

Performance Measures for Arterial Traffic Signal Systems

By

Dr. Steven Jones, Jr., Dr. Daniel S. Turner, and Ms. Lily Wang
Department of Civil, Construction, and Environmental Engineering
The University of Alabama
Tuscaloosa, Alabama

Dr. Virginia Sisiopiku
Department of Civil, Construction, and Environmental Engineering
The University of Alabama at Birmingham
Birmingham, Alabama

Dr. Michael D. Anderson and Mr. Roy Berryman
Department of Civil and Environmental Engineering
The University of Alabama in Huntsville
Huntsville, Alabama

and

Mr. Abhishek Acharya, Transportation Engineer
Green International Affiliates, Inc.
Westford, Massachusetts

Prepared by

UTCA

University Transportation Center for Alabama

The University of Alabama, The University of Alabama at Birmingham,
and The University of Alabama in Huntsville

UTCA Report Number 06121
May 2009

Performance Measures for Arterial Traffic Signal Systems

By

Dr. Steven Jones, Jr., Dr. Daniel S. Turner, and Ms. Lily Wang
Department of Civil, Construction, and Environmental Engineering
The University of Alabama
Tuscaloosa, Alabama

Dr. Virginia Sisiopiku
Department of Civil, Construction, and Environmental Engineering
The University of Alabama at Birmingham
Birmingham, Alabama

Dr. Michael D. Anderson and Mr. Roy Berryman
Department of Civil and Environmental Engineering
The University of Alabama in Huntsville
Huntsville, Alabama

and

Mr. Abhishek Acharya, Transportation Engineer
Green International Affiliates, Inc.
Westford, Massachusetts

Prepared by

UTCA

University Transportation Center for Alabama

The University of Alabama, The University of Alabama at Birmingham,
and The University of Alabama in Huntsville

UTCA Report Number 06121
May 2009

Technical Report Documentation Page

1. Report No FHWA/CA/OR-	2. Government Accession No.	3. Recipient Catalog No.	
4. Title and Subtitle Performance Measures for Arterial Traffic Signal Systems	5. Report Date Submitted December 2008; published May 2009		
	6. Performing Organization Code		
7. Authors Steven Jones, Jr., Daniel S. Turner, Lily Wang, Virginia Sisiopiku, Abhishek Acharya, Michael D. Anderson, and Roy Berryman	8. Performing Organization Report No. UTCA Final Report Number 06121		
9. Performing Organization Name and Address Dept. of Civil, Construction & Environmental Engineering The University of Alabama Box 870205 Tuscaloosa, Alabama 35487-0206	10. Work Unit No.		
	11. Contract or Grant No. DTSR0023424		
12. Sponsoring Agency Name and Address University Transportation Center for Alabama The University of Alabama Box 870206 Tuscaloosa, AL 35487-0206	13. Type of Report and Period Covered Final Report: August 15, 2006 – October 31, 2008		
	14. Sponsoring Agency Code		
15. Supplementary Notes			
16. Abstract This project was conducted to investigate new concepts, new tools and emerging technologies directed at enhancing traffic operations and safety on signalized urban arterials that operate under saturated conditions. McFarland Boulevard, a six-lane urban arterial running north-south through Tuscaloosa, AL served as the research focus and test bed for the project. There are nine urban intersections along the study route, with a variety of configurations, turning movements and traffic volumes. In a unique approach, this project was conducted as three related and parallel efforts by the three participating UTCA universities. UAH investigated the feasibility of using video data for determining control delay on the approach to signalized intersections, and used the results to investigate the accuracy of delay predictions by popular simulation models. UAB investigated use of VISTA as a simulation model for saturated arterial traffic flow analysis. UA investigated methods to optimize traffic flow at saturated intersections through enhanced simulation models.			
17. Key Words Saturated arterials, control delay, delay at traffic signals, VISTA, simulation of congested arterials, cell transmission models		18. Distribution Statement	
19. Security Class (of report)	20. Security Class. (Of page)	21. No of Pages 72	22. Price

Table of Contents

Table of Contents	iii
List of Tables	vi
List of Figures	vii
Executive Summary	viii
1.0 Introduction.....	1
Background – The Rise of Congestion	1
Project Objective – Mitigating Congestion	2
Research Approach	2
2.0 Comparison of Measured Control Delay to Simulation Delay	4
Introduction	4
Literature Review	4
Methodology	5
Results	7
Overall Comparison.....	7
Comparison of Individual Intersections	7
Potential Causes of Weak Comparison Predictive Performance.....	8
Conclusions and Future Studies	11
3.0 Modeling Oversaturated Conditions on Arterials Using VISTA.....	13
Objective	13
Simulation Model Overview	13
Model Selection.....	14
VISTA Background.....	14
VISTA Capabilities	14
VISTA Limitations	15
VISTA Applications	15
VISTA Modules	16
Cell Generator.....	16
Demand Profiler.....	16
Simulation.....	16
DTA – Path Generation	16
DTA – Dynamic User Equilibrium.....	17
Signal Optimization	17
Study Methodology	18
Approach	18
Selection of Study Test Bed	19

Data Acquisition and Model Development	20
Network Data.....	20
Demand Data	21
Control Data.....	21
Data for Model Validation.....	21
Model Validation.....	22
Identification of Closure Site.....	23
Development of Testing Scenarios.....	23
Results of Simulation	25
Base Case.....	25
Incident Case 1 – One-Lane Closure for Different Durations; No Information Provided to Road Users	26
Incident Case 2 – Two-Lane Closure for Different Durations; No Information Provided to Road Users	27
Incident Case 3 – Two-Lane Closure for Different Durations; Optimal Signal Timings and No Information Provided to Road Users	27
Incident Case 4 – Two-Lane Closure for Different Durations; Information Provided to Road Users	28
Increased Demand Case – Existing Signal Timing Plan on Corridor	28
Increased Demand Case – Optimized Signal Plan on Corridor	29
Increased Demand Case – Optimized Signal and Information Provided to Road Users Through VMS	30
Analysis of Results.....	30
One-Lane vs. Two-Lane with Existing Signal Plan	30
Existing vs. Optimized Signal Plan for Two-Lane Closure	31
DTA vs. Optimized Signal Plan for Two-Lane Closure	32
Increased Demand Case – Existing vs. Optimized Signal Plan	32
Increased Demand Case – VMS Design with Optimized Signal Case	33
Conclusions	34
Recommendations	34
Appendix.....	36
Simulation Model Overview	36
Definition of Traffic Simulation Models.....	36
Simulation Advantages.....	36
Simulation Reservations.....	37
Simulation Types.....	37
Concept of Traffic Assignment.....	38
Static Traffic Assignment.....	38
Dynamic Traffic Assignment	39
Commonly Used Traffic Analysis Tools	39
Highway Capacity Software.....	39
CORSIM.....	40
Synchro.....	41
AIMSUN	41
VISTA and Other DTA-Based Simulation Models.....	42

