INCORPORATING SOCIO-ECONOMIC FACTORS IN TRAFFIC MANAGEMENT AND CONTROL

RUBI HAN

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Civil Engineering

Montasir M. Abbas, Chair
Antoine G. Hobeika
Linbing Wang

August 26th, 2015
Blacksburg, Virginia

Keywords – Signal control strategies; Large urban networks; Alexandria case study; TRANSIMS; Macroscopic Fundamental Diagram.

INCORPORATING SOCIO-ECONOMIC FACTORS IN TRAFFIC MANAGEMENT AND CONTROL

RUBI HAN

ABSTRACT

Traffic Congestion is a critical problem in large urban areas. In this thesis, six different control strategies aiming to alleviate congestion are performed through TRANSIMS simulation in the city of Alexandria. Main objective of this thesis is to study and explore the impacts of these control strategy in terms of system performance. Macroscopic Fundamental Diagrams has been used during research to present traffic movement and evaluate traffic performance. This thesis also look at the outcome of each strategy at different household income group in the city. The attention are drawn to the importance of taking socio-economic impact in traffic management decisions. Some of the control strategies presented in this thesis have different impacts on different income groups in the city, while other control strategies have similar impacts (negative, or inconclusive) on different groups in Alexandria city. The thesis gives the conclusions on the impact of selecting different signal control strategies.

ACKNOWLEDGEMENTS

I would never have been able to finish my thesis without the guidance of my committee members, help from friends and faculty members, and support from my family.

Firstly, I would like to express my sincere gratitude to my advisor Dr. Montasir M Abbas for the continuous support of my Master study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Master study while at Virginia Tech.

Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Antoine G. Hobeika and Dr. Linbing Wang for their insightful comments and encouragement, but also for the hard question which incented me to widen my research from various perspectives.

I thank my fellow lab mates in VT-SCORES lab for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last two years. Also, I take this opportunity to express gratitude to all of the Department faculty members for their help and support.

Last but not the least, I would like to thank my parents for supporting me spiritually throughout writing this thesis.

DEDICATIONS

I would like to dedicate this thesis to my parents Aimin Han and Aihua Tang. They always have supported me in my academic pursuits. Without their encouragement and support I wouldn’t have completed my studies. And finally I would like to dedicate this to all my friends who believed in me even before I did in myself.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Annually, drivers in Washington, D.C. and Northern Virginia spend approximately 80 hours delayed in 30 minute commutes. They will experience a high-volume, stop-and-go traffic through Monday to Friday, between 6:30-9 A.M. eastbound Interstate 66 (I-66) which outstrips road capacity. Most commuters, driving vehicles with two occupants, travel this corridor at the same time every workday, causing severe congestion. Because largely suburban regions like Northern Virginia lack the infrastructure and funding to support the increasing number of vehicles, I-66 congestion often extends into “off-peak” periods and spills onto Routes 29 and 50. Regional travel times are projected to worsen with forecasted job and housing market growth to exceed current values by 40 percent by 2040.

We can see from previous numbers from traffic condition of northern Virginia that traffic congestion is a critical problem in large urban areas characterized by high household numbers and traffic densities. The overutilization of the cities’ road network beyond its capacity limit, has become the leading cause of the increasing numbers of vehicles delays, queue length, and travel times. Different levels of congestions and bottlenecks can be seen around Alexandria city. This situation is even more exasperated during peak hours. There are different ways to reduce traffic congestion based on the underlying reasons of congestion. This thesis’s research and developed strategies are focused on the changes pertaining to traffic signal control systems and patterns.

Traffic signal control has been considered a very cost-effective method for the improvement of urban traffic systems in many ways such as travel time, safety and environment. However, there is a need to quantify the impact of different signal control and optimization strategies on network performance. In this thesis, we discuss six different control strategies and explore their effects on network. By changing the timing plan and phasing plans of the network based on different scenarios, we can evaluate the effectiveness of each signal control strategy and make contributes on alleviate current traffic situation in Alexandria case study.

In order to understand more about the of different signal control strategies, with simulation results from TRANSIMS, this thesis also applies traffic volumes and densities of each link in the whole network to receive different well-defined macroscopic fundamental diagram (MFD) in Alexandria case study. After drawing MFD for each signal control strategy, this thesis illustrates the link number changes between base case and each strategy aiming to find out the change of traffic performance by various timing plans.

Also, Understanding the relationship between different control strategies and socio-economic factors can help decision makers selecting strategies that are equitable to the society. For example, making a decision on selecting control strategies that redistributes delay on the network would be more informative when knowing which group-income would be affected in the region. This can also make it easier to link control strategies with road and network pricing options. In this case, socio-economic factors are brought into discussion in this thesis.

1.1 RESEARCH OBJECTIVES:

The major objectives of this research

- To propose six different signal control strategies in Alexandria network and simulate all the related data through TRANSIMS
- To explore and illustrate the socio-economic impacts of different signal control strategies on overall traffic networks
- To find out the socio-economic impact with the help of MFD analysis on three different signal control strategies

1.2 THESIS CONTRIBUTION:

This thesis conduct a research through TRANSIMS simulation to examine the effectiveness of six different signal control strategies proposed based on traffic condition in Alexandria city. Taking socio-economic factors with MFD into consideration of selecting signal control strategies raises a new way to improve traffic performance. This method will help decision makers in transportation engineering think about a new aspect when selecting the appropriate signal control strategies for urban networks.

1.3 THESIS ORGANIZATION:

The thesis is organized into five chapters. Chapter 1 presents an introduction, research objectives, and contribution of the thesis. Chapter 2 gives a detailed literature review on TRANSIMS software and macroscopic fundamental diagram history. Chapter 3 presents details of six signal control strategies and the impact of combining economic factors with traffic travel time. Chapter 4 describes a further study of socio-economic factors by taking macroscopic fundamental diagram into analysis and discussion. Chapter 5 presents the research conclusions and recommendations for future research.

2. LITERATURE REVIEW

2.1 TRANSIMS REVIEW

Figure 1 provides a concept structure for the TRANSIMS architecture. We can see from the figure that the system consists of five modules.

The first module, the population synthesizer, is used to create a synthetic population of the households in the Alexandria area. It provides aggregate information summarized by census tract or block group and disaggregate information from the public use micro samples (PUMS) census record which record the data from nearly five percent of the respondents. These information gives us the distinct household information linked to each vehicle. The household information generated from census tract and block group are similar to the realistic population data in study areas. The demographics and the household distribution of the synthetic population agree with real population data. The demographics of synthetic population are the base for individual household and vehicle activity. The synthetic population generated include gender, age, household location, education, income, vehicle type and employment. These census data can generate and chose from variables.

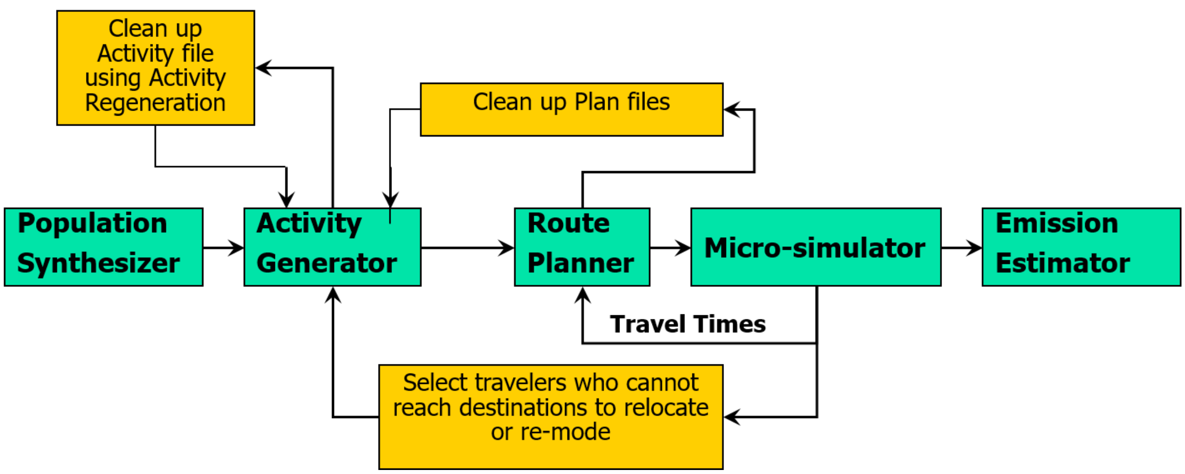


FIGURE 1 TRANSIMS architecture

The second module, the household activity generator, generates the daily activities of each synthetic household and the corresponding person and vehicle in it. The input of this module is activity location, land use network, transportation network, household population information and a regional activity survey which lasts for a 24-hour duration. Sometimes the duration would be longer. The outcome of this module will identify the population and all the daily activities and trips of each household. The total number of trips is identified as all the location changes in the daily activities. And the daily activities is desired similar to the traditional travel diary of the travel in the whole population. The attributes of these activities are activity priority, start time, end time, time duration, mode preferences, constraints and possible locations.

The third module, the route planner, generates the transportation routes for each trip and activity from previous module the household activity generator. This module identifies the individual goals for each traveler from second module. The route attributes in the TRANSIMS software consists of the link a traveler located, the mode, changes in that mode, the parking location and also the companions of the traveling. The input to these attributes includes all the travelers' information, all the activities' information and all the information for the whole network such as link location and link travel times. Information including departure time, arrival time and links for each mode for each trip are listed detailed enough in TRANSIMS. The output from the route planner is a complete enumeration of the transportation demand by mode and disaggregated by time of departure.

The fourth module, the microsimulation, generates the microscopic level of detail using route plans from second module and third module as inputs to simulation the whole transportation network. Although the simulation is at a lower accuracy comparing other traffic simulation models, it still obtain the information between demand (the synthetic population's desire to travel between activity locations) and supply (the ability of the transportation system to meet this demand) during the 24-hour simulation procedure. The outcome for the microsimulation module can gather information at any desired level such as obtain travel's information second by second. That means we can get information between the sub-link information in one second to total network information during the whole day.

After the four steps from previous module, the effectiveness of the simulation is calculated from results generated especially from microsimulation module. Since the vehicles are modeled at a microscopic level of detail, their emissions are not estimated within the microsimulation module but from the aggregate output data. The important point is that while TRANSIMS has been calibrated to macroscopic flow observations there is no guarantee that the microscopic speed profiles are accurate or reasonable enough. Therefore, the individual vehicle speed profiles, and associated accelerations and decelerations cannot be used for calculating vehicle emissions.

2.2 MFD REVIEW

The very beginning idea to generate a Macroscopic Fundamental Diagram (MFD) can be dated back to 1960's. However, the real concept and accelerated research about the MFD was brought up again in 2007 by Daganzo aiming to find out the potential control and management of the network traffic. The overview of papers talking about MFD during past years is given below: Daganzo brought up the start of the MFD theory about overcrowded networks lead to a set back to the traffic performance; Geroliminis and Daganzo conducted research in Yokohama, Japan and used the real field data finding out there is a relationship between the production and performance; They then used the Yokohama and san Francisco field data for simulation and theoretically explained the shape of MFDs; Buisson and Ladier used the real data from urban freeway found out there is scatter on the Fundamental Diagram (FD) if the detector are not ideally located on inhomogeneous congestion; Ji et al. simulated the urban freeway to get a scatted MFD and concluded that inhomogeneous congestion should be considered in network control because it reduces traffic flow; Knoop and Hoogendoorn simulated the grid network to get the assumption that traffic congestion can attract congestion and production is a continuous function of accumulation of density; Gayah and Daganzo simulated the grid network found out the Hysteresis loops exist in MFDs based on a quicker recovery of un-congested parts and it would be reduced with rerouting. Among all these finding during the history of MFD, the best-known studies are the ones by Daganzo, Geroliminis and Daganzo.

Also, the MFD could be used for control purposes because the speed on neighborhood roads are connected and the traffic state in a whole area can be concluded by an average MFD. The traffic could be rerouted based on the accumulation in subnetwork using the speed originated from the network MFD. In this case, the traffic network situation can be improved. However, it is hard to formulate the MFD due to the complex calibration between consecutive links and diversity of the traffic condition, especially in congested networks. There are few proposed Single-Regime Models, which are made for evaluating and forecasting the performance of single components such as an intersection or a section of highway. In this thesis, four common models have been used for calibrating the relationship between speed/density and flow/density: Greenshields model, Greenberg model, Underwood model and Northwesten Group model.

The paper published by Greenshields in 1935 may has done the seminal work during the history of duplication the speed-flow curves. He depicted the speed-flow curve by combing a linear speed- density relationship together with the <flow = speed * density> equation. Two basic parameters are free flow speed and jam density. Greenberg Model was proposed after Greenshields using hydrodynamic analogy he combined equations of motion and one-dimensional compressive flow and derived the equation. The disadvantage of this model is that the free flow speed is infinity. The Underwood Model as a result of traffic studies on Merrit Parkway in Connecticut, it raised interests in free flow regime as Greenberg model was using an infinite free flow speed. This model requires free flow and optimum density. The disadvantage of this model is that the speed would never reach zero and jam density is infinite. The Northwestern Group model is a formulation related to Underwood Model. Two basic parameters are free flow speed and optimum density. In this model, speed would never go to “zero” when density approaches jam density.

And for large-scale urban network, there existing maybe more complex problems waiting to be solved. First, it is different from air travel network or other kinds of transportation network, almost every household and activity location in a city can be an origin/destination if activity exists not only in several separated nodes or specific links. So it often shows more randomness than other transportation networks. Secondly, all kinds of vehicle-based travel or pedestrian travel must rely on road network which cannot be changed during a short period. In this case, the traffic network represents a kind of accuracy. Last but not least, road networks are also consisted of different kinds of links and intersections which have totally different functions in network structure.

