr>
<tr>
<td>List of Abbreviations</td>
<td>viii</td>
</tr>
<tr>
<td>Abstract</td>
<td>ix</td>
</tr>
<tr>
<td>Chapter One - Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Chapter Two – The Problem</td>
<td>9</td>
</tr>
<tr>
<td>Chapter Three - Method</td>
<td>10</td>
</tr>
<tr>
<td>Chapter Four - Results</td>
<td>21</td>
</tr>
<tr>
<td>Chapter Five – Conclusion</td>
<td>35</td>
</tr>
<tr>
<td>Chapter Six – Future Work</td>
<td>39</td>
</tr>
<tr>
<td>Appendix</td>
<td>41</td>
</tr>
<tr>
<td>References</td>
<td>42</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1: Number of visits for each route ................................................................. 30
Table 2: Average Annual Daily Traffic (AADT) for roads along the control route..... 32
Table 3: AADT for Maryland Roads near beltway .................................................... 34
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1 Screen shot of importing a text file</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2 GetRouteJunctions model</td>
<td>14</td>
</tr>
<tr>
<td>Figure 3 Map of the control route with two traffic incidents</td>
<td>16</td>
</tr>
<tr>
<td>Figure 4 The Agent Based Model and schedule editor</td>
<td>19</td>
</tr>
<tr>
<td>Figure 5 Thesis methodology flow diagram</td>
<td>20</td>
</tr>
<tr>
<td>Figure 6 Screen shot of the Agent Based Model</td>
<td>21</td>
</tr>
<tr>
<td>Figure 7 Google Maps Screen shot of Seattle</td>
<td>22</td>
</tr>
<tr>
<td>Figure 8 Control route in red</td>
<td>23</td>
</tr>
<tr>
<td>Figure 9 Second route in pink</td>
<td>24</td>
</tr>
<tr>
<td>Figure 10 Third route in green</td>
<td>26</td>
</tr>
<tr>
<td>Figure 11 Control route with 20 agents</td>
<td>27</td>
</tr>
<tr>
<td>Figure 12 Route 2 with 20 agents</td>
<td>28</td>
</tr>
<tr>
<td>Figure 13 Route 3 with 20 agents</td>
<td>29</td>
</tr>
<tr>
<td>Figure 14: ATR locations near the beltway in Montgomery and Prince George’s counties in Maryland</td>
<td>33</td>
</tr>
</tbody>
</table>
LIST OF ABBREVIATIONS

Agent Based Model .................................................................................................. ABM
Army Geospatial Center ......................................................................................... AGC
Average Annual Daily Traffic .............................................................................. AADT
Automatic Traffic Recorders ................................................................................ ATR
Geographic Information System .......................................................................... GIS
Geospatial Research Laboratory .......................................................................... GRL
Global Positioning System .................................................................................. GPS
Interstate Highway System .................................................................................. IHS
Mobile Social Network ......................................................................................... MSN
Volunteered Geographic Information ................................................................ VGI
ABSTRACT

Using Traffic Modeling to Explore How Congestion Information Affects Traffic
Jennifer Smith, M.S.
George Mason University, 2016
Thesis Director: Dr. Kevin M. Curtin

Transportation plays a major role in a country as the performance of the transportation system is important to its economic or social health. The time to get to an event is dependent on transportation system or traffic. When talking about traffic, the issue is not only the distance to be traveled but it is about the number of drivers on the road and the traffic congestion created by the number drivers on the road. Traffic congestion is an increasingly common problem for drivers. It impacts travel speeds and increases the amount of time to get to the desired activities. The objective of this master’s thesis is to investigate how the information about traffic congestion affects traffic. The hypothesis is that due to the information traffic congestion such as information provided by sources such as social media, drivers would take an alternate route which helps reduce traffic congestion. Results will show that due to the information about traffic congestion, traffic was affected.
Traffic congestion information could come from information from friends or by information from social media. As people see using these sources to gain information about traffic incidents and thus taking alternate routes to avoid the incidents, either from their own experience or from experiences they hear about on social media or other sources, the more alternate routes will be taken and traffic congestion would be affected.
CHAPTER ONE - INTRODUCTION

Transportation plays a major role in a country’s dynamics because the performance of the transportation system is important to its economic and social health. Transportation is a significant in that allows people to go places and for goods to be transported. (“why is transportation important?”, 2015) In the early years of the United States, people would travel long distances along long rivers and coastlines. As the country matured, railroads offered a fast and convenient way to move people and cargo over land. In urban centers, bicycles and wagons offered short-distance transport. Over time there were further developments in methods of travel. Electric trams and cars reduced the dependence on horses in cities. Highways and large roads made it easier for cars to travel long distances. (“how transportation has changed”, 2015)

The Interstate Highway System (IHS) consists of the roads in the United States and is a major part of our lives. This transportation system began in 1938 and in 1947, the highway department incorporated geography by mapping the IHS. With the growth of the country, especially in the western and southern states, it became increasingly important to be part of the IHS. Being part of the IHS made it possible to connect manufacturing, agriculture, war industry, and metropolitan areas. Over time, the IHS added additional metropolitan areas. The IHS had a great influence on travel and economic patterns and culture, especially as more routes are added to the system (Weber, 2012).
The transportation system provides accessibility to land and influences growth patterns. People that use the transportation system influence its success (Tang, 2005). This is supported by an article in the Journal of Transport Geography by Steven Faber (2011). The distance between people’s desired locations has a major impact of their lives. It influences their success and opportunities. Roads in a HIS follow a certain spatial pattern. The ease that individuals move in that spatial pattern is important. There are many benefits to being part of the transportation system. However, there are major factors that have to be overcome. Distance is one factor. Another factor is traffic congestion. Traffic congestion in urban areas is becoming more and more problematic. It reduces the ability of people to get to their desired location because it reduces the speed that drivers can drive along the roads and increases the time to get to the desired activity.