4.0 Cell Transmission Model Based Traffic Signal Timing in Oversaturated Conditions	45
Introduction	45
Literature Review	46
Existing Research for Oversaturation.....	46
Existing Traffic Signal Optimization Software	47
Optimization Tool for This Portion of the Project	47
Methodology	48
Cell Transmission Model	49
Genetic Algorithm (GA).....	52
Implementation.....	53
Case Study.....	54
Case Description.....	54
Case 1-A – Comparison of Original and Enhanced CTM.....	54
Case 1-B – Evaluation of Fixed Time and Dynamically Timed Signals	55
Conclusions	59
5.0 References.....	61

List of Tables

Number		Page
2-1	Comparison of Field Observations to Simulation Results.....	8
3-1	Summary of Scenarios Tested	25
3-2	Base Case System Performance Results.....	25
3-3	Base Case Corridor Performance Results.....	26
3-4	One-Lane Closure System Performance Results.....	26
3-5	One-Lane Closure Corridor Performance Results.....	26
3-6	Two-Lane Closure System Performance Results	27
3-7	Two-Lane Closure Corridor Performance Results	27
3-8	Two-Lane Closure with Optimized Signal System Performance Results	27
3-9	Two-Lane Closure with Optimized Signal Corridor Performance Results	28
3-10	Two-Lane Closure with DTA System Performance Results.....	28
3-11	Two-Lane Closure with DTA Corridor Performance Results.....	28
3-12	Increased Demand System Performance Results	29
3-13	Increased Demand Corridor Performance Results	29
3-14	Increased Demand with Optimized Signal System Performance Results	29
3-15	Increased Demand with Optimized Signal Corridor Performance Results	30
3-16	Increased Demand with Optimized Signal and VMS System Performance Results....	30
3-17	Increased Demand with Optimized Signal and VMS Northbound Corridor Performance Results	30
3-18	Comparison of DTA-Based Simulation Models (Mouskos, et al. 2006)	44
4-1	Case 1-A, Travel Times for CTM, Enhanced CTM and Simtraffic (sec/veh)	55
4-2	Case 1-B, Average Delay of the Fixed Plan and Dynamic Plan (sec/veh).....	56
4-3	Case 1-B, Vehicles in Each Cell: Fixed-Time Signal Timing Plan.....	57

List of Figures

Number		Page
1-1	McFarland Boulevard, project study site.....	3
2-1	Time stamps assigned to vehicles approaching and editing the traffic signal.....	5
2-2	Intersection configuration and turning movements for McFarland Boulevard and 37 th Street	6
2-3	Intersection configuration and turning movements for McFarland Boulevard and Skyland Boulevard	7
2-4	Percent difference, Synchro vs. HCM+.....	9
2-5	Percent difference, Synchro vs. video	10
2-6	Percent difference, HCM+ vs. video	10
3-1	VISTA module flow chart for dynamic traffic assignment (Mouskos, et al. 2006).....	18
3-2	General map of the study network.....	20
3-3	Basic Tuscaloosa network developed in VISTA.....	21
3-4	Signals considered in the study	22
3-5	Observed vs. simulation counts	23
3-6	Selection of closure site.....	24
3-7	One-lane vs. two-lane closure with existing signal timing plan.....	31
3-8	Delay comparison for existing and optimized signal plan	31
3-9	Delay comparison for DTA and optimized signal plan	32
3-10	System and corridor delay for increased demand case.....	33
3-11	Delay for VMS design on system and northbound corridor.....	33
4-1	Overflow blocks lane entrance	45
4-2	Relationship between oversaturated condition and proposed methodology	49
4-3	String structure for one intersection	52
4-4	The procedure for Generation 0 to Generation 1.....	53
4-5	Cell representation of network	55

Executive Summary

This project was conducted to investigate new concepts, new tools and emerging technologies directed at enhancing traffic operations and safety on signalized urban arterials that operate under saturated conditions. McFarland Boulevard, a six-lane urban arterial running north-south through Tuscaloosa, AL served as the research focus and test bed for the project. There are nine urban intersections along the study route, with a variety of configurations, turning movements and traffic volumes.

In a unique approach, this project was conducted as three related and parallel efforts by the three participating UTCA universities. The University of Alabama in Huntsville (UAH) investigated the feasibility of using video data for determining control delay on the approach to signalized intersections, and used the results to investigate the accuracy of delay predictions by popular simulation models. The University of Alabama at Birmingham (UAB) investigated use of VISTA as a simulation model for saturated arterial traffic flow analysis. The University of Alabama (UA) in Tuscaloosa investigated methods to optimize traffic flow at saturated intersections through enhanced simulation models.

1.0 Introduction

Background – the Rise of Congestion

The loss of mobility has become a very serious problem in the United States, to the point that removing congestion choke points is one of two special emphasis issues by the US Department of Transportation. It threatens economic competitiveness by choking shipments of both raw goods and finished products, and it threatens quality of life because American commuters are spending more and more time stuck in traffic.

According to the *2003-2008 Strategic Plan* of the US Department of Transportation, our nation's transportation system annually serves over 4.9 trillion passenger miles and 3.8 trillion ton miles of domestic freight and the transportation demand is constantly increasing (*US DOT Strategic Plan*, 2003). It is apparent that construction of new highways and the increase in transportation supply are lagging behind the increasing demand.