3. CONSIDERATION OF ECONOMIC FACTORS WHEN SELECTING SIGNAL CONTROL STRATEGIES IN LARGE SCALE URBAN NETWORKS

RUBI HAN

Graduate Research Assistant

Civil and Environmental Engineering

Virginia Polytechnic Institute and State University

Tel: 520-275-3150; Email: hrubi@vt.edu

MONTASIR ABBAS, PH.D., P.E., CORRESPONDING AUTHOR

Associate Professor

Civil and Environmental Engineering

Virginia Polytechnic Institute and State University

Tel: 540-231-9002; Email: abbas@vt.edu

Word count: 4,185 words text + 13 figures x 250 words (each) = 7,435 words

Submission Date: August 1st, 2015

ABSTRACT

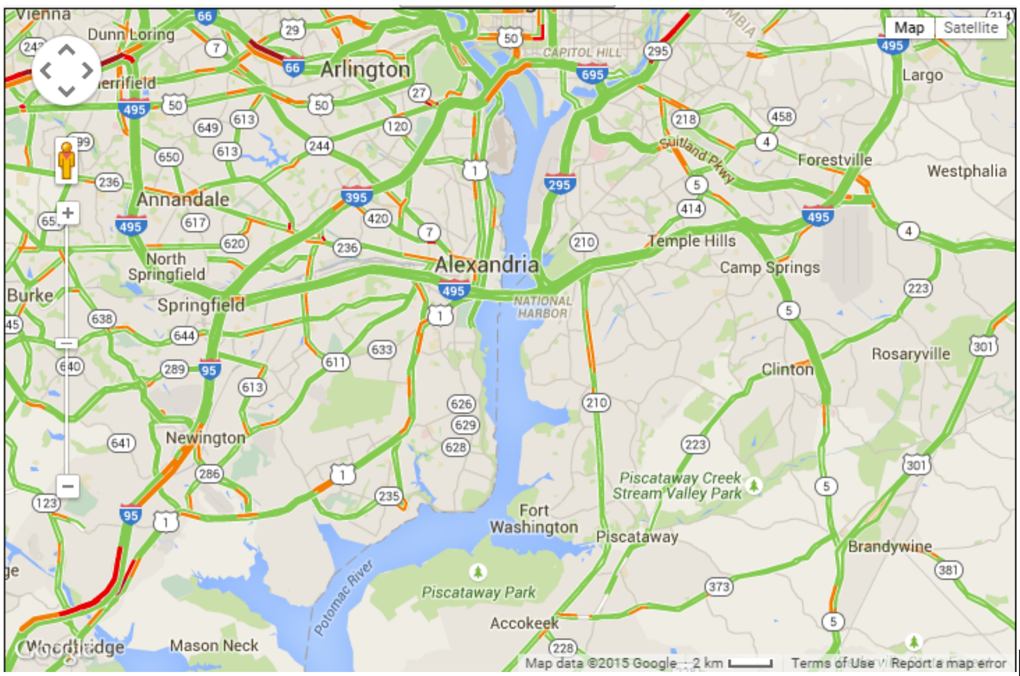
In this research, we perform TRANSIMS simulation of six different control strategies in the city of Alexandria. Our main objective is to study and explore the impacts of these control strategy in terms of system performance. However, we also look at the outcome of each strategy at different income group in the city. We aim to draw the attention to the importance of taking socio-economic impact in traffic management decisions. Some of the control strategies presented in this paper have different impacts on different income groups in the city, while other control strategies have similar impacts (negative, or inconclusive) on different groups.

Keywords: Control strategies; Large urban networks; Alexandria case study; TRANSIMS, NEXTA.

3.1 INTRODUCTION

Background

Traffic Congestion is a critical problem in large urban areas characterized by high household numbers and traffic densities. The overutilization of the cities' road network beyond its capacity limit, has become the leading cause of the increasing numbers of vehicles delays, queue length, and travel times. Taking the city of Alexandria, Virginia, as a case study of this paper, Figure 2 below presents a live traffic map during non-peak hours. Different levels of congestions and bottlenecks can be seen around Alexandria city. This situation is even more exasperated during peak hours. There are different ways to reduce traffic congestion based on the underlying reasons of congestion. This paper's research and developed strategies are focused on the changes pertaining to traffic signal control systems and patterns.



[1]

FIGURE 2 Alexandria live traffic map during non-peak hours.

Traffic signal control has been considered a very cost-effective [2] method for the improvement of urban traffic systems in many ways such as travel time, safety [3] and environment. However, there is a need to quantify the impact of different signal control and optimization strategies on network performance. In this paper, we discuss six different control strategies and explore their effects on network. We utilize the next generation transportation planning software package – TRANSIMS and the transportation network analysis software package – NEXTA in our work.

TRANSIMS[4] (TRansportation ANalysis SIMulation System) is a segregate, behavioral transportation planning package developed at the Los Alamos National Laboratory (LANL) [5]over the last several years with funding from USDOT[6], EPA, and the Department of Energy. Accurate and complete information has been given to transportation planners with a structured system of travel forecasting models on traffic congestion and traffic impacts. The recent advances in the computer software were brought to the field of transportation modeling during its development. The core element of TRANSIMS, an agent-based[7] simulation system, is capable of simulation every vehicle and every household movement second by second trough the transportation network of a large urban area.

NEXTA [8](Network EXplorer for Traffic Analysis), on the other hand, is a graphical visualizer interface to assist on traffic simulation preparation and analysis of simulation-based dynamic traffic assignment datasets. Extended from DSPEd 1.0, NEXTA was developed by ITT Industries, Inc. for the Federal Highway Administration (FHWA) in 2004 by Dr. Xuesong Zhou. He has been do development and maintain for its capabilities since then.

Paper Objectives

The objective of the paper is to explore and illustrate the socio-economic impacts of different signal control strategies on overall traffic networks. The Alexandria network is used as a case study in northern Virginia. TRANSIMS visualizer, NEXTA, is used to compare and contrast the results.

Organization of Paper

First, the paper presents a review of the transportation-planning package, TRANSIMS, and of the existing transportation network analysis software package NEXTA. This is followed by a literature review. Subsequently, a large urban network focusing on optimization signal control strategies together with the developing procedure of TRANSIMS and NEXTA is presented. The signal control strategies applied to the Alexandria city case study in northern Virginia and their evaluations are stated afterward. Socio-economic findings are conducted using TRANSIMS and are presented in the paper. Finally, conclusions and recommendation for further research are summarized.

The next section begins with an introduction of the core signal control parameters in TRANSIMS followed by its current analysis tool NEXTA and particularly a TRANSIMS case project of Alexandria, VA development. The needs of a large urban network focusing optimization methodology for TRANSIMS are also discussed in this section. Next, six different focused optimization signal control strategies as introduced, and detailed explanation of adjusting procedure for Alexandria case study are discussed in this section. Nest, the evaluation of both optimized situation of Alexandria case study traffic signal control and economic findings during research are presented. Finally, we provide a brief discussion and summary of the findings.

3.2 LITERATURE SYNTHESIS

3.2.1 TRANSIMS review

Introduction

TRansportation ANalysis SIMulation System (TRANSIMS) started at the Los Alamos National Laboratory (LANL) as a new modeling tool for transportation planning organizations. This modeling tool takes a look at individual interactions in the aspect of vehicles as well as the whole effect on the network. After a period of initial development, TRANSIMS changed from a tool for private use to an open source software so that every transportation planners and engineers are able to customize it for their own use. A set of modules, including network synthesizer, population and activity generation, routing, and microsimulation, are the fundamental functions in the use of the TRANSIMS software. In order to fully understand the procedure of using TRANSIMS, a framework of processing TRANIMS, adapted from the original TRANSIMS framework[9] is shown in Figure 3.

In this paper, signal control strategies are proposed and conducted in TRANSIMS. To sustain the creation and management of the complex Alexandria network files required for signal control optimization[10] development in TRANSIMS, a number of tools were used. TransimsNet.exe uses a simple node table, link table and zone table to build a refined TRANSIMS network. IntSignal control.exe uses phasing plan table, timing plan table and signalized or unsignalized node table to assign traffic signal control devices and develop signal control plans for the whole network. Also, socio-economic finding are conducted during simulation with the help of Population Synthesizer and Activity Generator.

TransimsNet is the tool that help create the whole network files. From the information provided in input link, node, shape, and zone files, TransimsNet creates TRANSIMS files for links, nodes, zones, pocket lanes (turning lanes), lane connectivity, parking locations, activity locations, and process links (links help connecting parking and activity locations). The information for links, nodes, zones, pocket lanes, and lane connectivity can be found in the input directory, while TRANSIMS puts activity locations, parking locations, and process links in network directory. Also, sign and signal warrants for the network can be created through TransimsNet. The inputs for TransimsNet are normally created outside of the TRANSIMS framework, and the files in network directory are used in almost all future modules.

With the sign and signal warrants created by TransimsNet, IntSignal control creates traffic signal control files for the whole network. Information about signalized intersection and traffic signals can be found in the files called signalized node, phasing plan, timing plan, and detector files. Also, unsignalized node file contains all the information like the position of yield and stop signs. Parameters information in the traffic signals are well defined in the signal control file for IntSignal control, while changes in this file will apply to the whole network signals.

The Population Synthesizer module creates network households' information that represent every real individual household in the Alexandria case study. These households' information has synthetic persons matching the Census Block Group population demographics generated from the Census Bureau. In this paper, household ID, location and corresponding income information are needed during research. The Activity Generator module creates household activity tables for each person through matching households' information with household information from surveys including travel and activity participation information for each household member according to similar demographic characteristics. The household information from surveys is classified by the Classification and Regression Tree (CART) algorithm.

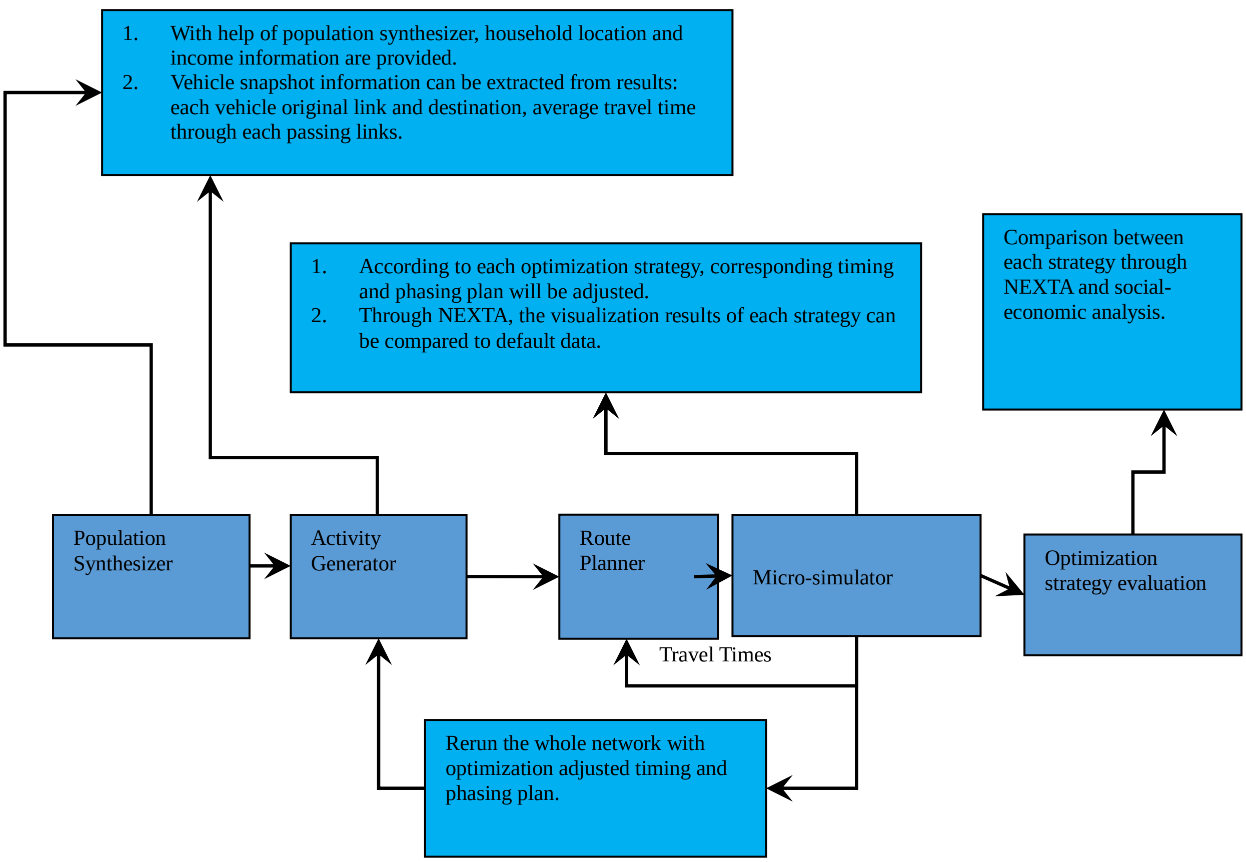


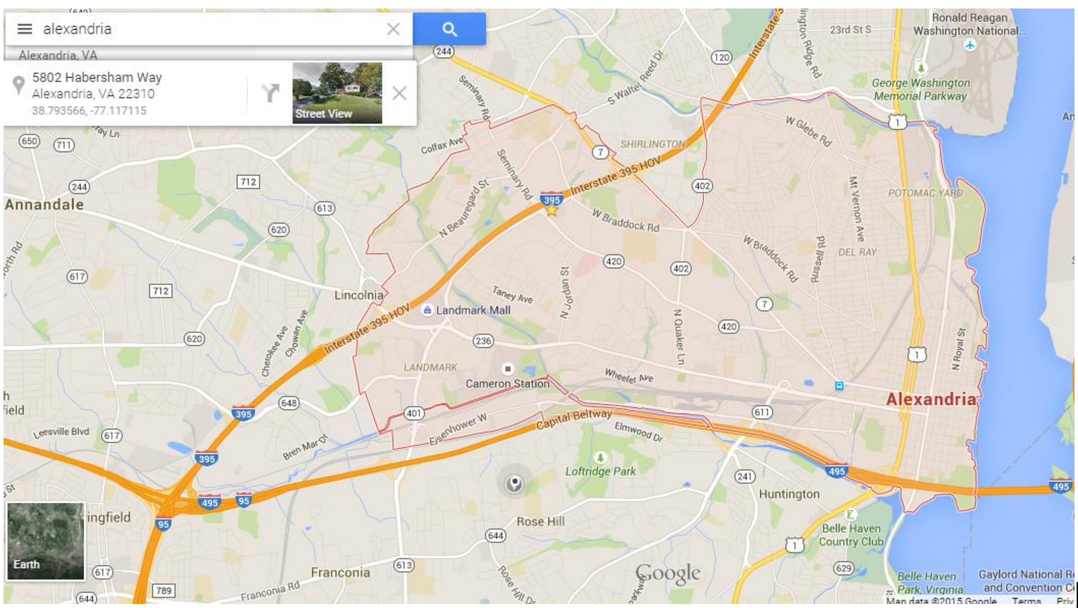
FIGURE 3 TRANSIMS process framework.