Automobility, or the use of automobiles, affects social well-being directly by modifying time-use and activity participation patterns. It is generally agreed that participation in an activity is desirable only if the benefit gained from doing so exceeds the hardship associated with travel and the opportunity cost of missed participation in a different activity during that time. Travel time, a cost associated with participation in an activity, is less likely to dissuade people from participating in mandatory activities than discretionary ones (Farber, 2011). The time to get to an event is dependent on the transportation system or traffic.

When talking about traffic, the issue is not only the distance to be traveled. It is also about the number of drivers on the road and the traffic congestion created by increasing number drivers on the road. That issue is the hardship that drivers have to deal
with when driving from one place to another. Traffic congestion is defined as the condition of road networks that occurs as use of that road increases. It is characterized by slower speeds and longer trip times ("Traffic congestion", 2015). When traffic demand is high due to the large amount of cars on the road, the interaction between cars slows the speed in the traffic stream. When drivers have to go around traffic incidents, it causes these drivers to slow down. This effect, in turn, causes the drivers behind them to slow down and the drivers behind them and so on. This continuing domino effect creates an increase in driving time from the start of the trip to the end when the driver arrives at the destination. When the speed of cars slows down due to an incident, the effect becomes intensified and driving time increases significantly. This statement was supported in a work by Kerner (2013) that describes the car-following model developed by Gazis, Herman, and Rothery (GHR) in which an instability of vehicular traffic flow has been explained by a finite driver reaction time leading to a driver’s over-deceleration effect. If a vehicle begins to decelerate unexpectedly, then due to the driver reaction time the following vehicle stops and starts. When the time delay is significant, the driver of the following vehicle brakes harder to avoid a crash. As a result, the speed of the following vehicle becomes lower than the speed of the vehicle ahead. Many times, traffic movement comes to a complete stop which results in tardiness, anger, frustration, and road rage. There are many other costs, such as loss of productivity.

Traffic congestion is a common problem for many cities around the world. The problem is not just the time spent in traffic jams but also pollution, traffic accidents, and increased wear on motor vehicles. Transportation plays a key role with respect to how
easy it is to move around the city and plays a large role in determining where one lives and commutes. For some, a commute of more than 20 minutes is burdensome. However, for many reasons, many people commute to or from work for more than an hour one way. For those drivers, traffic congestion is a definite problem and a great concern.

The relationship between the time-of-day and duration of the activity is an important factor (Lee, 2009). Travel on the weekend versus week day is another important factor as it influences the amount of time to get to desired activities. Morning travel time is greater on week days than on weekends. The reason is mainly because of the increased traffic congestion. Steven Farber also talks about commuter travel in his article. He indicates that going to and from work is the most dominant travel purpose in terms of time commitment and participation frequency. Its importance has also increased significantly from 1992 to 2005 (Faber, 2011). When considering a worker’s day, the amount of time devoted to their commute has a significant bearing on their lifestyle.

Obtaining information about traffic congestion would be beneficial to commuters. There are several sources for obtaining information about traffic congestion. Those are getting information from friends and volunteered geographic information (VGI). VGI has revolutionized the ability to obtain this information. VGI is defined in an article in the International Journal of Geographical Information Science as “‘a special case of the more general Web phenomenon of user-generated content.” The development of VGI allows “users to share and pool geographic information via the Internet at lower costs, in effect creating a global digital commons of geographic knowledge that is released from traditional mechanisms of production and distribution.” (Hardy, 2012) If drivers change
their behaviors, it would affect traffic congestion. This change could be taking an alternate route or delaying their start time. An article in Science Daily on 20 Dec 2012 states “that incorporating data from drivers' cell phones showed that the adoption of alternatives by a small percentage of people across a metropolitan area might not be very effective.” The study in the article demonstrates that canceling or delaying the trips of 1 percent of all drivers across a road network reduces delays caused by congestion by only about 3 percent. But canceling the trips of 1 percent of drivers from carefully selected neighborhoods would reduce the extra travel time for all other drivers in a metropolitan area by as much as 18 percent.

Getting information about traffic congestion is beneficial. There are many sources to get this information. One source is using social media. Drivers could report traffic incidents to other drivers. With the information from social media, drivers may change the route plan when they are informed about an incident on the road. This information or VGI is more beneficial than traffic reports that are played on the radio or television. Many times the traffic reports are referring to roads that may not be important to the driver. Or the information is missed. As a result, the driver continues down the impacted road and ends up contributing to the congestion. With social media, information could be tailored to report on roads in the driver’s route. Then the driver would have the opportunity to decide whether to continue on the original route or choose an alternate route.