Between 1980 and 2003, new roadway miles increased by five percent whereas vehicle miles traveled (VMT) increased by 89 percent (*Traffic Congestion Factoids*, 2006). These statistics show that congestion is inevitable, especially in urban areas. According to a 2005 study conducted in 85 urban areas by the Texas Transportation Institute (TTI), congestion results in 3.7 billion hours of delay annually, or an annual delay per person of 43 hours. The study estimates the cost of congestion in those 85 metropolitan areas to exceed \$63 billion or \$384 per person in wasted time and extra fuel (*Traffic Congestion Factoids*, 2006). It is well recognized that congestion severely hampers roadway efficiency, reduces productivity, and creates economic and environmental problems.

Congestion can occur due to various reasons and can be classified as recurring or non-recurring. In addition to commuting, special planned or unplanned events such as construction and traffic crashes can generate significant congestion. Such events often generate unmet demand needs because the full use of roadway capacity is not permitted. The extent of congestion varies depending upon the severity and duration of road closure.

The vast majority of US metropolitan areas that are currently facing congestion problems consider a variety of congestion mitigation strategies. In the recent years, the focus of congestion mitigation changed from supply expansion to better use of existing transportation infrastructure assets and demand management. Due to issues related to cost, available right of way, and environmental and social considerations, it is often impractical to build new roads or expand existing facilities. Hence engineers, planners, and developers are looking for ways to optimize the use of existing facilities by spreading the demand over time and space.

Traffic signal optimization is considered to be one of the alternatives in minimizing arterial network congestion during peak hours. Many studies document the benefits for traffic operations of improved signal timings. For example, signal timing improvements in Chandler, AZ, reduced AM peak-period delays by 30 percent and PM peak-period delays by seven percent (*Traffic Congestion Facts*, 2006). Researchers and engineers are considering this option for minimizing recurrent traffic congestion.

Similarly, incident management is another important option that is being considered for increasing the operational efficiency of transportation systems. Incident management is a coordinated management technique for detecting a potential incident on the transportation system and responding to that with proper measures, thus increasing operational efficiency. The *2005 Urban Mobility Report* by the TTI (Schrank, et al. 2005) indicates that implementation of an incident management program provides smoother and faster traffic flow and also improves traffic safety by reducing emergency response time and the likelihood of secondary collisions. This report also states that incident management in freeways alone results in 177 million hours in delay reduction and saves \$2.93 billion (Schrank, et al. 2005). Effective incident management requires coordination among all governmental as well as non-governmental agencies and the proper implementation on technology.

Project Objective – Mitigating Congestion

This project was conducted to investigate new concepts, new tools and emerging technologies directed at enhancing traffic operations and safety on signalized urban arterials that operate under saturated conditions. McFarland Boulevard, a six-lane urban arterial running north-south through Tuscaloosa, AL (Figure 1-1) was the research focus and test bed for the project. There are nine urban intersections along the study route, with a variety of configurations, turning movements and traffic volumes.

Research Approach

In a unique approach, this project was conducted by The University Transportation Center for Alabama (UTCA) in three related and parallel efforts by the three participating UTCA universities:

At The University of Alabama in Huntsville (UAH), Dr. Michael Anderson investigated the feasibility of using video data for determining control delay on the approach to signalized intersections. The results were used to investigate the accuracy of delay predictions by popular simulation models. This work is described in Chapter 2 of this report.

At The University of Alabama at Birmingham (UAB), Dr. Virginia Sisiopiku investigated new simulation techniques for saturated arterial traffic flow, concentrating on the VISTA simulation package. This work is described in Chapter 3 of this report.

At The University of Alabama (UA), Drs. Steven Jones and Dan Turner investigated methods to optimize traffic flow at saturated intersections through enhanced simulation models. This work is described in Chapter 4 of this report.



Figure 1-1. McFarland Boulevard, project study site.

Altogether, these three efforts will provide immediate enhancement to the Tuscaloosa Department of Transportation in operating McFarland Boulevard and long term knowledge for the transportation profession.

2.0 Comparison of Measured Control Delay to Simulation Delay

Introduction

With continuing increases in congestion and shortfalls in transportation funding, there is a need for quality decision making by transportation officials. Basing decisions on inaccurate data wastes precious funds and builds frustration. Since delay is one of the primary decision metrics in urban areas, this portion of the project investigated the accuracy of delay estimates for two commonly used simulation programs.

This study developed a technique to use the existing video surveillance systems on McFarland Boulevard to capture the control delay experienced by vehicles as they approached traffic signals and stopped for a red signal indication. The technique was developed at UAH, using recorded video images of McFarland Boulevard. Control delay is the measure of delay a vehicle experiences because of a signalized intersection.

Literature Review

The Highway Capacity Manual (HCM) is the authoritative document for studies of traffic flow and congestion. In this study, the *HCM* definition of control delay was used, “the delay a vehicle experiences due to signalized intersection control.” It appears that data collection techniques involving video surveillance for delay measurements have not had been widely researched, as most people tend to rely on the default parameters of software packages. This is the most efficient and cost-effective way to determine the LOS of an intersection.

Several previous researchers have investigated control delay or have collected data for purposes of measuring control delay. For example, Quiroga calculated control delay using GPS data (Quiroga, et al. 1999). An investigation of free flow travel time (FFTT) and its comparison to actual time through an intersection was documented in a paper by R. M. Mousa (Mousa, 2002). Mousa’s method of data collection was different than the method proposed for this project because of the utilization of closed circuit television (CCTV). The data collection technique described by Michael Dixon (Dixon, et al. 2007) was found to be useful to this project; however, the extrapolation of the data was different. While Dixon was more interested in showing approach delay of a vehicle in comparison with an *HCM* approach delay conversion, this study was designed to determine control delay of a vehicle.