Alexandria case study

The Alexandria network is provided with the TRANSIMS open source as a test case. After debugging the problems with sets of efforts, the Alexandria, Virginia TRANSIMS model was set as an introduction of TRANSIMS, due to its fairly simple TRANSIMS network with all the signal control and batch files needed to run the network. The network is located between I-395, I-95/495, and the Potomac River, as seen in Figure 4.

A few assumptions have been made during TRANSIMS simulation methodology for the whole network and researchers:

1. Basic sets of signal control files and batch files will help in order to run the network.
2. Researchers have a basic understanding of GIS software package
3. Researchers know how to run individual modules and meaning of each module stands for.
4. The TRANSIMS network that is complete and functional can be counted as an accurate regional model.



[11]

FIGURE 4 Overview of Alexandria, Virginia - source: Google Maps, 2015.

The Alexandria network was chosen due to its size, and existing batch and signal control files. It demonstrates an area much larger than usual networks used in simulation software like VISSIM, but is still small enough that 5 router loops and 5 micro simulator runs can be completed in less than two hours on a personal computer. Also, the diversity observed in large regions is contained in this network: a downtown area with a very structured road network, more residential areas with a more random road network, a transit network, as well as interstates. The only shortage of this network is mainly residential area, with commercial areas observed to be sprinkled throughout.

3.2.2 NEXTA Review

The purpose of NEXTA is to allow transportation planners and traffic engineers to quickly visualize link-based and vehicle-based simulation results from their research work. Traffic networks can be easily built in NEXTA. Instead of spending time learning how to use a DTA program, transportation planners and traffic engineers are able to display, edit and store the data they need as well as making decisions during the time they analyze the data. NEXTA provides a medium where it is possible to hide data and network complicated relationships, due to its characteristic as a user-friendly Graphical User Interface (GUI).

NEXTA is also able to provide many considerable features that many other traffic networks editors do not have. Some of the features are listed below:

1. Dividing links by dropping a node inside it,
2. Easily extending a network by dragging links out from one node,
3. Use of a background image to establish nodes and links correctly.

The usage of NEXTA in this paper is to visualize the output from TRANSIMS after each Signal control strategy run is completed.

3.3 METHODOLOGY

The basic land use map and income distributed map in Alexandria, VA, is presented in Figure 5. Combined with the bottleneck info provided by TRANSIMS and visualizer snapshot provided by NEXTA shown in Figure 6, one can see that the congested areas and bottlenecks mostly occur in commercial sections. There exist two major types of traffic signal control modes: Pre-timed and Actuated. Selecting the appropriate signal control strategy[12] that best optimizes the vehicular flow in the network (whether pre-timed or actuated) depends on the network topology and traffic patterns.

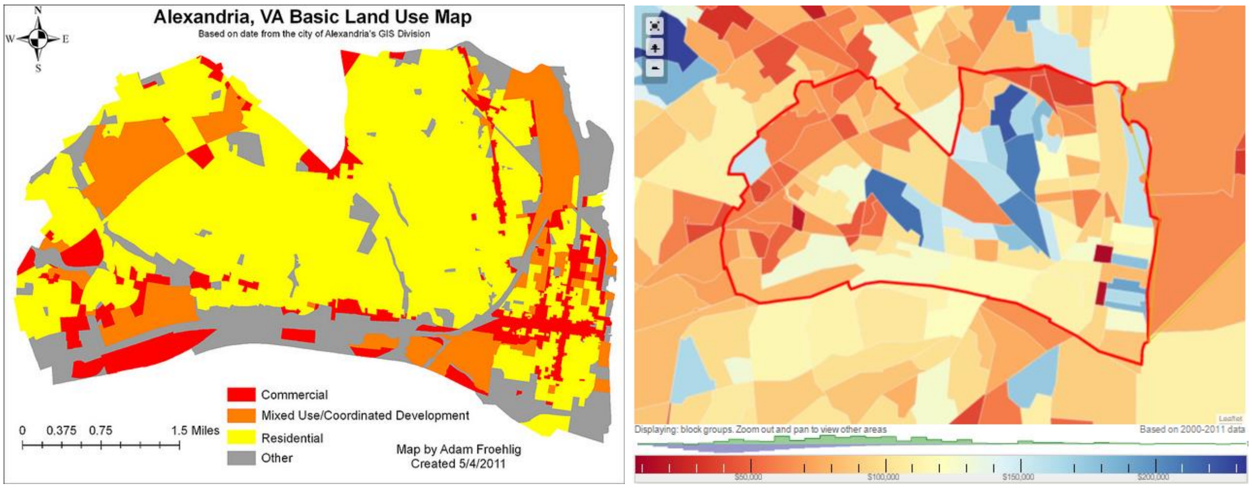


FIGURE 5 Alexandria, VA Basic Land Use Map VS. Income heat map.

[13]

FIGURE 6 Alexandria bottleneck map.

Six different optimization signal control strategies were proposed based on corresponding scenarios, and are shown in the following section with detailed structure explanation and optimization processing steps in TRANSIMS.

3.3.1 Signal control strategy 1

The Old Town area on the southeast corner of Alexandria city is the most congested area due to its commercial land use type. However, most intersections in Old Town are controlled by stop signs and all the signalized intersections are pre-timed. Corresponding to this current signal control pattern, signal control strategy 1 is to change all the stop signs to signalized intersections with a similar timing plan to that on north-south trending avenue.

3.3.2 Signal control strategy 2

Due to the fact that traffic along W Braddock Rd is congested according to the bottleneck information provided from TRANSIMS, the second signal control strategy is based on dividing the single direction traffic flow from west to east into more directions. In addition, the maximum green time [14] of turning movements is increased by adding 5 seconds to left turning movements and 5 seconds to right turning movements. At the same time, the maximum green time of through movements was decreased by 10 seconds. More existing bottlenecks problems on northern side are also taken into consideration to balance both turning directions, behaving as equivalent green time adjusted in both turning movements.

3.3.3 Signal control strategy 3

Signal control strategy 2 provides a method that release the congestion along W Braddock Rd without changing the cycle length by decreasing the maximum green time on the through movements and adding more maximum green time on turning movements. Similar to this strategy, signal control strategy 3 maintains the signal timing plan along W Braddock Rd but changes the maximum green time of signalized intersections besides W Braddock Rd. This method increases the maximum green time of movements turning into parallel directions of W Braddock Rd and decreases the maximum green time of other directions. The changes of relevant green time are all up to 5 seconds for each direction.

3.3.4 Signal control strategy 4

Based on our observation of pre-timed signal timing plans and actuated signal timing plans on the network, links with more actuated signal timing plan are less congested compared to links with only pre-timed signal systems and stop signs. So, signal control strategy 4 was to change all the pre-timed signal systems into actuated signal systems with method of adding the extend-green time[15] by 10 seconds.

3.3.5 Signal control strategy 5

With the help of basic land use map of Alexandria city in Virginia, commercial areas marked with red color are all on the boundaries surrounding the residential areas marked yellow in the center of Alexandria. Based on this observation and combined with the bottleneck information provided in TRANSIMS, signal control strategy 5 maintains all the signalized intersections in residential area and increases the maximum green times of signalized intersections in commercial areas by 10 seconds.

3.3.6 Signal control strategy 6

Figure 7 below presents the ratio between actual speed and speed limit in the whole network. Red marks means the actual speed and speed limit ratio is below 50%. Green means the actual speed and speed limit ratio is above 90%. Based on this observation, minor roads and branches have more red marks than main roads. According to this observation, signal control strategy 6 was to maintain all the signalized intersections on the main roads and increase both minimum and maximum green times of signalized intersections on minor roads and braches by 5 seconds.

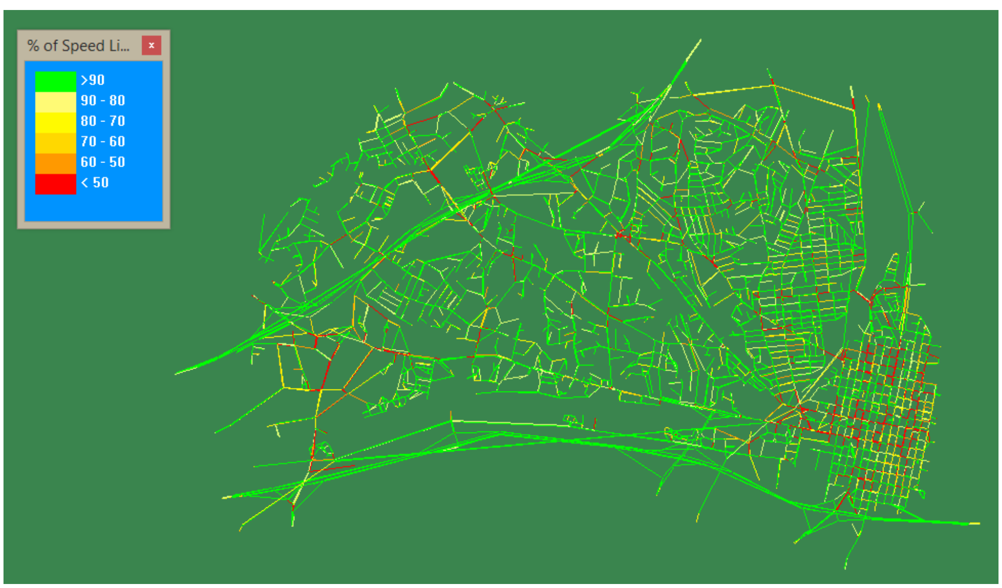


FIGURE 7 Actual speed and speed limit ratio map.

3.4 ANALYSIS

3.4.1 NEXTA analysis

Figure 8 to Figure 13 below show the output of each Signal control strategy compared to the default network using travel time contours function in NEXTA.

For Signal control strategy 1:

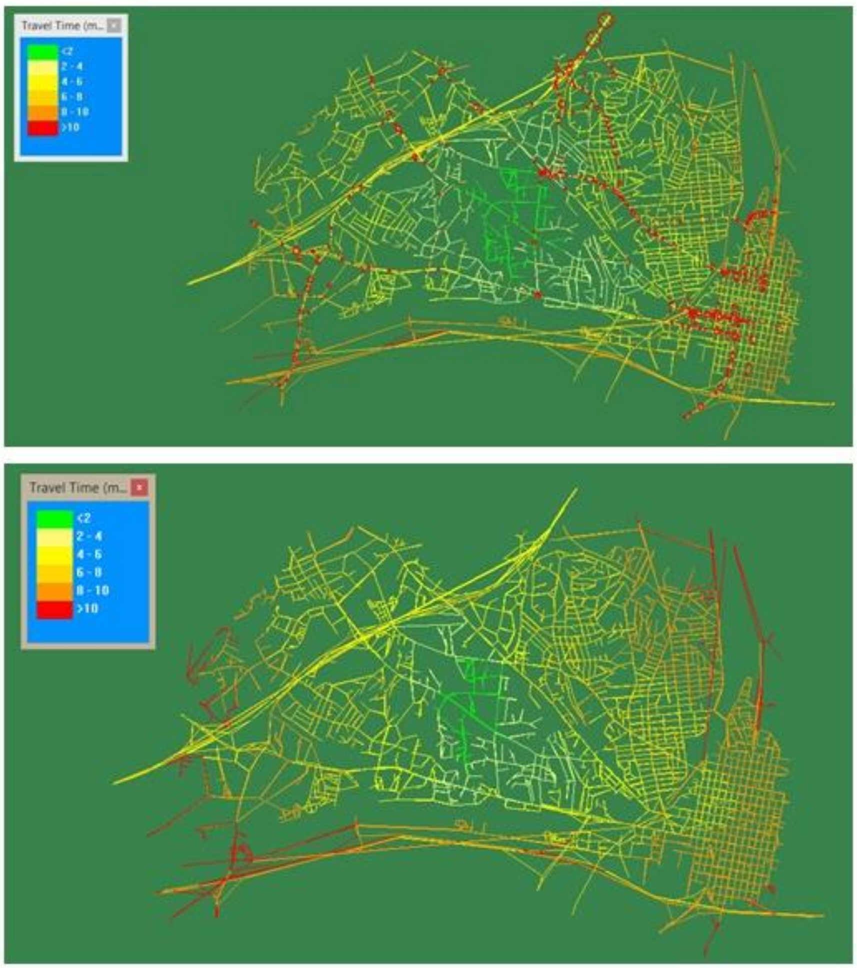


FIGURE 8 Before and after comparison map for strategy 1.