With the popularity of using mobile devices on the rise. Mobile devices aid in the communication of traffic congestion. This began with the increased popularity of OnStar.
As mobile devices became more accessible ("Will In-Car Social Media Kits Kill the Traffic Jam?", 2013), drivers are now able to communicate traffic and road conditions. This information is transported to the cloud to be interpreted, verified, and disseminated to a network of drivers. The technology of location-awareness in mobile devices (DeSouza, 2010) has helped by being more than a talking and texting device. Knowing one’s location can aid in connecting people and help place their location on a map. This makes it possible to connect with one another according to their relative distance. This makes it possible for people to have relationships among others connected in a social network. Mobile phones have been analyzed as interfaces used to connect large numbers of people in many-to-many communication settings in a mobile social network (MSNs).

GPS signals have become much more accurate, which generated a renewed interest in the development of location-aware technologies. Artists, researchers and the entertainment industry began exploring the potential implications of attaching information to places and locating people and things in physical space. The application of GPS in everyday devices has made it possible to combine geo-position and social networking. This is because the coupling gives people the ability to find the closest gas stations, restaurant, golf course, or bar. It was only a matter of time before the coupling provided drivers with traffic information.

Waze ("Waze", 2015) proclaims itself as “one of the world's largest community-based traffic and navigation applications.” Waze connects drivers in their area by sharing real-time traffic and road info and states that it saves drivers time and gas money on their daily commute.
The Waze navigation system ("Waze", 2015) puts the power in the hands of the driver. By driving around with the Waze client installed on the mobile phone, real-time information is shared. Information such as traffic conditions, accidents, police traps, blocked roads, and weather conditions is reported to the community of drivers who are also using Waze. Waze was created as a social navigation tool to provide the fastest or shortest route, depending on the settings, for all neighboring segments and routes. Waze uses real-time road speeds from other Waze users. Waze uses the information on the route to calculate average speed, check for errors, and improve road layout.

Using Facebook, a social network “utility that connects people with friends and others who work, study and live around them” ("what is facebook", 2015), is one another avenue to relay information to your Facebook friends. Drivers can also alert other drivers or friends about traffic incidents by using Twitter which is “an online social networking service that enables users to send and read "tweets", which are text messages limited to 140 characters”.

Google Traffic is a feature on Google Maps which displays traffic conditions of major roads and highways in over 50 countries. Google Traffic can be viewed at the Google Maps website or by using the Google Maps application on a mobile device. Google Traffic works by analyzing the Global Positioning System (GPS)-determined locations transmitted to Google by a large number of mobile phone users. ("google traffic", 2015) The colored routes on Google Maps are used to show the traffic speeds where red is for high congestion, yellow is for medium congestion, and green is for low congestion. Google Maps uses traffic views from sensors that show real-time data and
average speeds from historical data. It does not use data for social media. The updates to
the maps are from the sensors which in turn becomes historical data for the future.

In recent years, there has been significant research and advancements using
drivers and their mobile devices as a source of traffic information (Predic, 2015). The
idea is to use drivers and their mobile phones to collect traffic and road related
conditions, events and information and send that information to a central server or to
mobile devices in the vicinity. The drivers are also the users of collected, processed and
analyzed dynamic traffic information generated by crowd intelligence about traffic
related events and conditions.

In the appendix are some research during the literature review of traffic systems.
In Bratislav Predic’s paper, the presented VGI systems in Predic’s paper do not include
the functionality for sending notifications of detected real-time information related to
short traffic events. Such features would fully employ crowd sourcing and crowd
intelligence approaches in dynamic and collaborative navigation. These systems give
valuable VGI information about traffic like information traffic congestion. The driver has
to determine whether to stay on that route and wait for the traffic incident to clear or
travel slowly by the traffic incident. Or the driver can decide to take an alternate route
around the traffic incident. The question is why do some drivers use the information and
other do not. Is it because the driver is not comfortable with social media? Or is the
driver not comfortable with the traffic system determining the alternate route? Or is it that
the benefit of taking the alternate route is not presented? What would encourage the
driver to take alternate routes and thus reduce traffic congestion?
CHAPTER TWO – THE PROBLEM

Drivers that live in one state such as Maryland and work in another state such as Virginia spend a lot amount of time driving to and from work. With travel distances of 35 miles or more, these commutes range from 45 minutes to 1.5 hours. The biggest factor in increasing driving time is due to traffic congestion. Traffic congestion is on the rise (Copeland, 2013) and is caused by many things, road construction, weather, accidents, and, of course, the large amount of cars on the road.

There needs to be a better way of providing information to drivers about traffic incidents which is the main cause of traffic congestion. There are many sources such as getting information from friends and using social media. Getting traffic congestion information affects traffic congestion. This information can be used to inform drivers of the traffic incidents. When the drivers alter their route, it affects traffic congestion. The objective of this master’s thesis is to explore how traffic congestion information (possibly by social media) affects traffic congestion. The hypothesis is that due to the traffic congestion information provided, drivers may take alternate routes which result in reducing traffic congestion.
CHAPTER THREE - METHOD

Agent analyst is an agent based modelling (ABM) system that runs as a module in ArcGIS 9.3. ArcGIS is a Geographic Information System (GIS) software package that helps use spatial information to perform deep analysis, gain a greater understanding of the data, and make more informed decisions. (Johnston, 2013)

In ABM, instructions are programmed to agents that allow them to interact with other agents. From these interactions, patterns are generated in time or space. These agents explore the reasons and causes for the individual decisions that the agents are making. Their actions or behaviors are based on their state and other influences such as other agents and the external world.