Methodology

In this portion of the project, video data of McFarland Boulevard was analyzed to identify control and stopped delay as vehicles approached a signalized intersection. The existing traffic surveillance system of the Tuscaloosa Department of Transportation was accessed through the UTCA Intelligent Transportation System/Traffic Management Center (ITS/TMC) laboratory in Shelby Hall at The University of Alabama. Video were recorded in the lab and forwarded to UAH to obtain the necessary parameters to model delay and create discrete control and stopped delay measurements.

While viewing the recorded video, it was possible to access the time stamps for the individual video frames. This allowed the reviewer to record the time stamp of a vehicle as it entered the analysis zone at the point where deceleration began (arrival point), and to record the time stamp at the point that the vehicle stopped. A third time stamp was recorded when the vehicle crossed the stop bar and exited the analysis zone. Figure 2-1 displays this procedure.

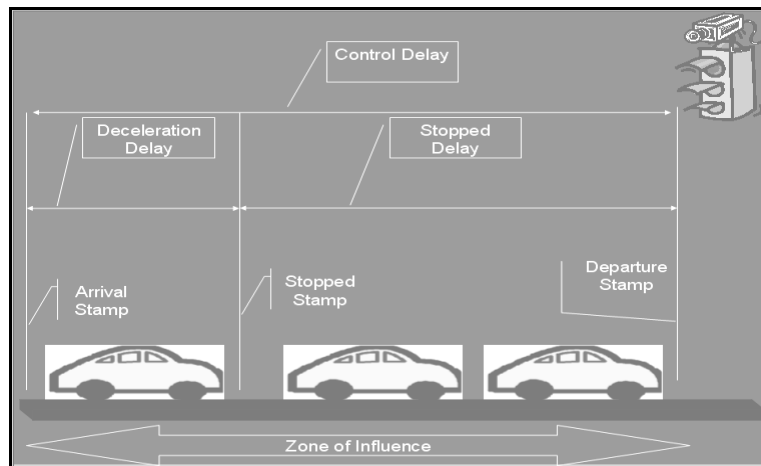


Figure 2-1. Time stamps assigned to vehicles approaching and exiting the traffic signal.

The method is based on FFTT versus the observed time to traverse the zone. The observed time is the Departure Stamp minus the Arrival Stamp. If a car does not have to stop no stopped time stamp is taken. Stopped delay was directly measured from the time stamps and is not relative to FFTT (Eq. 2-1). Control Delay was computed from the video surveillance by subtracting the FFTT from the actual time in the zone (Eq. 2-2). Deceleration Delay was computed by subtracting control delay from stopped delay (Eq. 2-3). Stopped and deceleration delay were not used in any comparisons.

$$\text{Stopped Delay} = \text{Departure Stamp} - \text{Stopped Stamp} \quad \text{Equation 2-1}$$

$$\text{Control Delay} = (\text{Departure Stamp} - \text{Arrival Stamp}) - \text{FFTT} \quad \text{Equation 2-2}$$

$$\text{Deceleration Delay} = \text{Stopped Delay} - \text{Control Delay} \quad \text{Equation 2-3}$$

Two widely respected traffic software packages (Synchro 7 and Highway Capacity Software+) were used to model the same intersections. Synchro 7 is a multipurpose simulation tool, and HCS+ software has modules that address many facets of traffic flow (signalized intersections, roadway segments, freeways, etc.).

The results of the analysis of video surveillance were compared to the results of simulation. The controller type (actuated-coordinated), timing patterns, vehicle volumes, and geometric considerations were also observed during the analysis period and the desired parameters were input into Synchro 7 and HCS+ software for the simulation results. The intersections studied were all actuated uncoordinated. HCS+ software was also used to help account for different equations and methods to calculate delay.

The two approaches analyzed were at the intersection of McFarland Boulevard and 37th Street (southbound) and McFarland Boulevard and Skyland Boulevard (northbound). The two intersections were different enough in type and far enough apart that they represented two different sample types. The Tuscaloosa DOT cameras faced oncoming traffic on Skyland Boulevard intersection and departing traffic on the 37th Street approach. Data was collected between 4:00 PM and 7:00 PM. for two consecutive days during September of 2007. This included both peak and non peak flow. Twelve one-hour samples were taken for the control delay analysis. Parameters were extrapolated from the video so that traffic volumes and other intersection data could be entered into the Synchro and HCS+ software packages, for the time periods of the 12 data points. Figures 2-2 and 2-3 display the intersections, their turning movements, and their lane groups.

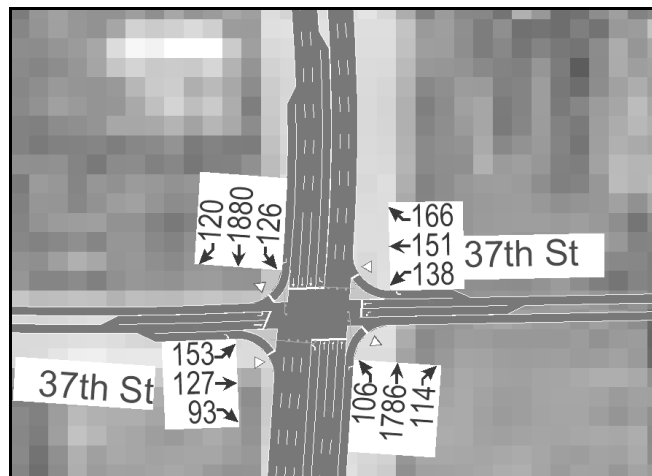


Figure 2-2. Intersection configuration and turning movements for McFarland Boulevard and 37th Street.

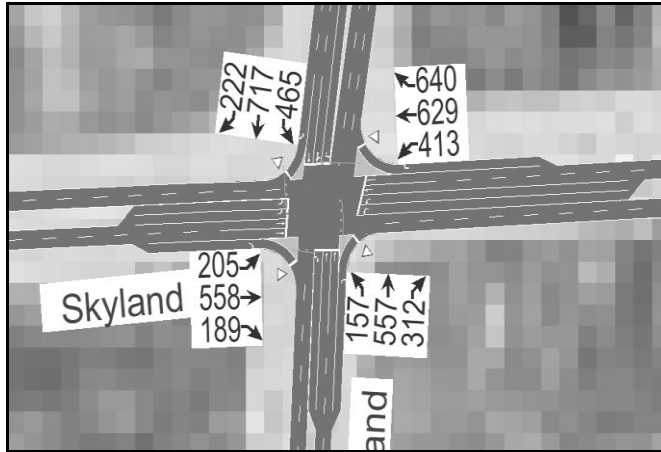


Figure 2-3. Intersection configuration and turning movements for McFarland Boulevard and Skyland Boulevard.