Signal control strategy 1 has been proven to be not very successful according to the simulation visualizer and comparison. Changing all the stop signs into actuated signal control system not only increases the congestion in old town area, but also leads to congestion around old town. The reason causing this phenomenon is in commercial areas in old town, blocks and streets are in close proximity with each other. Changing stop signs to signalized intersection would only increase the queue length in every block.

For Signal control strategy 2:

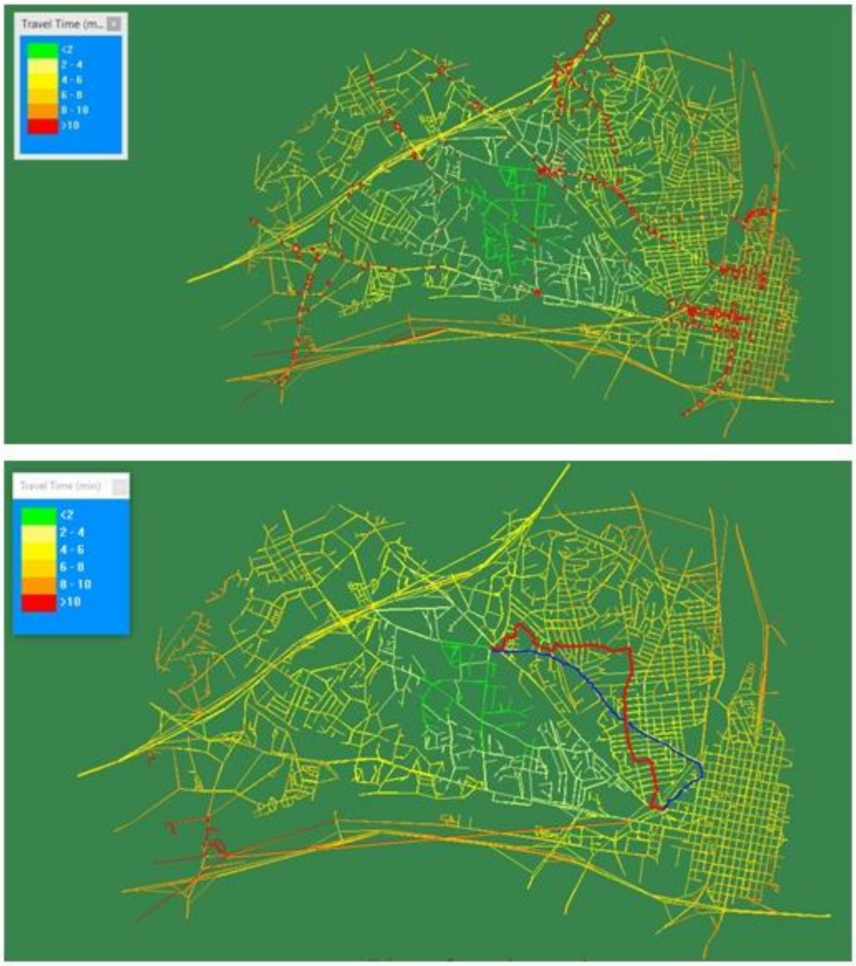


FIGURE 9 Before and after comparison map for strategy 2.

After diving traffic flow following W Braddock Rd through movement into other turning movement, the congested area has decreased with signs of less red and orange marks in the network visualizer. Also, using <find the shortest path> function in NEXTA, the shortest is rerouting to northbound (Shown as red line in figure 8) instead of following the through movement. (Shown as blue line in figure 8). Also the shortest path travel time is 7.0 minutes instead of 7.9 minutes.

For Signal control strategy 3:

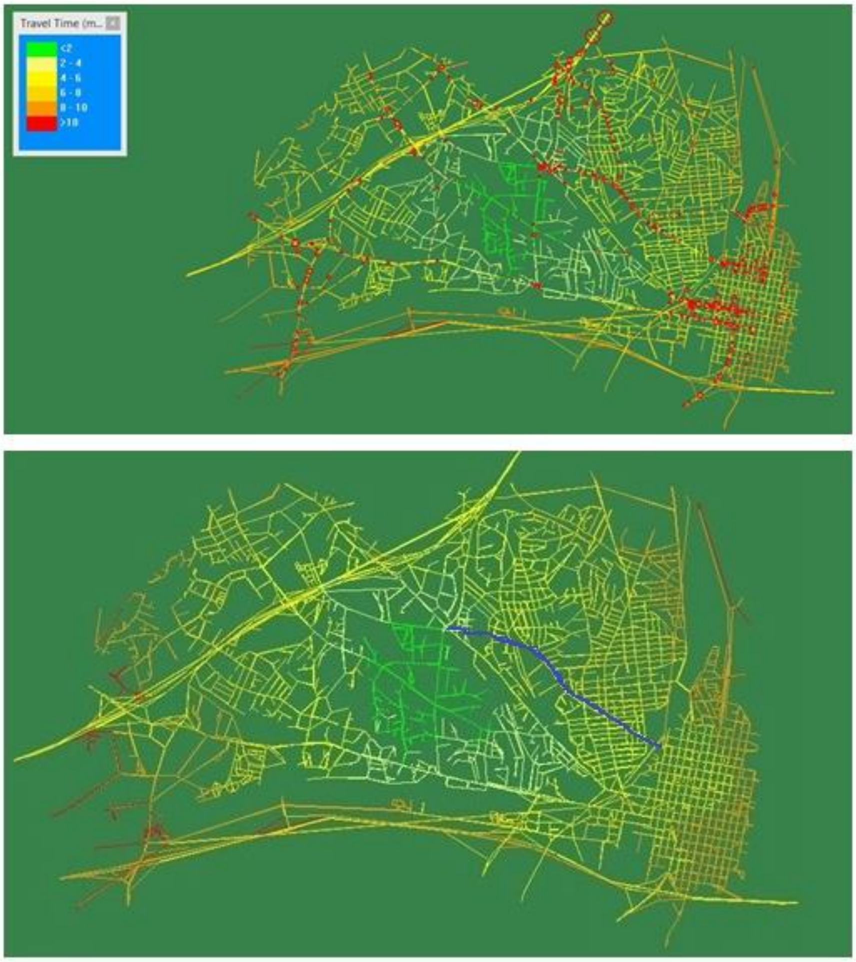


FIGURE 10 Before and after comparison map for strategy 3.

Dividing the traffic volume from through movement flow (Shown as blue line in figure 9) to other directions (north or south side of blue line flow) improves the congestion situation along W Braddock Rd (Shown as blue line in figure 9). However, the traffic volume stays the same, the original and destination of these traffic volumes are also the same. In this case, the surrounding areas on the boundaries does not have obvious changes at this level of visualization.

For Signal control strategy 4:

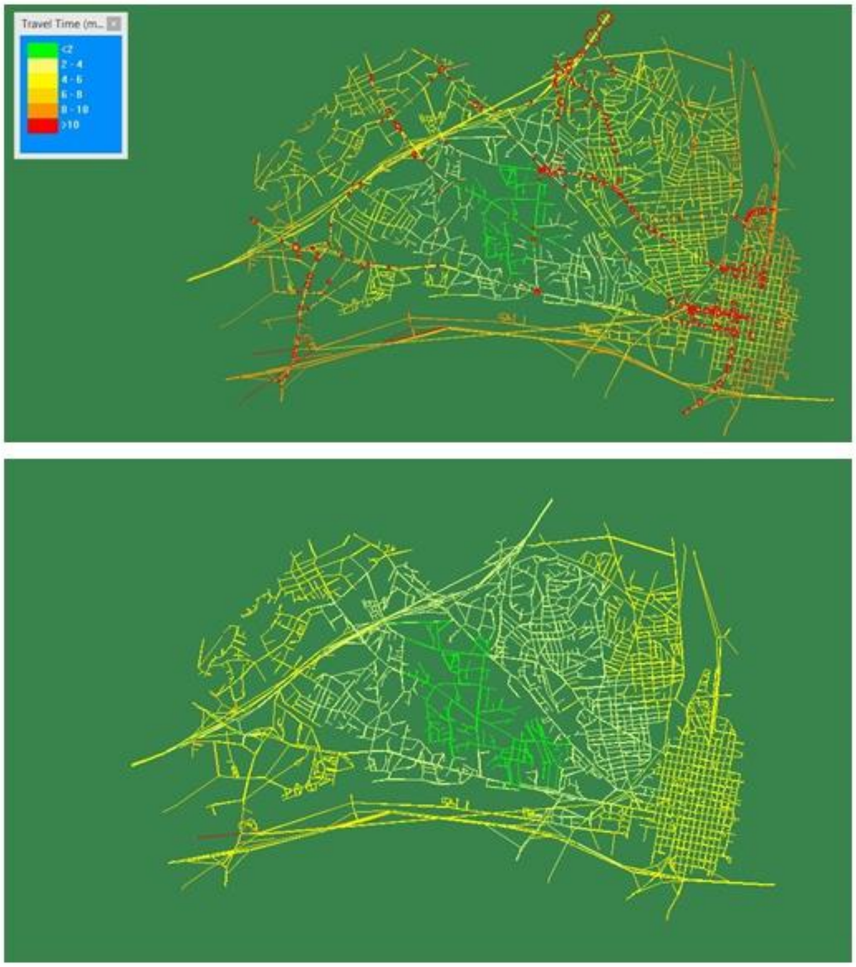


FIGURE 11 Before and after comparison map for strategy 4

Changing pre-timed signal control system into actuated signal control time show obvious improvement after simulation. The reason that this situation happens is that increasing extended green time leads to increasing maximum green. For same traffic volume, the larger capacity for each link can decrease the congestion and delays in each link.

For Signal control strategy 5:

FIGURE 12 Before and after comparison map for strategy 5.

Increasing the maximum green time in commercial areas results in a satisfying outcome based on the NEXTA visualizer, with less red and orange marks but more yellow marks in commercial areas. Increasing maximum green time leads to increasing capacity of each link in commercial areas, which was more congested compared to residential areas. Actuated control system shows up more in commercial areas, which means changing signal timing plans in commercial areas and adjusting actuated signal systems have similar effects. With these two reasons, signal control strategy 5 and signal control strategy 4 share similar visualization results.

For Signal control strategy 6:

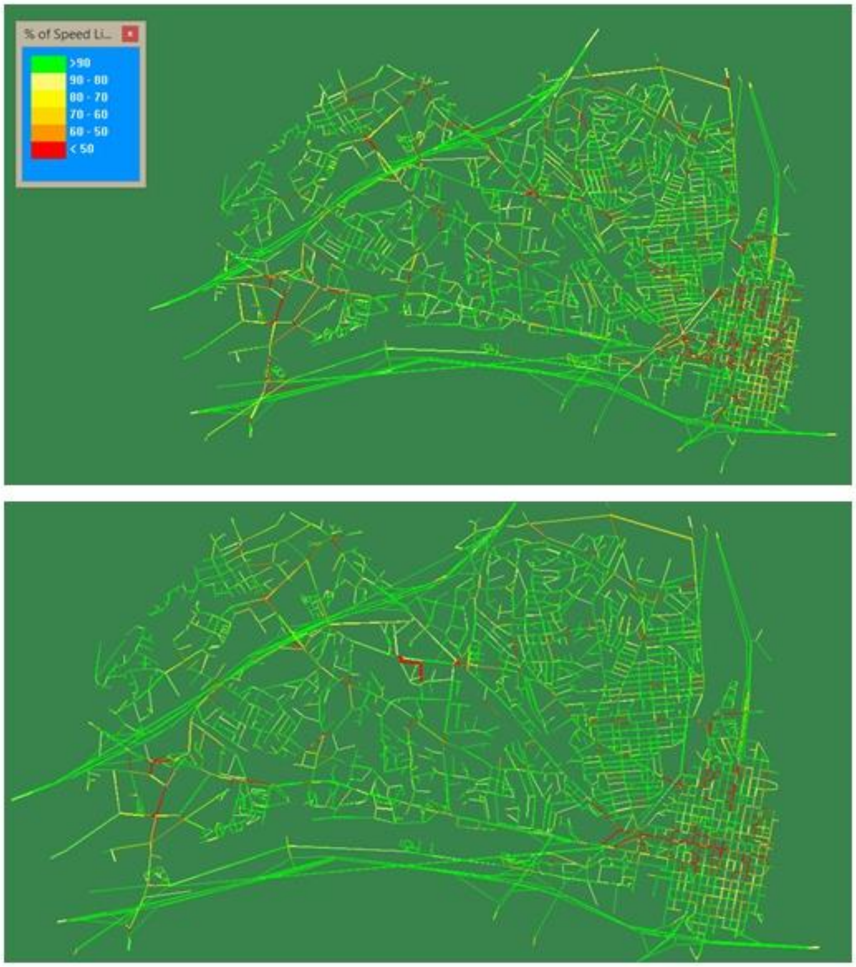


FIGURE 13 Before and after comparison map for strategy 6.

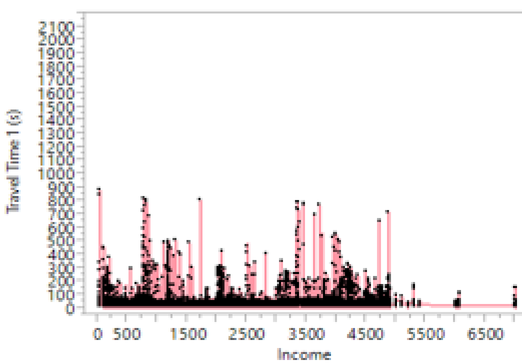
Figure 12 shows that increasing maximum green time on minor roads and branches, more green marks show up in visualization results instead of the increase of red marks compared to the base case. This situation illustrates that actual speed/speed limit ratio has improved on those changed links. The increase in actual speed/speed limit ratio leads to the increase in actual speed due to the unchangeable characteristic of speed limit unless the link level of service has been changed. In the study case, there is no mention of changing level of service for any link. So, higher speed means less congestion. However, this strategy only have positive impacts on minor intersections, so no obvious change of bottleneck problems show in the outcome maps.