Using ABM, instructions are programmed to virtual agents to allow the agents the ability to make decisions and to interact. The model produces results based on these decisions to a particular event. Agents generally adapt or learn from their experiences over time. This learning can be deep, in that agents can develop completely new behaviors. Or the agents can be shallow in that the agents adjust simple parameters that determine their next actions. Analyzing these events and decisions, a perceived pattern can be observed, results interpreted, and conclusions drawn. ABM models are of significant value in modeling urban neighborhoods to obtain feedback regarding the
interaction between vehicle and pedestrian traffic and the general dynamic of traffic patterns.

Having the agents move “human-like” is the key for showing realistic movements. Human movement to get to a particular destination is not as simple as random movement. Most human-like movement is not random because it has a goal in mind. That goal is the final destination.

For this thesis, the objective is to have the agents move on a road network. The tutorial in the Agent Analyst module has an example of moving along a road network with stops along the route. Each agent has a specific starting location and ending location. Some agents have a home location, grocery store, and recreational activity location along the route. The locations are located at the intersections of the streets and represented as nodes in the model.

For this thesis, the data and scripts in the tutorial have been modified to fit the problem. To simulate a typical “rush hour” with many cars travelling in the same area, there will be multiple agents in the model. The control route will be altered to simulate an agent stopping or slowing down due to the traffic incident or altered around the traffic incident.

The model will run for a specified number of ticks where the ticks equal one minute in time. The results from the model are the number of visits of the intersections along the route. The greater number of visits would result in greater traffic congestion and increased time to travel from the starting and ending points.
The control route is the route that will be highlighted after the model is run. To get a baseline, the control route will be traveled by the single control agent without any input or information through social media about the traffic incident. The control route will be altered in two ways. One will be taking an alternate route around the traffic incident based on traffic congestion information provided about the traffic incident. The other will be staying on the route and be stopped or slowed down. The resulting number of visits along either choice will be compared with the control route.

The model setup is broken up into four parts.

Setup Part 1 - The first part was to define the path the agents traversed along. The agents are called ActiveNode agents and move along a specific shape file which simulates a routine travel route. The model was adjusted to ingest a file on the path with nodes instead of connecting to the network database due to Agent Analyst shortcoming.

A comma-delimited text file was imported as XY Data. This file contains a list of the nodes the agent visits in a day that was used to create the network paths. From Figure 1 Screen shot of importing a text file
ArcCatalog, the option to “Create Feature Class” was used to import the “XY Table” (Figure 1). Then the “Load Locations” and the “Solve” in Network Analyst were used to create the network path from the imported nodes.

Article in ArcGIS about routes solved in Network Analyst states that the route is solved by Dijkstra’s algorithm (“Algoritms used by Network Analyst”, 2016). The Dijkstra’s algorithm is described as:

“The classic Dijkstra's algorithm solves the single-source, shortest-path problem on a weighted graph. To find a shortest path from a starting location $s$ to a destination location $d$, Dijkstra's algorithm maintains a set of junctions, $S$, whose final shortest path from $s$ has already been computed. The algorithm repeatedly finds a junction in the set of junctions that has the minimum shortest-path estimate, adds it to the set of junctions $S$, and updates the shortest-path estimates of all neighbors of this junction that are not in $S$. The algorithm continues until the destination junction is added to $S$."

While the information about the algorithms that Google Traffic or Waze use are hard to find, it is probably based on the same algorithms that Network Analysts uses (“how mapping software gathers and uses traffic information”, 2015). It also uses historical information to determine the best route. It also relies on real-time information.

Agent Analyst uses the route created by Network Analyst. However, because Agent Analyst cannot read this route for the agents to travel, a list of nodes needed to be created in the order the agents are traversed from this route. This was done by using the junctions of the intersections.

A geoprocessing model called GetRouteJunctions was run to generate the output. As the agents in the model visited their places in a particular order, the junctions within the route had to be in the correct order.
The GetRouteJunctions model took three parameters (shown in Figure 2 in the blue ovals).

1. Network Analyst route layer that was just created when solving the new route. This route layer is used by "Select Data" to select only the route that was created. Next, "Feature Vertices To Points" converted the route from a line to its vertices. "Make Feature Layer" was used to pass this layer to "Select Layer By Location", which was used the "Network Junctions" from the network dataset and selected only junctions that made up the route created.

2. Network Junctions was the Seattle_ND_Junctions that were created when built the network dataset. They were joined with the selected layers just created. These selected junctions were written to an in-memory feature class and a Spatial Join was done to get the proper order of the junctions.

Figure 2 GetRouteJunctions model
3. Final Route Junctions was the shapefile that will be written out containing the list of the junctions that make up the route. Another Spatial Join was done to get the unique ID from the nodelist that was created onto these junctions so that the IDs for the nodes that were read into Agent Analyst match the node IDs of the routes.

Setup Part 2 - Activity Spaces of agents have spatial and temporal aspects. The spatial aspects consist of the places visited and the routes between those places. This is defined using two files. One file lists the home, work, and recreation nodes. The other file contains a list of nodes that have to be traversed during the course of a day. Together these files make up the spatial component of an activity space and had to be read into the model before the agents travel along the route. The temporal component has to do with the length of time an agent spends at each place and in transit.