Results

A general comparison was made to determine the percent difference of the simulated delay from the software. The results are contained in Table 2-1. Several observations were drawn, as explained in the following subsections.

Overall Comparison

First, the results for the intersection of McFarland Boulevard and Skyland Boulevard appear to be reasonable. For the six hours of data at the two intersections, the observed (video) values of the LOS agreed with the simulated values 62.5 percent of the time, and there were no instances in which the error was more than one Level of Service. The difference in average seconds of delay between the video observations and the simulation software ranged from +15.8 percent to -44.9 percent. The agreement between the video and simulation models was in error by an average of 21.5 percent for the seconds of delay for the 24 individual observation periods.

Comparison of Individual Intersections

When the intersections are examined one at a time, McFarland Boulevard at Skyland Boulevard is an encouraging comparison for the procedure developed in this portion of the research. The LOSs agreed 83 percent of the time. The difference in seconds of delay predicted by the video analysis and the simulation models ranged from a high of +15.8 percent to a low of -26.4 percent. The 12 simulation values averaged 9.2 percent from the video delay value. When viewed individually, these values confirm that simulation results can match actual delay occurring at traffic signals.

Table 2-1. Comparison of Field Observations to Simulation Results

McFarland Boulevard and 37th Street									
Day	Sample Period	Video Delay, Sec.	LOS	Synchro Delay, Sec.	Compare with video	LOS	HCS++ Delay, Sec.	Compare with video	LOS
Day 1	Hour 1	46	D	29	-37.0%	C	27.5	-40.2%	C
	Hour 2	49	D	27	-44.9%	C	27.2	-44.5%	C
	Hour 3	35	C	24.2	-30.9%	C	24.3	-30.6%	C
Day 2	Hour 1	49	D	32	-34.7%	C	30	-38.8%	C
	Hour 2	44	D	37.5	-14.8%	D	34	-22.7%	C
	Hour 3	34	C	24.3	-28.5%	C	24.4	-28.2%	C
LOS 50% correct						LOS 33% correct			
McFarland Boulevard and Skyland Boulevard									
		Video Delay, Sec.	LOS	Synchro Delay, Sec	Compare with video	LOS	HCS++ Delay, Sec	Compare with video	LOS
Day 1	Hour 1	58	E	46.8	-19.3%	D	42.7	-26.4%	D
	Hour 2	44	D	47	6.8%	D	41.9	-4.8%	D
	Hour 3	41	D	44.5	8.5%	D	40.4	-1.5%	D
Day 2	Hour 1	44	D	40.8	-7.3%	D	45.1	2.5%	D
	Hour 2	52	D	45.4	-12.7%	D	55.1	6.0%	D
	Hour 3	36	D	38.6	7.2%	D	41.7	15.8%	D
LOS 83% correct						LOS 83% correct			
Overall for both signals: 62.5% correct; error range -44.9% to + 8.5%; no errors more than one LOS									

However, the intersection of McFarland Boulevard and 37th Street did not produce positive results. Almost 60 percent of the time, the observed LOS differed from the simulation model’s LOS values. There was an average error of 33 percent in predicting delay. These findings are a potential concern. These are not stellar values, and certainly do not confirm the accuracy of the simulation.

Potential Causes of Weak Comparison Predictive Performance

A feeling for the differences in video observation, Synchro 7 simulation and HCS+ simulation can be obtained from Figures 2-4 thorough 2-6. Although there are clear differences, the figures do not suggest a cause for those differences.

The researchers reviewed the recorded video to identify the source of delay and of source of error in the simulation results. The main difference between the two intersections was in the progression and arrival rates. The models treated the signal coordination system incorrectly. This suggests that transportation decision making can be flawed if it is based upon simulation results (especially if the simulation model was not properly calibrated). It is important for traffic engineers to understand the signal systems under their control and to be familiar with the nuances of software used to optimize signal control systems.

Synchro / HCM

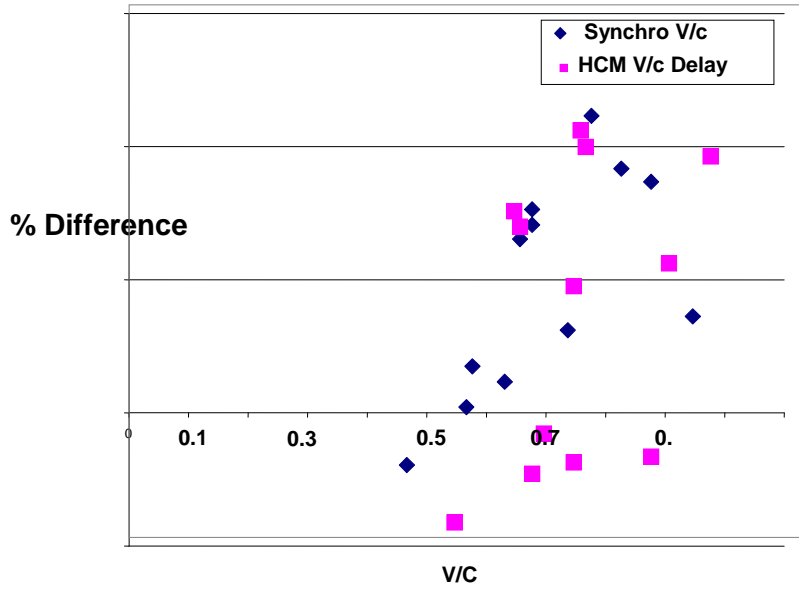


Figure 2-4. Percent difference, Synchro vs. HCM+.