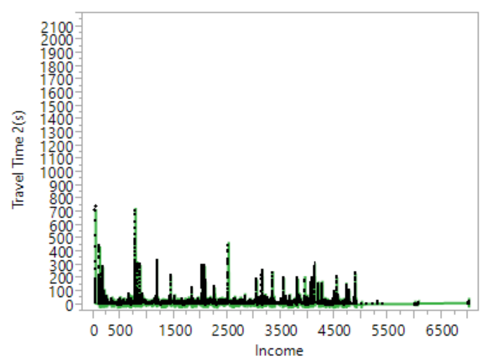
3.4.2 Socio-economic analysis

The most helpful function that distinguishes TRANSIMS from other simulation software is that it provides all the household and vehicle snapshot information together with activity locations. In file < 10.Alex.2005.Trip> under directory <results>, the originated, passing and destination link information of each vehicle are listed with accurate starting and arriving time. In this case, the originated link and average travel time of each vehicle can be calculated from this file for each signal control strategy. On the other hand, household ID, household location and corresponding income are listed in file < Alex.2000.Act.Households> under directory <demand> generated by Population Synthesizer. Finally, the corresponding link for its location has been provided in file <Activity_Location> under directory <network>.

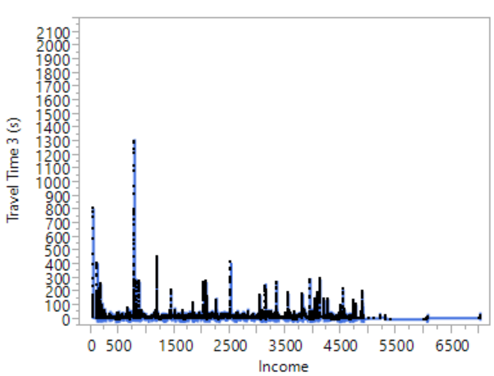
With all the information provided in TRANIMS that has been listed above, the relationship between household income and average travel time calculated from the vehicle information originated from each homologous household was analyzed through EXCEL. Figure 14 (a) to (g) below presents this socio-economic relationship after each signal control strategy together with the travel time calculated from default settings in the same graph.

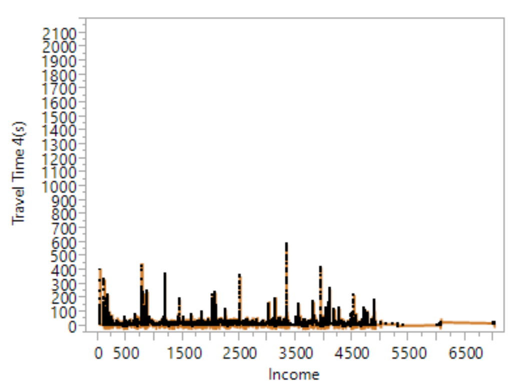
Understanding the relationship between different control strategies and socio-economic factors can help decision makers selecting strategies that are equitable to the society. For example, making a decision on selecting control strategies that redistributes delay on the network would be more informative when knowing which group-income would be affected in the region. This can also make it easier to link control strategies with road and network pricing options.





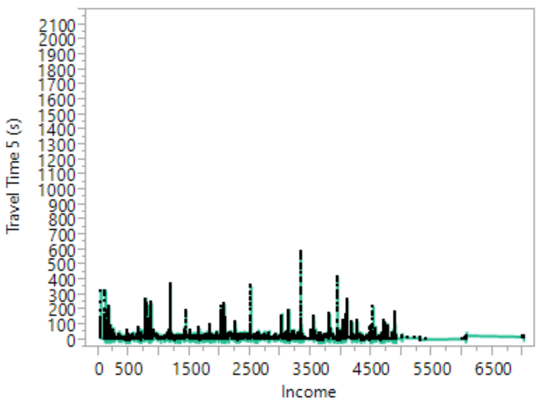
(a) Signal control strategy 1 (b) Signal control strategy 2



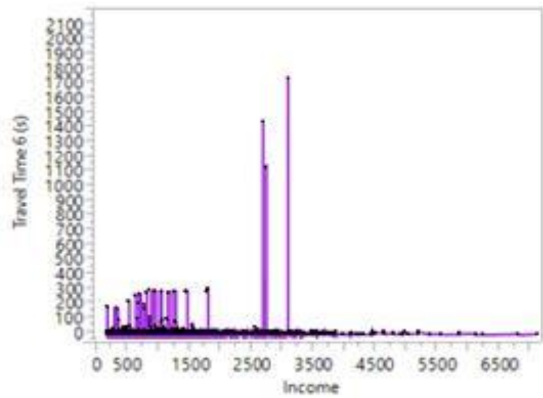


(c) Signal control strategy 3

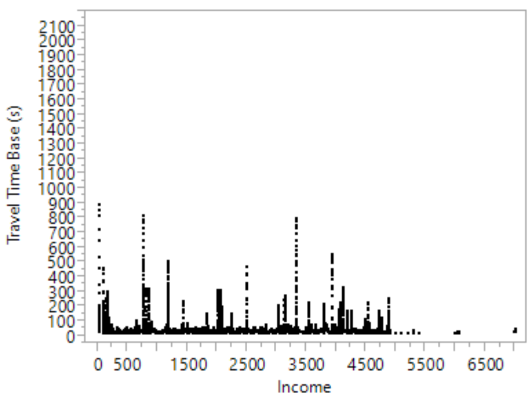
(d) Signal control strategy 4



(e) Signal control strategy 5



(f) Signal control strategy 6



(g) Signal control strategy base case

FIGURE 14 Income VS. Average Travel Time for each vehicle for six strategies.

By observing figure 5 and figure 14, bottleneck problems mostly occur in relatively higher income areas. It should also be noted that commercial areas are placed in relatively lower income areas.

Signal control strategy 1 results in more travel time throughout the whole network, and has negative impacts on both higher income areas and lower income areas. Signal control strategy 2 and 3 both result in less travel time in relatively higher income areas and more travel time in relatively lower income areas. Signal control strategy 4 and 5 show less average travel time in relatively lower income areas but more travel time in some higher income areas. Signal control strategy 6 results in no change in traffic capacity on each link and no change in traffic flow.

3.5 CONCLUSIONS AND FUTURE WORK

3.5.1 Conclusion

This research explores the impacts of several signal control methods on a regional planning case study in TRANSIMS and a traffic simulation analysis in NEXTA. The results are explained and evaluated. In general, the following conclusions and limitations could be drawn from the research:

1. Six signal control strategies were explored and were found to have different impacts on the network. Signal control strategy 1 has proven to be unsuccessful because it does not alleviate the traffic congestion problem in the city of Alexandria, while signal control strategy 6 has no obvious outcomes. So, changing stop signs into signalized intersection and changing maximum green times on minor intersections are not good options. On the other hand, for signal control strategies 2 to 5, the congested situation has been alleviated at different levels. In this case, increasing the maximum green time in turning directions on W Braddock Rd has a positive outcome on the congestion problem.
2. After taking socio-economic factors into consideration in selecting appropriate signal control strategies, signal control strategy 2 and 3 were found to have similar effects on alleviating traffic congestion problem by reducing bottlenecks along W Braddock Rd. However, both strategies were found to have positive impacts on higher income areas but negative impacts on lower income areas. On the other hand, Signal control strategy 4 and 5 share similar effects of less congestions in commercial areas. So they have more positive impacts on lower incomes areas and negative impacts on higher incomes areas. Care should therefore be taken when choosing between these strategies.

3.5.2 Recommendation for further study

The research conducted in this work was mainly exploratory. This paper only use NEXTA's output visualizer function for TRANSIMS. Further research and development could be conducted on exploring more functional settings with NEXTA such as comparing different Measure of Effectiveness (MOE) with selecting links in the same figure. By MOE comparison, detailed router choice behavior can be analyzed after optimization.

Furthermore, more case studies of large urban networks should be developed and simulated in TRANSIMS in order to crosscheck different optimization signal control strategies in large urban networks. Socio-economic results were found to be informative for decision making. Further research can also improve the data collection procedure by collecting household information together with its corresponding traffic condition such as O-D table or average travel time and delay.

REFERENCES

1. Hurwitz, D.S., M.A. Knodler Jr, and B. Nyquist, *Evaluation of driver behavior in type II dilemma zones at high-speed signalized intersections.* Journal of transportation engineering, 2010.
2. Abbas, K.Z.J.B.D.M.M., *Improved Detection and Control System for Isolated High-Speed Signalized Intersections.*
3. Bonneson, J.M., D; Zimmerman, K; Charara, H; Abbas, M, *Intelligent Detection-Control System for Rural Signalized Intersections.* 2002.
4. Yahong, G., *Integrating a Regional Planning Model (TRANSIMS) With an Operational Model (CORSIM).* 2004.
5. Li, P. and M.M. Abbas. *A Markov process based dilemma zone protection algorithm*. in *Winter Simulation Conference*. 2009: Winter Simulation Conference.
6. Li, P., et al. *A new dilemma zone protection algorithm based on the vehicle, trajectories prediction and Markov Process*. in *Transportation Research Board 89th Annual Meeting*. 2010.
7. Satish V. Ukkusuri, H.M.A.A.a.F.Z., *Agent-Based Traffic Management and Reinforcement Learning in Congested Intersections.*
8. Lei, X.Z.J.T.H., *Open-Source NeXTA Version 3 User's Guide.* 2011.
9. Lu, G., et al., *Analysis of yellow-light running at signalized intersections using high-resolution traffic data.* Transportation research part A: policy and practice, 2015. **73**: p. 39-52.
10. Montasir M. Abbas, N.A.C., Anuj Sharma, Steven P. Venglar and Roelof J. Engelbrecht *Methodology for Determination of Optimal Traffic Responsive Plan Selection Control Parameters.*
11. Bonneson, J., et al., *Development and evaluation of a detection-control system for rural intersections*. 2001.
12. Zain Adam, M.A., Antoine G. Hobeika,Hesham A. Rakha and Raghu Pasupathy, *Development and Applications of Multi-Objectives Signal Control Strategy during Oversaturated Conditions* **2259**.
13. Gazis, D., R. Herman, and A. Maradudin, *The problem of the amber signal light in traffic flow.* Operations Research, 1960. **8**(1): p. 112-132.
14. Pengfei Li, M.A., Raghu Pasupathy and Larry Head, *Simulation-Based Optimization of Maximum Green Setting Under Retrospective Approximation Framework.* **2192**.
15. Zain Adam, M.A.a.P.L., *Evaluating Green-Extension Policies with Reinforcement Learning and Markovian Traffic State Estimation.* **2128**.

4. USING MACROSCOPIC FUNDAMENTAL DIAGRAMS TO EVALUATE THE CLASS OF SERVICE FOR DIFFERENT SOCIO-ECONOMICAL GROUPS

Rubi Han[1] and Montasir Abbas[2]

Abstract: In this paper, the researchers deal with macroscopic traffic control in Alexandria case study and used macroscopic fundamental diagram (MFD) to evaluate the class of service for different socio-economical groups. TRANSIMS is performed upon this case study for the basis data of MFD. The researchers' main objective is to calibrate and estimate macroscopic fundamental diagrams (MFD) of each control strategy in terms of system performance. On the other hand, the outcome of each strategy at different income group in the city is evaluated. Our purpose is to draw the attention to the significance of take socio-economic impacts into consideration of traffic management. Three control strategies presented in this have different impacts on different income groups in Alexandria city.

Author Keywords: Control strategies; Large urban networks; Alexandria case study; TRANSIMS, macroscopic fundamental diagram.

[1]Graduate Research Assistant, Civil and Environmental Engineering, Virginia Polytechnic Institute and State University. Tel: 520-275-3150, Email: hrubi@vt.edu.
[2]PH.D., P.E., Corresponding Author, Associate Professor, Civil and Environmental Engineering, Virginia Polytechnic Institute and State University. Tel: 540-231-9002, Email: abbas@vt.edu.

4.1 INTRODUCTION

4.1.1 Background

Traffic congestion is a serious problem around the world, especially in large urban areas during peak hours with increasing number of households and rapidly growth of traffic volumes and densities. Changing relevant traffic signal control systems and patterns to solve congestion problems has some impact on the quality of living in urban areas. Changing signal control timing plans has been considered an effective way to alleviate the traffic congestion problems. In this paper, the researchers give an understanding on how different signal control strategies affecting the road system with evaluation the relationship between different classes of Macroscopic Fundamental Diagram (MFD).