Each file of places and street nodes that created the route was read in separately. This enabled more than one potential activity space to be read into Agent Analyst for each agent. Moving the agent along the shortest paths between each set of activity nodes simulates the routine travel paths of the agent. Adding the fields’ editor data allowed for the attributes to hold the information about the activity nodes and the path nodes. Because activity spaces are complex, an array of objects with each having its own values was needed to be built for each object having its own values.
Then the assignNodeInfo action was implemented because to achieve directed movement, the agent needed to know more than just its current node. In advanced movement, the agent needed to maintain its activity nodes and be able to identify the places that correspond to these locations. Agents also needed to maintain the set of nodes (path node list) that they traverse in the course of visiting their activity nodes as well as their current position in their list of path nodes. To accomplish this, the fields that were utilized earlier for the agent were used in the assignNodeInfo action to populate these values for each individual. The assignNodeInfo action populated the fields by reading the files for each agent. In this code, the first section was where the activity nodes are read.

Figure 3 Map of the control route with two traffic incidents.
The reader read the .csv file, parsed the file, and set the values for the activity nodes. Then `assignNodeInfo` was called to assign the values to the fields for each agent (Figure 3).

The `citizenSet` object was created and then `assignNodeInfo` action was called to read the data to populate the agent variables. Last an agent was added to the `ActivityNode` class with the field values from earlier.

Setup Part 3 -- To move the agents at every time step, the step action code needed to be modified. At the start of each model step, each agent evaluates its status to see if it is supposed to stay at the place or move somewhere else. The code tells the agent what to do under each condition. The simplest way to move agents is to have them traverse their activity space one node at a time. To accomplish this, the code was added in the step action of the `Citizen` class. Just as with random travel, directed travel uses an `ActiveNode` class to keep track of which street nodes have an agent on them. To move the agents, each agent’s current position in its path nodelist was used to assign the agent to a node (a place agent). In this “stripped down version”, the `ActiveNode` class was used to avoid having to iterate through the agent’s current position (target = self.position + 1).

Finally, the agent’s current node was changed to reflect its movement to a new node. In the code for step, the agents are assigned to an active node. The first statement checks to see if the agent is at the end of its path. If it is, the else condition executes. If an agent is not at the end of its path, then it is associated with a current street node. To do this, the code parsed out the decimal place from the string and converted to an integer. The next section of code added the node to a list of active nodes. It identified each node occupied by an active agent and then added the node to the `ActiveNode` Class. If the
array had values in it, there was an ActiveNode agent that existed with a particular string node (strnode) value in it. There is an ActiveNode agent that existed with a particular strnode value, so the code added the name of the agent to the agentList. If there is no ActiveNode with the same value as the currentNode, it was added to the agentList.

When the location of the agents was known, they needed to be moved. The code set the position equal to the next node by adding 1 to the current position (target – self.position + 1). Before moving the agent to a new node, it needed to be sure that the location was not at the end of the path based on the new position. This was accomplished by using a conditional statement that tested to make sure the agent is not at the end of its path. If the agent was at the end of its node list, then its current node was set to the home node. If the agent was not at the end of the list, then the current position was set to the target position. To actually move the agent to a new node, it was necessary to use the position of the target node to get the value of the node object. This takes a few steps similar to those used to assign the node originally. In the step action, each active agent had been moved by one node along its route. In addition, the agent’s new node has been added to the list of active nodes in preparation for the next tick of the model.

Setup Part 4 - The current model was set up to update the display every 100 ticks through the Schedule Editor (Figure 4). In the Schedule Editor, the writeAgents script was modified so that it would display every tick.
The tutorial provided 20 agent paths to be used in the model. One of the agent’s paths will be used as the control route. The control route will be altered in two ways and highlighted. One route will be altered around the traffic incident in the control route. This will simulate an agent learning about the traffic problem by social media or other sources. The other route will stay on the control route with the traffic incident. Additional points where the traffic incident occurred will be copied to simulate a delay or stop. These alternate routes will be compared to the control route.

Figure 4 The Agent Based Model and schedule editor
The summary of the methodology is shown in the diagram below (Figure 5).

Figure 5 Thesis methodology flow diagram
CHAPTER FOUR - RESULTS

First, the model was run with only one agent to get a baseline. When the model was run, the movement of the agent along the streets of the city was captured by showing the number of visits at each intersection or node along the route. The model was run for 138 ticks where one tick represents a minute as shown in Figure 6.

![Figure 6 Screen shot of the Agent Based Model](image)

To see what happens in “real life”, the control route that was used in the model was displayed in Google Maps. Using the same starting and ending points, the route that it
showed came up with 13.4 miles with a time of 38 minutes. This gives a speed of 21.16 mph. Figure 7 is a screen shot.

![Google Maps Screen shot of Seattle](image)

**Figure 7 Google Maps Screen shot of Seattle**

One of the outputs from the model shows the number of visits or stops along the street intersections. Figure 8 shows the control route in red that is the stops of the control agent. The distance from the start to the end is 13.4 miles. With the ticks equaling one minute, the time is 138 and the speed is 5.82 mph. The control agent’s speed was reduced due to traffic congestions.
Figure 8 Control route in red.
Figure 9 is a figure of the second route shown with pink circles. There was no information provided to this agent about the traffic incident. This agent stayed on the route with the traffic incident.