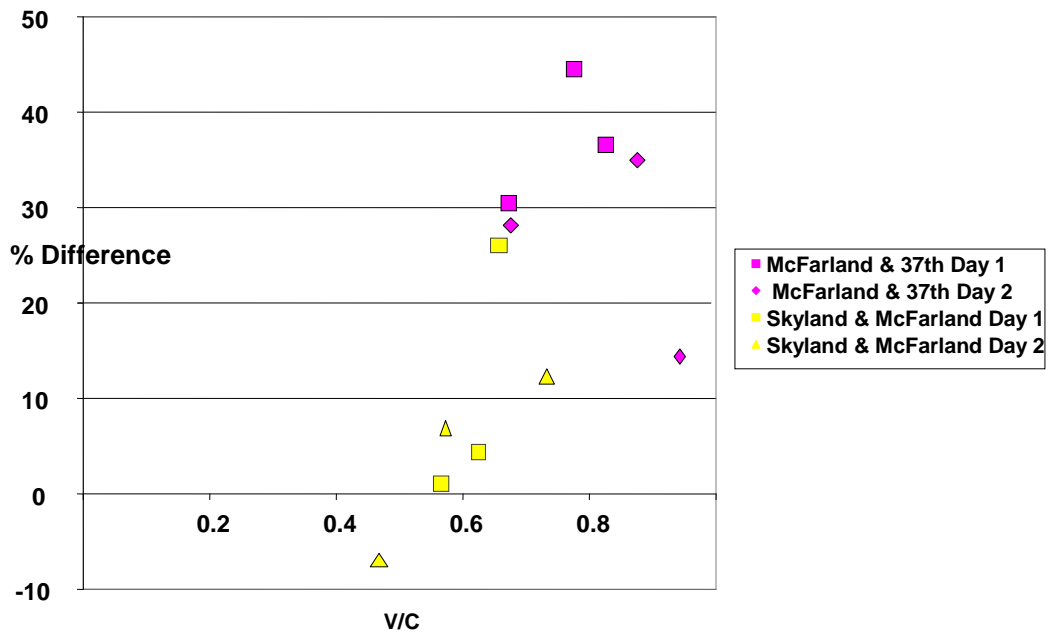


Figure 2-5. Percent difference, Synchro vs. video.

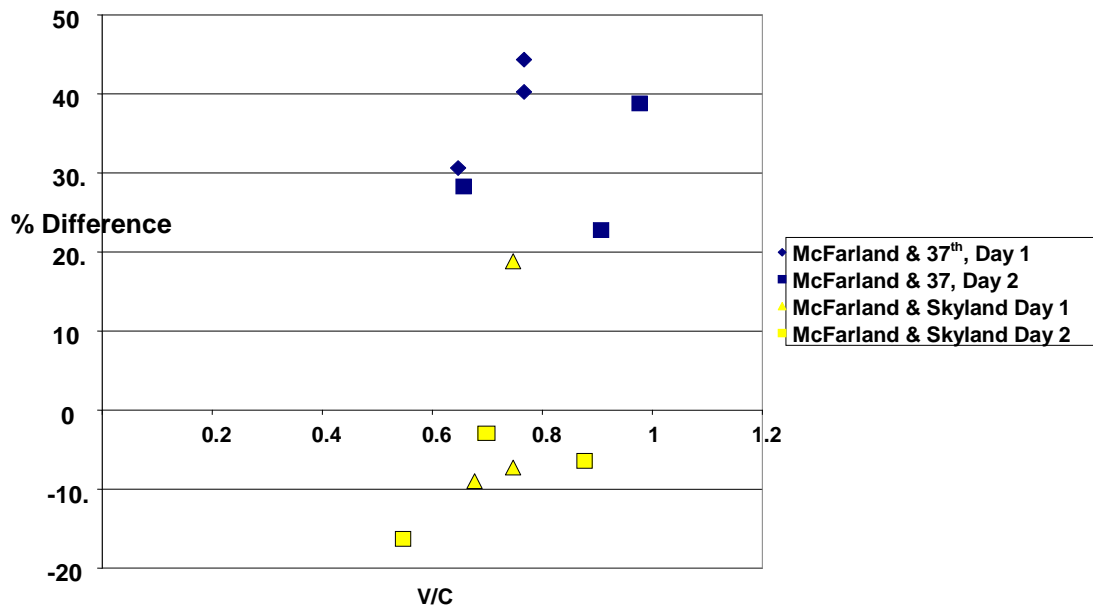


Figure 2-6. Percent difference, HCM+ vs. video.

Of the nine situations when the software produced the wrong LOS (false data points), seven were from the McFarland and 37th Street intersection. From the incorrect data, four were produced by Synchro 7 and five were from HCS+. From Table 2-1 and Figures 2-4 and 2-5, it can be seen that there is a major difference in how well the software predicted LOS.

Why was the LOS agreement good for one intersection and poor for another? From observation of the video data, the progression was poor on the southbound approach, and neither of the software packages accounted for the poor efficiency of the intersection signal timing. The video showed about 10 seconds of wasted green time per cycle because the upstream queue had not arrived yet. Synchro is often used for modeling networks of intersections due to being able to input the surrounding intersections in the software. The intersection at McFarland and Skyland Boulevards had no offset as it was the master intersection; this potentially explains some of the error in the other intersections.