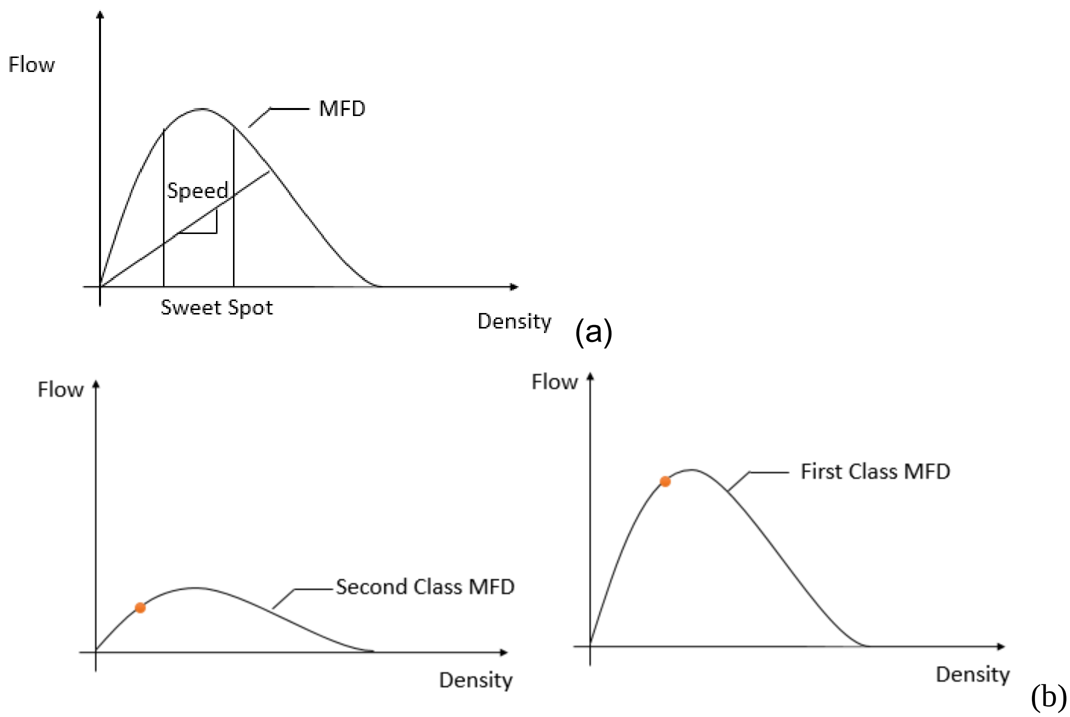


FIGURE 15 Sample traffic flow macroscopic fundamental diagram.

The fundamental diagram of traffic flow is a diagram that presents a relationship between the traffic flow (vehicles/hour) and the traffic density (vehicles/km). A macroscopic traffic model involving traffic flow, traffic density and speed forms the basis of the fundamental diagram. It can be used to predict the capability of a road system. The peak value of the curve in macroscopic fundamental diagram is the capacity of this system. With simulation results from TRANSIMS, this paper applies traffic volumes and densities of each link in the whole network to receive different well-defined macroscopic fundamental diagram (MFD) in Alexandria case study. Fig. 1 (a) presents a general MFD for understanding.

In order to better illustrate the change between different MFD for different socio-economic groups, the following example is given in Fig 1 (b). The researchers assume that the round dot in the figure represents one link simulated from TRANSIMS and it originates from relatively lower income groups. The term Class of Service is newly defined in this paper in order to represent different MFDs identified for each signal control strategy. First class MFD means curve with larger capacity, which has bigger maximum traffic volume and density in the figure and second class MFD means smaller capacity comparing to first class MFD. If there are more than two curves in the figure, numbers should be given in the standard sequence going like third class MFD, forth class MFD and etc..

Before applying any signal control strategies, this link belongs to the second class MFD. And after adjusting the timing plans of one control strategy in TRANSIMS, it shifts from second class MFD to first class MFD. This change means this control strategy has positive effect on this link from lower income groups because it experiences better service after applying the signal control strategy. The whole research is to explore how many links shift from one class MFD to another and the difference between the changes would show negative or positive effect on the socio-economic groups.

For the purpose of further analyzing the effect of different signal control strategies mentioned in previous paper(R.H., Abbas, 2015), three specific signal control strategies have been listed out for obtaining the relationship between traffic volumes and densities: signal control strategy 2, 4 and 5. Signal control strategy 2 is to divide the traffic flow following W Braddock Rd through movement into other turning movements. Signal control strategy 4 is to change pre-timed signal control system into actuated signal control time system and signal control strategy 5 is to increase the maximum green time in commercial areas of Alexandria city.

The reason to choose these three strategies is that signal control strategy 1 and 6 have little influence on alleviating the traffic congestion due to the outcome through TRANISMS visualizer NEXTA. All signal control strategy 2, 3, 4 and 5 are proved to be effective on different levels of reducing traffic congestion. At the meantime, signal control strategy 2 and 3 have similar adjustment of timing plans and share similar impact on the network. Therefore, signal control strategy 2, 4 and 5 are chosen in this paper for analysis due to their different characteristics of solving traffic congestion problems. In this case, observing the changes of MFD for three different changes of signal control patterns will show us the network resource allocation(Tsekeris, 2013) after applying each strategy.

4.1.2 Paper Objectives

The purpose of the paper is to deal with macroscopic traffic control in Alexandria case study and used macroscopic fundamental diagram (MFD) to evaluate the class of service for different socio-economical groups. Also, TRANSIMS simulation results from Alexandria case study in northern Virginia are used to compare between each strategy.

4.1.3 Organization of Paper

The remainder of this paper starts with a literature review section of corresponding knowledge of the transportation-planning package, TRANSIMS. This section also includes a brief introduction of existing studies about MFD. Subsequently, the methodology to obtain MFD from average volume and density information of each link are introduced through in the paper. Next, alterations of links between the base case and each signal control strategy are discussed in the next section. Furthermore, the evaluation of socio-economic findings based on MFD observations during research are presented. At last, this paper provides a brief discussion and summary of the findings.

4.2 LITERATURE SYNTHESIS

4.2.1 TRANSIMS review

Introduction

TRansportation ANalysis SIMulation System (TRANSIMS) represents the next generation of travel forecasting and travel demand modeling tools that contribute to the computer both in hardware and software by fulfilling the field of transportation modeling. The core of TRANSIMS is to enable an agent-based simulation system capable of simulating second-by second movements of every person and every vehicle through the transportation network of a large urban area.

TRANSIMS, as a traffic forecasting and simulation tool, provides us with detailed results about speed, density and volume in file titled < 10.Alex.2005.Trip> generated from control file <10.Alex.2005.Trip.LinkDelay>after 5 router loops and 5 micro simulator runs(2002). This LINKDELAY file is under directory <results>.

TRANSIMS uses the information in the link delay file to initialize the link volumes and travel times for each time period. The data for each link during each time period are listed detail in the delay output file, including link number, average volume, turning directions, average speed, average density, and so on. The time periods are typically 15 minutes long(Hanbali and Fornal, 2004). The traffic speed, volume and density data used during research are average value during the peak hour (2 hours) for each individual link.

4.2.2 Alexandria case study

The Alexandria network is provided with the TRANSIMS open source as a test case. It is located between I-395, I-95/495, and the Potomac River in northern Virginia. This network is observed to be a diverse and structured region with easier to obtain MFDs after calibration. There are a total number of 2,508 links for analysis with link numbered from 1 to 3,207.

4.2.3 MFD Review

The Macroscopic Fundamental Diagram (MFD)(Nan Zheng, 2012) is considered as a significant tool to evaluate the traffic performance in and urban network(Carlos F. Daganzo, 2008) at a macroscopic scale. The MFD represents a continuous relationship between the average flow and density within an urban network(Daganzo, 2007). Traffic variables such as speed, flow and density are connected with “fundamental diagram” (Toshio Yoshii, 2010), which describe the traffic at a specific location in traffic flow theory. The MFD(N Geroliminis, 2011) can help research measure the traffic by fitting the average of high-scattered flow and density data into a right model and plotting the model as a low-scatter MFD curve.

However, it is hard to formulate the MFD due to the complex calibration between consecutive links and diversity of the traffic condition, especially in congested networks. There are few proposed Single-Regime Models, which are made for evaluating and forecasting the performance of single components such as an intersection or a section of highway(Greenshields, Channing et al. 1935). In this paper, four common models have been used for calibrating the relationship between speed/density and flow/density: Greenshields model, Greenberg model, Underwood model and Northwester Group model(Marshall and Berg, 1997).

The paper published by Greenshields in 1935 may has done the seminal work during the history of duplication the speed-flow curves. He depicted the speed-flow curve by combing a linear speed- density relationship together with the <flow = speed * density> equation. The first theoretical propose for unimodal relationship between flow and density was developed by Godfrey in 1969. This proposition was later refined by Herman and Prigogine in 1979 with functions of the average speed in urban network and by Herman and Ardekani in 1984 with further functioned by the average density.

The first observation of MFD model in congested networks was presented by Geroliminis in 2007 and Daganzo in 2008. It was found in a study of Yokohama, Japan(Geroliminis and Daganzo, 2008). The study in Yokohama illustrates the existence and properties of MFD and the congestion distribution in urban network. Although this finding cannot represent the universal existence of MFD, the potential relationships between average flow and density are still brought up for analysis in certain networks. The thesis written by Geroliminis and Daganzo suggested an analytical model for predicting MFD by adopting variation theory to approximate an upper boundary for the MFD(Mehdi Keyvan-Ekbatani, 2012).

4.3 METHODOLOGY

During research procedure, the researchers first used TRANSIMS simulation program to come up with the link results the researchers need for data of three key elements: speed, density and flow of the macroscopic fundamental diagram. After simulation on Alexandria case study base case and three signal control strategies' alterations, four different MFDs can be obtained from each scenario. For each MFD, there are different classes of service, which can be identified by model calibration with relationships between speed/density and density/flow. The model equation can also be calculated during calibration. Upper MFD with higher capacity is considered as first class MFD in this paper and lower MFD with lower capacity is second class MFD.

Also, the link information such as location and household information on each link is generated in TRANSIMS. Vehicle originated from each household and trip routes are able to obtain from TRANSIMS simulation. In this case, MFDs for each signal control strategy incorporating with different socio-economic groups are analyzed and discussed in the paper. After discussion, findings and conclusion are given at the end.

4.3.1 Model Calibration

The objective of model calibration(Toshio Yoshii, 2010) is to obtain the best matching curves between model performance estimates(Nicolas C hiabaut, 2009) and the performance of simulation data. As it is mentioned in last section, there has not been found any universal accepted procedures for calibrating and validating the complex traffic networks (2014). So, a suitable method to conduct model calibration is significant. Based on validation criteria suggested by the Federal Highway Administration (Obenberger and Collura, 2001), this paper provides a model calibration procedure using advanced data analyst tool—JMP Pro 11.

First of all, link number, average speed, flow and density data for base case and three signal control strategies are needed during research. An example of the snapshot in result file is given below in Fig. 2. It is obvious to see from the figure that link number 1 from time 0:00 to 0:15 has an average volume of 16 and average density of 0.02.

The relationship between speed and density are calibrated using "Column Formula" function and "Non-linear Modeling" function. Formulas are from the equations of Greenshields model, Greenberg model, Underwood model and Northwester Group model. Find out the relatively best model fitting the data with the least SDME values calculated from JMP. Then adapt this calibrated speed model into equation <flow = speed * density> and redo the model calibration procedure for the relationship between average flow and density to gain the best-fitting model.

LINK	DIR	START_TIN	END_TIME	AVG_VOL	IN_VOLUN	OUT_VOL	AVG_SPEE	AVG_TIME	AVG_DEL	AVG_DEN	MAX_DEN
OUT_LINK	OUT_DIR	OUT_TURI	OUT_TIME								
1	0	0:00	0:15	16	17	15	36.21	35.3	-7.3	0.02	0.35
1	0	0:15	0:30	12	12	12	36.21	35.3	-7.3	0.08	0.53
1	0	0:30	0:45	11	12	10	36.21	35.3	-7.3	0.08	0.35

FIGURE 16 Sample of result snapshot.

4.3.2 Signal Control Strategy Comparison

After running the Alexandria base case data for microscopic simulation for a 3-hour time period, the macroscopic link properties for each link such as volume, speed and density from TRANSIMS are collected. Using the function commander “AVERAGEIF” to calculate the average value of each property in a 3-hour period from 18:00 to 21:00 as peak hour period for each corresponding link number (Delete the duplicate link numbers in excel using function “Remove Duplicates “under menu “DATA”). Calibrate the relationship between average flow and density to find out the matching MFD models for base case data. The same procedure may be easily adapted to obtain MFDs after getting the results from running three signal control strategies.

Observing the number of MFDs for each scenario(Yangbeibei Ji, 2010), and then determining which MFD represents major road and which are minors. The criteria for determination is major road MFD has higher traffic volume and large value of density. In order to observe link changes between major and minor roads, few steps are listed below to be followed. Besides, make socio-economic factors into observation and obtain the impact of economic findings based on MFD.

1. Compare the link numbers between base case and each signal control strategy based on similar MFD scenario. Cross out the links that make no change during all three comparison process.

2. Calculate the number of link change from one MFD to another in one control strategy. Find out which one is greater, link change from major road to minor ones or the other way around.

3. Look up the median household income defined by US government in 2000 for all income values. Households or links with income value greater than or equal to the median value are considered in higher income area.

4. Associating the income data with link numbers based on household information generated from TRANSIMS, count the number of links which have income area change. Income area change is defined as from higher income areas to lower income areas or middle income areas, vice versa.

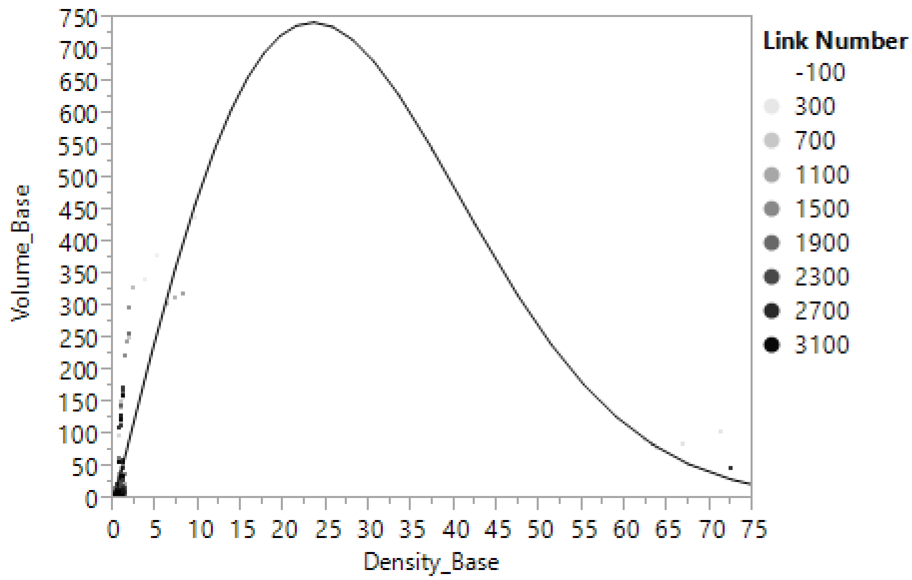
5. Discuss the findings and conclude with further thought.