Figure 9 Second route in pink
In the black circle in the inset is where the additional points were added on the route. This is where the traffic incident occurred. These points were copied to simulate a delay or stop. The additional points were copied directly on top of the other nodes. This would force the agent to visit the stops again, thus taking extra time. To arrive at the same ending point, it took 140 ticks. The number of visits along that route was compared to the number of visits along the control route. The number of visits along that route will be compared to the number of visits along the control route. The distance from the start to the end is still 13.4 miles. Given the ticks equal one minute, the speed is 5.74 mph.

Figure 10 is a figure of the third route shown in green circles. This route was altered by adding three nodes. One was to the left, one above and one to the right, following the street next to the position of the traffic incident in the control route that is shown in the figure in red circles. This simulates that when the agent was made aware of the traffic incident by social media or other sources (shown in the sample text message in the figure), the agent made the choice to take the third route to avoid it. To arrive at the same ending point, it took 138 ticks. The number of visits along that route was compared to the number of visits along the control route. The distance from the start to the end is 13.42 miles. Given the ticks equal one minute, the speed is 5.83 mph.
Figure 10 Third route in green

There is an accident ahead. Take this route to avoid the accident.
The model was modified by adding 19 agents. The additional agents were created in the same method as the control agent was created. The starting and ending node, with two other nodes, were imported into Network Analyst to create a shortest path. As with the control agent, the script “Get Route Junctions” was used to make up the route. These routes were used by the model. The model shows the number of visits for each intersection which shows the congestion at that intersection.

Figure 11 Control route with 20 agents
The greater the number of visits, the greater the congestion. Figure 11 shows the control route with 20 agents. The inset is the picture of the number of visits at the location of the traffic incident. There are 4 visits at that location.

Figure 12 Route 2 with 20 agents
Figure 12 shows Route 2 with the 20 agents. The inset is the picture of the number of visits at the location of the traffic incident. There are 6 visits at that location.

Figure 13 Route 3 with 20 agents

There is an accident ahead. Take this route to avoid the accident.
Figure 13 shows Route 3 with the 20 agents. The inset is the picture of the number of visits on that route which was altered around the location of the traffic incident. There is 1 visit at that altered location.

To compare the three routes, Table 1 shows the total number of visits at the location of the traffic incident. For each visit along the route, the agent would have to slow down or stop along the route. The greater number of visits along the control route would result in different traffic congestion and increased time to travel from the starting and ending points. The number of visits along the second route is greater number of visits than the control route. The number of visits decreased for the third route. The third route is the best route due to traffic congestion as the traffic congestion was reduced. Traffic congestion is a result of the number of other cars on the same road which is represented in this model by the number of visits. When there are less number of visits, then there is less congestion at that location.

<table>
<thead>
<tr>
<th></th>
<th># of Visits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Route</td>
<td>4</td>
</tr>
<tr>
<td>Route 2</td>
<td>6</td>
</tr>
<tr>
<td>Route 3</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1: Number of visits for each route
In addressing the hypothesis on whether information about traffic congestion either from social media or other sources affects traffic congestion, data on travel flow counts will help. The website, https://data.seattle.gov/Transportation/Traffic-Flow-Counts/7svg-ds5z, reports the traffic flows for a particular road in Seattle, Washington (the location of the model is run). This information could be used to help determine if information about traffic congestion affects traffic. Comparing the traffic flow counts from before 2013 to current traffic flow counts would help show if other roads are being used. If so, then it is possible that traffic congestion information from sources like social media is affecting traffic congestion. People are receiving information about an incident on the more popular roads and choosing to take alternate roads. Table 2 shows the traffic flow information (the Average Annual Daily Traffic (AADT)) for the roads (in order) along the control route shown in Figures 8-10 as well as the route shown in the Google Map screen shot in Figure 7 for years 2007 to 2009. This is the type of information that would be used in that analysis.
The above data on traffic counts was for Seattle, Washington. There is a trend of a decrease in traffic flow and a trend in an increase in traffic flow. What does that kind of information report on the roads in a more congested area? The AADT in Maryland along the beltway should be reviewed. To analyze the AADT in Maryland for roads along the beltway, data from the Traffic Monitoring System (TMS) Team was used. This team responsible for the collection, processing, analysis, summarization, and dissemination for the Maryland State Highway administration. The Automatic Traffic

<table>
<thead>
<tr>
<th>Street Name</th>
<th>Year</th>
<th>AADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>WESTLAKE AVE N</td>
<td>2007</td>
<td>26300</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>26800</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>24600</td>
</tr>
<tr>
<td>NICKERSON ST</td>
<td>2007</td>
<td>11800</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>23700</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>22000</td>
</tr>
<tr>
<td>15TH AVE NW</td>
<td>2007</td>
<td>32900</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>30600</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>31000</td>
</tr>
<tr>
<td>HOLMAN RD NW</td>
<td>2007</td>
<td>30300</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>28100</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>28700</td>
</tr>
</tbody>
</table>
Recorders (ATRs) records the AADT. Figure 14 shows the locations of the ATRs near the beltway in Montgomery and Prince George’s counties. These counties have the most traffic congestion in Maryland. Looking at a comparison between 2013 and 2014 would be significant as Waze was acquired by Google Traffic in 2013. With the increased popularity of Waze, more people are sharing traffic congestion information.