A further point of error might be the way in which the two simulation models predict delay. Synchro 7 calculates stopped delay by adding the uniform delay and random delay. Uniform and random delays are calculated based on the theoretical arrival rates, departure rates, cycle lengths, and effective green times. Synchro multiplies stopped delay by 1.3 to obtain control delay (Eq. 2-4). The progression factor (PF) is calculated for an intersection based on the surrounding network it. In Equations 2-4 and 2-5, the d3 term takes into account any pre-existing queue; however, for the intersections in this study this term was negligible. The d2 term accounts for randomness in the arrival rate, and the d1 term is standard uniform delay multiplied by the progression factor.

$$\text{Synchro 7 Software: Control Delay} = 1.3 \times (d1 \times PF + d2) \quad \text{Equation 2-4}$$

The HCS+ software follows the *HCM* methodologies for determining delay. The same basic equation is used in *HCM* as in Synchro. Lane group delay is initially uniform delay and is then adjusted to account for initial queues and progression. The Progression Factor must be hand calculated or assumed to be and “isolated” condition with a standard value of 1. This is a major difference in the two simulation packages. D2 is also subjective depending on using Synchro or HCS+ as they assume different values.

$$\text{Lane Group Delay} = d1 \times PF + d2 + d3 \quad \text{Equation 2-5}$$

The main difference in the delay predicted by the HCS+ and by the well-known Webster Delay formula is the assumptions the respective software makes. For example, Synchro computes a RTOR (right turn on red) volume per hour, progression factor (PF), and determines d2 slightly differently. The Webster equation does not consider these features.

Conclusion and Future Studies

A comparison of different delay prediction methods was conducted at two intersections on McFarland Boulevard in Tuscaloosa, AL to determine whether video is more accurate or more helpful than standard methods now in use.

- This study found that it is important for traffic engineers to recognize the nuances of software used to optimize signal control systems, and to make appropriate decisions about which software best applies to specific situations.

- The study found relatively high percent differences in the delays produced by observing video data and by using simulation results. This resulted in the two software packages incorrectly calculating the LOSs of an approach or an intersection nine times out of 24 observation periods (almost 40 percent of the time).
- These results of this research should cause concern on the part of traffic engineers with jurisdiction over major signalized arterials. They underscore the importance of gathering good data, calibrating simulation models to local conditions, and understanding the operation and the limits of simulations models. Incorrect or misleading results might be produced otherwise, leading to incorrect or weak decisions by the leaders of the agencies within which the arterials reside. The improvements might be as simple as using sampling techniques to make an estimate of the delay for a lane group. This process would significantly improve a portion of the data necessary for good simulation practices, and would allow a better understanding of simulation.
- An ultimate goal is for transportation decisions to be improved by agencies being able to establish LOSs and other measures of effectiveness by observing video data of their intersections. However, labor cost involved in this project indicates that it is not practical to collect actual delay data points in this manner, so improvements should be sought in conventional methods to estimate delay.

In closing, the authors point out that this study was done on a limited number of sites with limited data, and the study must be replicated many times at multiple locations prior to considering such findings to be conclusive.

3.0 Modeling Oversaturated Conditions on Arterials Using VISTA

Objective

The major objective of this portion of the project was to evaluate the performance of an arterial network under oversaturated conditions. Oversaturation in a transportation facility can be defined as a condition in which demand exceeds a capacity (i.e., volume over capacity ratio exceeds one). A secondary objective was to investigate the applicability of signal timing optimization as well as dynamic traffic assignment (DTA) in mitigating arterial congestion. To achieve these objectives, an arterial corridor was selected and analyzed for various supply and demand scenarios. Similarly, intelligent transportation systems (ITS) technology such as the variable message sign (VMS) was also evaluated in this study. For example, the impact of lane closures was evaluated for varying degrees of severity with and without information provision.

The study first modeled an existing traffic signal system and reported arterial performance under base conditions. Then the impacts of signal timing optimization on arterial performance and system performance were predicted. This was done through the employment of simulation and DTA modeling.

This part of the study used the same an arterial corridor in the city of Tuscaloosa, Alabama, as the other portions of the study. A regional transportation network model was developed and tested under various conditions. DTA using the Visual Interactive System for Transportation Algorithm (VISTA) platform was performed to assess the impact of signals and VMS on the system as well as the consequences of optimization. Similarly, congestion due to lane closures or corridor oversaturation was performed with DTA simulation. With the results obtained through simulation, the study was expected to provide guidance and develop procedures that can be used by traffic management centers (TMCs) to realize the full potential of traffic signal timing to mitigate congestion on oversaturated arterials and enhance traffic management and network efficiency.

Simulation Model Overview

There are many transportation models in common use. For readers not familiar with this topic, a general summary has been provided in the Appendix to this section of the report. This includes the definition of transportation simulation, traffic assignment, commonly used simulation models, and similar topics.

Model Selection

Simulation model selection is crucial in the outcome of the study. Selection of proper tool should consider the following:

- Model Capabilities (size of network, network representation, traffic representation, traffic composition, traffic operations, traffic control, model output, etc.)
- Data Requirements (model inputs, calibration/validation data)
- Ease of Use (pre-processor, post processor, graphic display, on-line help, and demos)
- Resources Required (cost of software, cost to run model, staff expertise requirements, technical support)
- Past Performance (credibility and user acceptance)

VISTA Background

VISTA is an innovative network-enabled framework with DTA capabilities. VISTA integrates spatio-temporal data to model a variety of transportation applications ranging from long-term transportation planning activities to other transportation engineering to operational analysis. This model has been well tested in various projects in the US and Europe. One major advantage of this model, compared to other traditional traffic simulation models, is the way it handles ITS applications. Moreover VISTA can model very large networks within a reasonable time and can incorporate real-time conditions into the modeling process.

VISTA Capabilities

As explained earlier, the VISTA simulation model can be used for a wide range of applications in transportation engineering and planning. Some of the capabilities of VISTA are as follows:

- VISTA runs over a cluster of Unix/Linux machines and is easily accessible to any and all authorized users via Internet/ Intranet. This allows access to and use of the model by a variety of users and eliminates the need to install new software and software upgrades.
- VISTA uses a universal database model that can be accessed through a web interface or GIS interface. The GIS interface enables users to edit on the network.
- VISTA has enormous capacity for handling large networks.
- The model provides DTA capabilities. Dynamic user equilibrium (DUE) is the main traffic assignment technique employed in VISTA. As a result, no user can switch path to decrease his/her travel time.
- VISTA can meet the functional needs of various areas by multiple types of DTA capabilities (descriptive vs. normative).
- VISTA is capable of distinguishing between informed and non-informed road users, as well as user classes, such as normal passenger cars, buses, and trucks in terms of operational characteristics.
- Congestion management strategies such as incident management techniques, ITS technologies, and work zone management activities can be modeled easily using VISTA.