4.4 ANALYSIS

4.4.1 MFD analysis

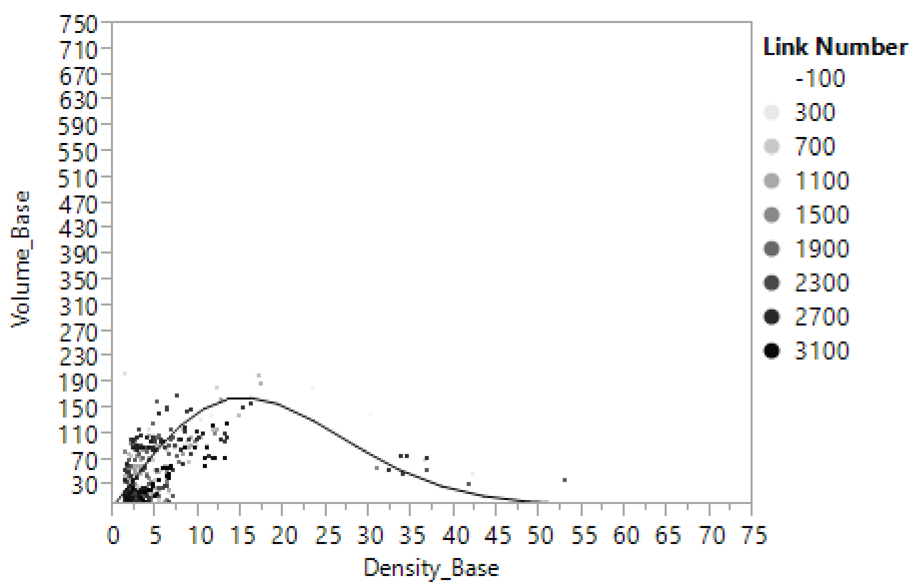
Fig. 3 to Fig. 6 below presents the MFD plots for each signal control strategy. Base case MFD plots are shown in Fig. 2 for comparison purpose. The relating calibrated model equation is achieved by statistical software JMP and listed under each figure. The color of Row Legends are from white to black corresponding with link number from smallest to largest. The best fitting model for each strategy is proved to be the Northwestern model after model calibration procedure.

For Base Case:



(a) First class MFD for base case.

Calibrated model equation: $Volume = 52.549 * e^{-\frac{1}{2}*(\frac{Density}{23.333})^2} * Density$

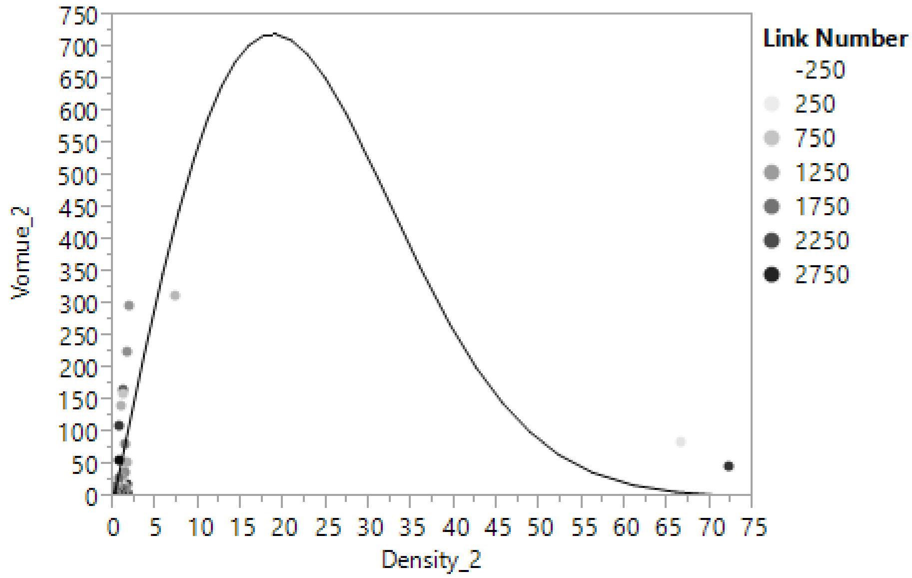


(b) Second class MFD for base case.

Calibrated model equation: $Volume = 18.039 * e^{-\frac{1}{2}*(\frac{Density}{15.294})^2} * Density$

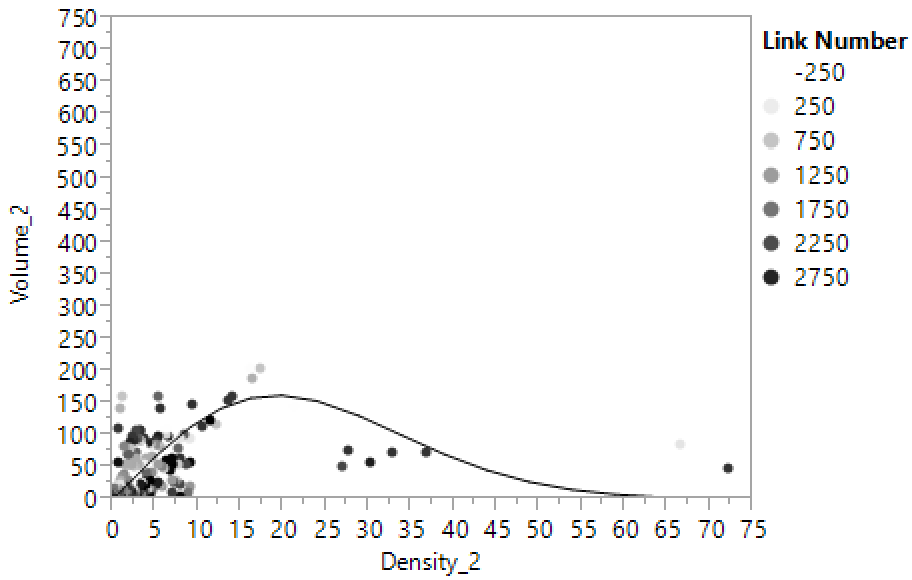
FIGURE 17 Volume-Density Fundamental Diagram for Base Case

For signal control strategy 2:



(c) First class MFD for signal control strategy 2

Calibrated model equation: $Volume = 63.824 * e^{-\frac{1}{2}*(\frac{Density}{18.627})^2} * Density$

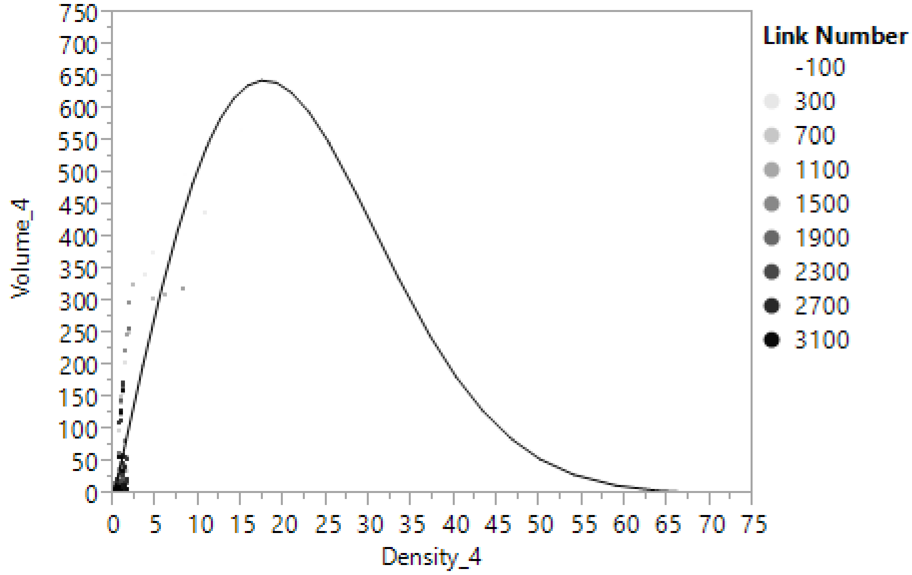


(d) Second class MFD for signal control strategy 2

Calibrated model equation: $Volume = 13.992 * e^{-\frac{1}{2}*(\frac{Density}{19.216})^2} * Density$

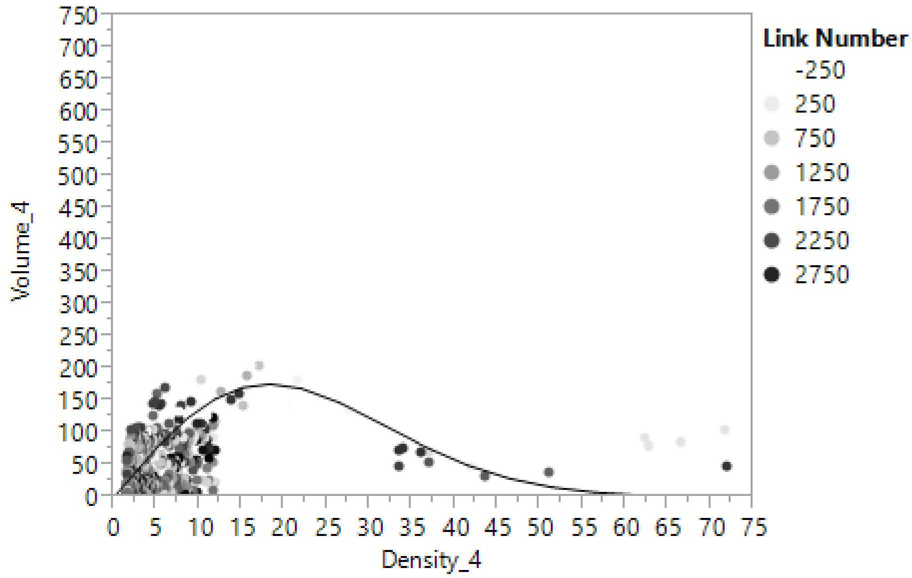
FIGURE 18 Volume-Density Fundamental Diagram for strategy 2.

For signal control strategy 4:



(e) First class MFD for signal control strategy 4

Calibrated model equation: $Volume = 60.294 * e^{-\frac{1}{2}*(\frac{Density}{17.647})^2} * Density$

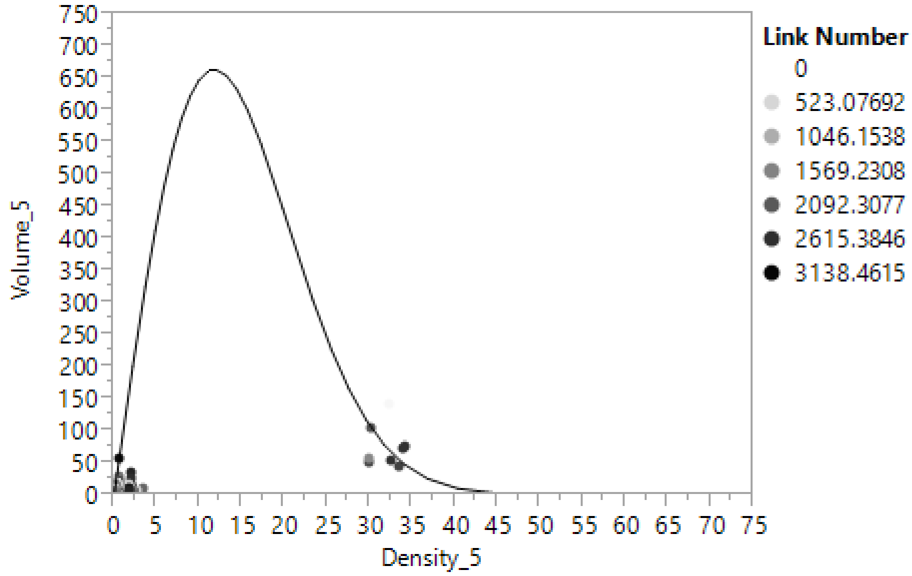


(f) Second class MFD for signal control strategy 4

Calibrated model equation: $Volume = 15.882 * e^{-\frac{1}{2}*(\frac{Density}{18.235})^2} * Density$

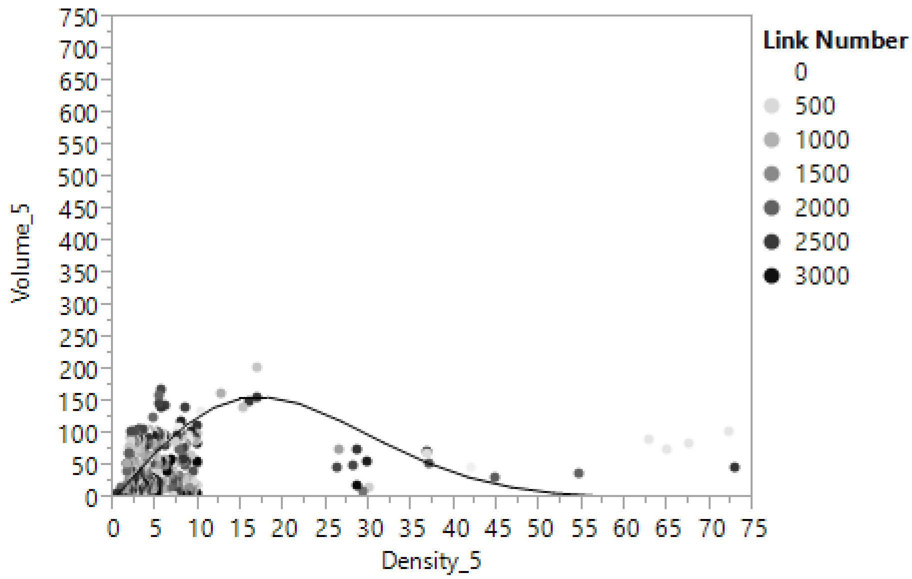
FIGURE 19 Volume-Density Fundamental Diagram for strategy 4.