Comparing years 2013 and 2014, the traffic counts for many of the roads along the beltway were reduced. Most have either been the same or reported a reduction in traffic counts. Table 3 below shows that some of the traffic data at the ATRs near the beltway that has been significantly reduced in traffic counts from 2013 to 2014. Some were reduced over 50 percent.

Figure 14: ATR locations near the beltway in Montgomery and Prince George’s counties in Maryland
While there may be many reasons to the reduction, traffic congestion information provided to drivers from social media or other sources would surely be included in reasons for reduced traffic congestion.

Table 3: AADT for Maryland Roads near beltway

<table>
<thead>
<tr>
<th>Road Section</th>
<th>AADT 2013</th>
<th>AADT 2014</th>
<th>Difference</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit 5 Ramp 03 RAMP 6 FR US 50 EB TO MD 410 SB TO VETERANS PKWY</td>
<td>9,413</td>
<td>2,150</td>
<td>7,263</td>
<td>77%</td>
</tr>
<tr>
<td>Exit 27 Ramp 06 RAMP 3 FR IS 495 EB TO IS 95X NB TO WEIGH STATION ACCESS RD (AHEAD)</td>
<td>1,555</td>
<td>470</td>
<td>1,085</td>
<td>70%</td>
</tr>
<tr>
<td>BELAIR DR TO MD 197</td>
<td>16,022</td>
<td>9,650</td>
<td>6,372</td>
<td>40%</td>
</tr>
<tr>
<td>EXIT 6 RAMP 2 FR RAMP 1 TO OLD MARLBORO PIKE</td>
<td>832</td>
<td>550</td>
<td>282</td>
<td>34%</td>
</tr>
<tr>
<td>Exit 7 Ramp 07 BRANCH AVE TO RAMP 6 FR MD 223 EB TO RAMP 7 (TO MD 5)</td>
<td>1,583</td>
<td>1,180</td>
<td>403</td>
<td>25%</td>
</tr>
</tbody>
</table>
CHAPTER FIVE – CONCLUSION

Traveling in a city is challenging at any time of the day. Rush hour traffic increases the travel time to and from the destination due to the amount of cars on the road at the same time. Certain factors delay the time even more. Some are unavoidable and affect everyone. They include weather events like snow and ice storms and rain events. Drivers become cautious and lower their speeds.

Other factors that delay the travel time are not unavoidable. They are incidents on the road that take up lanes on the highway. These include police related events, construction, or accidents. Drivers lower their speeds around these events because they have to merge into the free lane from the occupied lane, or for safety reasons, or for general curiosity reasons. This creates a domino effect because the drivers behind have to lower their speeds and so on and so on. The bottle neck delays the amount of travel time to and from a destination.

A remedy or helpful tip to drivers would be to alert drivers of the upcoming incidents so that they can avoid it by choosing an alternate path that goes around the incident. The traffic reports on the radio or TV try to give drivers information. However, these reports are not very helpful. More often, the reports are missed because the driver does hear the report because they are not tuned into that station when the traffic report is given. Another reason the traffic report is not helpful is that the particular road that the
driver is interested in does not “make the list”. That particular road is not a popular road with many drivers or the event is not big enough. This causes the driver to think there is not an incident on the road when there really is an incident on the road.

To help the traffic delays, the incidents that can be avoided must be relayed to the drivers. Social media is a perfect mechanism for relaying information about traffic congestion. Drivers would have access to all incidents or the incidents on the roads that the driver travels on would be relayed. Then they can choose alternate courses of action to avoid the incident such as choosing a different path or delaying their start time to let the incident and resulting bottleneck clear. This would decrease the amount of drivers which would ultimately decrease the bottleneck.

To show this, traffic modeling such as agent based modeling (ABM) was used. The model was run for 138 ticks where one tick equals a minute of time with a control route that had no traffic incidents. Then the control route was modified in two ways. The second route was delayed due to a traffic incident and the third route was altered around the traffic incident. After the results were analyzed, the results showed that the alternate routes had a difference than the control route. With the number of visits of the agents along the route and neighboring routes showed the congestion of traffic.

It was expected that the comparison to the control route to Route 2 would result in a greater number of visits. It was also expected that Route 3 that was altered around the traffic incident would result in a lower number of visits than the control route. This was shown in Table 1.
Getting people to use an alternate route is challenging. People have various reasons for not using an alternate route, even if it may be a better option. Reasons include routine, fear or uncertainty of an alternate route, or personal preference. In the book titled, *Traffic: Why We Drive the Way We Do (and What it Says About Us)*”, Tom Vanderbilt talks about the psychology of traffic. According to the author, even when drivers are given the information about traffic events that cause congestion, they will still take their original route. They may think that other people will take the alternative route which will alleviate traffic congestion. Or they may think the alternative path maybe just as congested. This is where ABM and traffic congestion information will help the greatest. The driver would be shown alternate routes with times to get to their destinations. Bottom line, people will drive exactly where they want.

However, the information about the benefit of taking an alternate route is not relayed. This information needs to be shared by either Waze or Google traffic. There needs to be a tool developed to let the user know that taking the alternate route would reduce the traffic congestion by a certain percentage. In some cases the alternate route may not reduce the congestion by that much. In some cases, it will. In some cases it would be better to stay on the same route and wait. This information would also be relayed in social media.