For Signal control strategy 5:



(g) First class MFD for signal control strategy 5

Calibrated model equation: $Volume = 92.941 * e^{-\frac{1}{2}*(\frac{Density}{11.765})^2} * Density$



(h) Second class MFD for signal control strategy 5

Calibrated model equation: $Volume = 15.294 * e^{-\frac{1}{2}*(\frac{Density}{17.059})^2} * Density$

FIGURE 20 Volume-Density Fundamental Diagram for strategy 5.

The median household income is $50,069 conducted by U.S. Census Bureau using Current Population Survey from March, 1999 to March, 2001. This median income value of each household used in the research is a 2- and 3-Year-Average medians for Virginia State. The academic class distribution for household income brought up by

Leonard Beeghley in 2004 is listed as 5 levels: the super-rich class is the top 0.9%; the rich class is the next 5%; the middle class (plurality/majority) is 46%; the working class is about 40-45% and the poor class is the last 12%. In this paper, the researchers used the top 6% households with more income defined as they are in higher income area. Households which have laid in the middle 46% was considered in middle income area and the rest 48% are considered in the lower income areas.

In general, there are a total number of 829 links change within first class MFD which has higher capacity and second class MFD that has lower capacity after comparing the base case MFD to Volume-Density fundamental diagram for each signal control strategy. There is one thing should be specifically mentioned in the paper which is the lower-scatted value in MFD. Although it is not obvious to see in the figure above, there are much more links belong to first class MFD than second class MFD. This phenomenon illustrates that value in first class MFD are more gathered. Also for each signal control strategy, there are more links located on the right side of the peak value in second class MFD as density grows (Ji and Geroliminis 2012). This means it is more congested in second class than in first class MFD. Detailed number of link change for base case and three signal control strategies are listed in Table 1 below.

TABLE 1 Number of Link change for three signal control strategies

Signal Control Strategies	No. of Links from First class of MFD to Second class MFD	No. of Links from Second class of MFD to First class MFD
Signal control strategy 2	339	490
Higher Income Area	21	29
Middle Income Area	107	274
Lower Income Area	211	187
Signal control strategy 4	371	458
Higher Income Area	26	24
Middle Income Area	212	169
Lower Income Area	133	265
Signal control strategy 5	311	518
Higher Income Area	32	18
Middle Income Area	94	287
Lower Income Area	185	213

4.4.2 Socio-economic analysis

One of the most helpful function distinguish TRANSIMS among all the other simulation software is that TRANSIMS provides all the households and link delay information together with activity locations for researcher to explore.

For signal control strategy 2, there are 151 more links moving from second class MFD to first class MFD. Also, there are more links in relatively higher income areas including higher income area and middle income area when traffic flow changes from second class MFD to first class MFD. On the contrary, links changing from first class MFD to second class MFD are more originated from lower income areas.

For signal control strategy 4, there are 87 less links moving from first class MFD to second class MFD. Also, links moving from second class MFD to first class MFD in lower income areas are a lot more than the other way around. However, there are more links in both higher income areas and middle income areas while altering from first class MFD to second class MFD.

For signal control strategy 5, there are 207 less links moving from first class MFD to second class MFD. Besides, for socio-economic part, number of links in both middle income areas and lower income areas show obvious less link numbers in changing from first class MFD to second class MFD. However, there are about 14 more links in higher income areas when changing from first class MFD to second class MFD.

4.5 CONCLUSIONS AND FUTURE WORK

4.5.1 Conclusion

This research explores the macroscopic fundamental diagram to analyze three different signal control methods on a regional planning case study of Alexandria city in TRANSIMS. The results are discussed and evaluated. In general, the following conclusions and limitations could be drawn from the research:

All three signal control strategies mentioned in this paper were explored to have positive impacts on the network. In MFDs, values located on the right side of the peak value means congestion. All three signal control strategies have less links located on the right side compared to the base case scenario. Also, more links change from second class of MFD to first class of MFD. This means, they have done a good job solving the congestion problem. This finding agree with the conclusions from previous paper that increasing the maximum green time in turning directions on W Braddock Rd has a positive outcome on the congestion problem.

After analyzing MFD and taking socio-economic factors into consideration in selecting appropriate signal control strategies, signal control strategy 2 were found to have positive impacts on higher income areas and middle income areas but negative impacts on lower income areas. On the other hand, signal control strategy 4 and 5 share similar impact on have more positive impacts on lower incomes areas. However, signal control strategy 4 have no obvious impact on higher income groups and negative impacts on middle income areas. Signal control strategy 5 show negative impacts on higher income areas but positive impacts on middle income areas. This also accords with conclusion in previous paper.

Pricing has been considered an effective management policy to reduce traffic congestion in transportation network. For all signal control strategies, more vehicles in higher income areas changing to be served with better class. This findings leading to household in higher income areas would contribute more to reduce traffic congestion by increase the capacity in Alexandria.

4.5.2 Recommendation for further study

The analysis and comparison are both based on number changing due to filtering thousands of numbers and large scale of this network. Future research work can be focused on visualization of MFD alterations in large-scale networks. Besides, during the research in this paper, the researchers only take the household income effect into consideration of selecting signal control strategies. Other socio-economic factors such as household ages and sizes can also be discussed in future work. Also, heat map consists of the socio-economic factors changing after different traffic conditions would be nice to present. In addition, to utilize more agent-based modeling capabilities into current work and to incorporate the class of service concept in MFD into the simulation model as an objective function of TRANSIMS would be useful for research.

4.6 ACKNOWLEDGEMENTS

I would never have been able to finish my thesis without the guidance of my committee members, help from friends and faculty members, and support from my family.

Firstly, I would like to express my sincere gratitude to my advisor Dr. Montasir M Abbas for the continuous support of my Master study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Master study while at Virginia Tech.

Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Antoine G. Hobeika and Dr. Linbing Wang for their insightful comments and encouragement, but also for the hard question which incented me to widen my research from various perspectives.

I thank my fellow lab mates in VT-SCORES lab for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last two years. Also, I take this opportunity to express gratitude to all of the Department faculty members for their help and support.

Last but not the least, I would like to thank my parents for supporting me spiritually throughout writing this thesis.

4.7 REFERENCES

"VISSIM Development and Calibration Report." (2014).from http://transportation.ky.gov/Planning/Planning%20Studies%20and%20Reports/Appendix%20B%20-%20VISSIM%20Development%20and%20Calibration%20Report.pdf.

Abbas, R. H. M. (2015). "Considertaion of Economic Factoes when Selecting Signal Control Strategies in Large Scale Urban Networks."

Carlos F. Daganzo a, Nikolas Geroliminis (2008). "An analytical approximation for the macroscopic fundamental diagram of urban traffic." Volume 42, Issue 9.Pages 771–781.

Geroliminis, N. and C. F. Daganzo (2008). "Existence of urban-scale macroscopic fundamental diagrams: Some experimental findings." Transportation Research Part B: Methodological 42(9): 759-770.

Greenshields, B., W. Channing and H. Miller (1935). A study of traffic capacity. Highway research board proceedings, National Research Council (USA), Highway Research Board.

Ji, Y. and N. Geroliminis (2012). "On the spatial partitioning of urban transportation networks." Transportation Research Part B: Methodological 46(10): 1639-1656.

Mehdi Keyvan-Ekbatani , A. K., Ioannis Papamichail, Markos Papageorgiou (2012). "Exploiting the fundamental diagram of urban networks for feedback-based gating." (Transportation Research Part B 46 (2012) 1393–1403).

Nan Zheng a, R. A. W. b., Kay W. Axhausen b, Nikolas Geroliminis (2012). "A dynamic cordon pricing scheme combining the Macroscopic Fundamental Diagram and an agent-based traffic model." Volume 46, Issue 8, Pages 1291–1303.

Nicolas C hiabaut, C. B. u., and L udovic L eclercq (2009). "Fundamental Diagram Estimation Through Passing Rate Measurements in Congestion." 10(2). Page 355 - 359.

N Geroliminis. (2011). "A Macroscopic Fundamental Diagram of Urban Traffic Recent Findings." Transportation Research E-Circular.

Toshio Yoshii, Y. Y., Ryuichi Kitamura (2010). "Ecaluation Of An Area Metering control method using the MFD." 12th WCTR, July 11-15.

Tsekeris, T. G., Nikolas (2013). "City size, network structure and traffic congestion." Volume 76, Pages 1–14.

Yangbeibei Ji, W. D., Serge Hoogendoorn, Sascha Hoogendoorn-Lanser and Xiaoyu Qian (2010). "Investigating the Shape of the MFD using simulation data." Page 40-48.

Daganzo, C.F. (2007), "Urban gridlock: macroscopic modeling and mitigation approaches",
Transportation Research part B, 41 (1), p.49-62.

Geroliminis, N. and Daganzo, C.F. (2007), Macroscopic modeling of traffic in cities, 86th Annual Meeting of the Transportation Research Board, Washington D.C.

Buisson, C. and C. Ladier (2009), "Exploring the Impact of the Homogeneity of Traffic Measurements on the Existance of the Macroscopic Fundamental Diagram". Tranportation Research Records, Journal of the Transportation Research Board.

Geroliminis, N. and Y. Ji (2011), "Spatial and Temporal Analysis of Congestion in Urban Transportation Networks". In Proceedings of 90th Annual Meeting of the Transportation Research Board.

Gayah, V. and C. Daganzo (2011), "Clockwise hysteresis loops in the macroscopic fundamental diagram: An effect of network instability". Transportation Research Part B.

Daganzo, C. (2007), "Urban gridlock: Macroscopic modeling and mitigation approaches". Transportation Research Part B: Methodological, Vol. 41, No. 1, Page 49–62.

Ji, Y., W. Daamen, S. Hoogendoorn, S. Hoogendoorn-Lanser, and X. Qian (2010), "Macroscopic fundamental diagram: investigating its shape using simulation data". Transportation Research Record, Journal of the Transporation Research Board, Vol. 2161, Page 42–48.

5. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

This thesis explores the impacts of several signal control methods on a regional planning case study in TRANSIMS and a traffic simulation analysis in NEXTA. Also, macroscopic fundamental diagram is brought into research to analyze three different signal control methods. The results are explained and evaluated. In general, the following conclusions and limitations could be drawn from the research:

Six signal control strategies were explored and were found to have different impacts on the network. By analyzing signal control strategy 1 and signal control strategy 6, changing stop signs into signalized intersection and changing maximum green times on minor intersections are not good options. On the other hand, for signal control strategies 2 to 5, the congested situation has been alleviated at different levels. MFD analysis shows the same outcome for signal control strategy 2, 4 and5. In this case, increasing the maximum green time in turning directions on W Braddock Rd has a positive outcome on the congestion problem.

After taking socio-economic factors into consideration in selecting appropriate signal control strategies, signal control strategy 2 and 3 were found to have similar effects on alleviating traffic congestion problem by reducing bottlenecks along W Braddock Rd. However, both strategies were found to have positive impacts on higher income areas but negative impacts on lower income areas. On the other hand, Signal control strategy 4 and 5 share similar effects of less congestions in commercial areas. Although MFD analysis shows that signal control strategy 4 and 5 share similar effects that having more positive impacts on lower incomes areas. However, signal control strategy 4 have no obvious impact on higher income groups and negative impacts on middle income areas. Signal control strategy 5 show negative impacts on higher income areas but positive impacts on middle income areas.

The American Society of Civil Engineers stated in 2012 that without a more efficient system, the region's practice of overuse and underservice will continue to contribute to the United States' $67 billion annual cost in infrastructure operation and repair. And pricing has been considered as an effective way to alleviate traffic congestions. In this case, based on the analysis during research, signal control strategies have positive impact on higher income areas and more links from higher income areas changed from second class MFD to first class MFD. This phenomenon illustrates that household in higher income areas would be willing to contribute more in order to increase the capacity of the urban networks.

5.2 RECOMMENDATION FOR FURTHER STUDY

The research conducted in this work was mainly exploratory. This thesis only use NEXTA's output visualizer function for TRANSIMS. Further research and development could be conducted on exploring more functional settings with NEXTA such as comparing different Measure of Effectiveness (MOE) with selecting links in the same figure. By MOE comparison, detailed router choice behavior can be analyzed after optimization.

Furthermore, more case studies of large urban networks should be developed and simulated in TRANSIMS in order to crosscheck different optimization signal control strategies in large urban networks. Socio-economic results were found to be informative for decision making. Further research can also improve the data collection procedure by collecting household information together with its corresponding traffic condition such as O-D table or average travel time and delay.

Besides, the MFD analysis and comparison are both based on number changing due to filtering thousands of numbers and large scale of this network. Future research work can be focused on visualization of MFD alterations in large-scale networks. Also, heat map consists of the socio-economic factors changing after different traffic conditions would be nice to present.

Last but not least, during the research in this paper, the researchers only take the household income effect into consideration of selecting signal control strategies. Other socio-economic factors such as household ages and sizes can also be discussed in future work. Also, heat map consists of the socio-economic factors changing after different traffic conditions would be nice to present. In addition, to utilize more agent-based modeling capabilities into current work and to incorporate the class of service concept in MFD into the simulation model as an objective function of TRANSIMS would be useful for research.