When the application shows traffic congestion, it usually colors the routes in red for high congestion, yellow for medium congestion, and green for low congestion. It would be more beneficial if it showed the difference in relative to surrounding roads. Also, when suggesting an alternate route, it should tell you the difference in the traffic
congestion from the current route the driver is on. This would be more important information that traffic congestion on the current route the driver is on. When determining whether traffic congestion information from social media or other sources affects traffic congestion, historical data is needed. Social media traffic applications, such as Waze, was acquired by Google in 2013.

As people see using traffic congestion information from sources such as social media to gain information about traffic incidents and thus taking alternate routes to avoid the incidents, traffic congestion would be affected.

ArcGIS Version 10.4’s analysis features were described at the Federal Users’ Conference in February 2016. Spatial and statistical analysis can help determine significant patterns. Combining that analysis with image analysis, real time data, change-detection can be done. Real time data can be set up to connect to feeds, send updates and alerts and be used for analysis. The analysis gets stronger with social media and crowd sourcing information is added. Overtime, traffic congestion will be affected due to the trust in the information about the alternative route suggested. The commuter will be given more than a suggested arrival time. The commuter will be provided information about the traffic congestion. As ArcGIS expands their analysis application to include data from social media and real time data, the analysis capabilities will expand. Hopefully there will some relief to the traffic congestion in cities.

Referring back to the hypothesis of this thesis, due to the traffic congestion information, when drivers take an alternate route which helps reduce traffic congestion.
CHAPTER SIX – FUTURE WORK

There are many other aspects of this topic that could be researched further. One topic would be to see how long it takes before people are comfortable with social media information with respect to traffic congestion. How long before people rely on the information about which route to take. The model and data in the ABM tutorial was used for this thesis were taken from Seattle, Washington. Future work would be the analysis of using social media in different cities, such as Dallas, New York, Los Angeles, and Washington DC. Questions could be focused on why some drivers in some cities tend to change their planned route while other drivers in some cities do not.

This question could be expanded to other countries. Cities such as London, Rome, Italy, or Paris, France could be considered to see how other cultures respond to social media with respect to traffic congestion. There are tips to driving in European cities that include learning about ways European drivers pass and getting used to roundabouts (“Behind the European Wheal: Driving Tips and Road Rules”, 2016). There are major restrictions to using a cell phone while driving. The tips do not include a lot of information on how to deal with traffic except using the express say and avoiding congestion times. Even in an article that discussed Belgium’s traffic problem, it does not talk about a traffic system, just a congestion charge (“Five reasons Belgium has the worst
traffic in Europe”, 2016). There needs to be research done to show Europeans that a traffic congestions system would help.

Information from State Highway Administration on AADT shows a decrease of traffic data from 2013. The Maryland State congestion assessment report gives a map for easy determination of road performance, but little in analysis. While there may be many reasons to the reduction, information provided to drivers from social media or other sources would surely be included. More research on the cause for this decrease.

Agent Analyst runs on ArcGIS 9.3, not ArcGIS 10.4, the current version. ArcGIS Version 10.4’s analysis features were described above. Spatial and statistical analysis can help determine significant patterns. Combining that analysis with image analysis, real time data, change-detection can be done. Real time data can be set up to connect to feeds, send updates and alerts and be used for analysis. Further research on using ABM in ArcGIS would provide more insight to the correlation between patterns of movement and social media.
APPENDIX

In this appendix is a literature review of a paper by Bratislav Predic. He reviews some research on some traffic systems. Although based on VGI approach and social navigation, none of the research considers application of appropriate data mining technique to improve the reliability and accuracy of reported traffic events and situations. Also, the presented VGI systems does not include the functionality for sending notifications of detected real-time information related to short traffic events. Such feature would fully employ crowd sourcing and crowd intelligence approaches in dynamic and collaborative navigation. The traffic systems are:

- The Pothole Patrol
- The Nericell
- In Perttunen
- Vittorio
- Control Unit
- The VTrack
- Coric, Djuric, and Vucetic
- A smartphone demo application
- Zambonelli
- CrowdITS
- Sha, Kwak, Nath, and Iftode
- Händel, Ohlsson, Ohlsson, Skog, and Nygren and Handel
- Song
REFERENCES


*Five reasons Belgium has the worst traffic in Europe.* Retrieved January 4, 2016 from https://www.ricksteves.com/travel-tips/transportation/driving-europe-tips


*How mapping software gathers and uses traffic information. The key element is you.* Retrieved August 28, 2015 from https://www.washingtonpost.com/national/health-science/how-mapping-software-gathers-and-uses-traffic-information-the-key-element-is-you/2014/02/14/693606d4-9263-11e3-b46a-5a3d0d2130da_story.html


Why is transportation important? Retrieved July 6, 2015 from http://www.ask.com/world-view/transportation-important-1c5dce86cf7f7f7d

BIOGRAPHY

Jennifer Smith graduated from Robert E. Peary High School, Rockville, Maryland, in 1984. She received her Bachelor of Science from the University of Maryland in 1990. She was employed by the Federal Government in 1987 at the National Weather Service in Silver Spring, Maryland. She joined the Corps of Engineers in 1994 in Alexandria, Virginia. She pursued her Master of Science in Geospatial Intelligence from George Mason University in 2016.