- VISTA can perform signal warrant analysis at unsignalized intersections as well as optimize signal timing plans for signalized intersections.
- VISTA offers a number of pre-confined reports to provide information on various types of MOEs such as travel time, delays, and VMT.
- VISTA also offers other customized outputs by running query to database directly in the web interface.

VISTA Limitations

VISTA offers a great deal of detailed traffic analysis but has some limitations. As with other simulation models, the user should understand these limitations before using the model. Some of the limitations of VISTA are as follows:

- VISTA is not capable of detecting a vehicle stop precisely because of its inherent nature.
- For complex networks, the computational time required for DTA within the VISTA is still high; therefore, it is not practical to use VISTA for detailed analysis involving a large transportation network.
- Since VISTA is a mesoscopic model, it is not as efficient in modeling detailed traffic interactions such as car-following, lane changing, and weaving as some microscopic simulation models counterparts.
- VISTA offers detail at the cell level, but it is hard for the user to determine the cell length and time step required for a desired level of detail.

VISTA Applications

VISTA has been tested successfully in much research and implemented for various purposes all around the world. Examples include the following:

- Atlanta Department of Transportation: Establishment of DTA model for Atlanta region to support various planning and operational improvements (Mouskos, et al. 2006).
- New Jersey: Evaluation of various infrastructure and operational improvements scenarios, and establishment of land use. Similarly, corridor DTA/ simulation and evaluation of ITS technologies were done on I-80 (Mouskos, et al. 2006).
- Chicago: Evaluation of the impacts and effectiveness of various transit signal priority strategies (Mouskos, et al. 2006).
- US Army Corps of Engineers: Prediction of transportation impacts of flooding on various areas around US (Mouskos, et al. 2006).
- Illinois DOT: Evaluation of trucking policies and interaction of trucks and cars (Mouskos, et al. 2006).
- Lake-Cook County, IL: Evaluation of multi-agency cooperation in emergency evacuation scenarios on Lake-Cook Road, Chicago (Mouskos, et al. 2006).
- Athens, Greece: Simulation/DTA for traffic management strategies for the Olympics (Mouskos, et al. 2006).

- Ohio DOT: Simulation/ DTA for large-scale assignment solutions (Mouskos, et al. 2006).
- Province of Bologna, Italy: Modeling of accidents to determine their impact on regional mobility (Mouskos, et al. 2006).

VISTA Modules

Cell Generator This module is used for converting the network of links and nodes into a network of cells. The RouteSim simulator employed in VISTA uses the cell transmission model to propagate vehicles in the cells. Links are divided into multiple cells of equal length to the distance traveled in one time step by a vehicle moving at free flow speed. In other words, vehicles can move one cell in one time step if there is no congestion present. In fact, the number of vehicles that move depends upon the space available on the downstream cell and the maximum flow permitted. In case of space constraints, vehicles do not move forward and queues develop (Abro, 2007).

Demand Profiler The percentage of delay in the delay table to implement during the simulation and DTA run can be specified in VISTA through the Demand Profiler. Although O-D demands refer to the whole simulation period, the time-dependent simulation or dynamic demand requires the exact percentage of vehicle departures. Hence each interval in the simulation can assign different weights using this module (Abro, 2007; Vista Transport Group, 2005). Oversaturation can be studied by loading large number of vehicles in the network using this module.

Simulation VISTA uses a mesoscopic simulator called RouteSim, which is based on an extension of Daganzo's (1994) cell-transmission model introduced by Ziliaskopoulos, et al., 1996 (*Overview of VISTA*). RouteSim offers adjustable cell size, which improves flexibility, accuracy, and other computational needs of the simulation model. It can use single cell and long time steps for long stretches of freeway that do not require detail modeling, whereas it uses multiple cells and short time steps for surface streets with congestion (*Overview of VISTA*). All vehicles are propagated according to the cell transmission rule, but the RouteSim simulator can differentiate between a transit vehicle and a passenger car, and it assigns transit vehicles as longer vehicles and models accordingly (Mouskos, et al. 2006). Similarly, RouteSim offers a high level of modeling options for DTA, optimization, and evaluation of performance.

The RouteSim simulator used in VISTA can simulate vehicles without DTA. Hence, the RouteSim simulator is active in performing the traditional simulation process without carrying DTA. In the case of simulation only, vehicles are assigned according to their originally assigned path and real-time conditions such as information provision do not affect the users' route choices (Vista Transport Group, 2005).

DTA – Path Generation In the DTA – Path generation module, traffic assignment is done by calculating the time-dependent shortest path for all vehicles in an iterative process. This process is a simulation-based process of dynamic traffic assignment, and the RouteSim simulator is automatically called in this module. The simulation process starts when DTA – Path generation

is started (Vista Transport Group, 2005). This process generates a dynamic least-cost path for all vehicles in O-D demand, depending upon the shortest path algorithm.

DTA – Dynamic User Equilibrium The DTA – Dynamic User Equilibrium module does not calculate the path for the vehicles but reshuffles the vehicles among the existing sets of paths. It should be noted that the DTA – Path Generation module should be performed before employing the DTA – Dynamic User Equilibrium. In the process of DUE, vehicles are redistributed until the desirable cost gap factor is reached (Abro, 2007; Vista Transport Group, 2005). The cost gap is the percentage error for the convergence of traffic assignment to the equilibrium condition. Generally a cost gap of five percent or less is considered to be acceptable.

Signal Optimization This module is used for the optimization of traffic signals in transportation networks. VISTA offers its own optimization tool for signal timing optimization. Moreover, it provides interface with other signal timing optimization programs, such as Synchro and TRANSYT. In addition, the VISTA signal optimization module can conduct signal warrants according to *Manual of Uniform Traffic Control Devices* (MUTCD) guidelines. The capability to conduct signal warrants at intersections and generate signals if they are warranted is unique when compared with similar models and enables transportation agencies and analysts to create proper signal timing plans when actual data is lacking.

Figure 3-1 provides an overview of the VISTA module flow chart for dynamic traffic assignment.

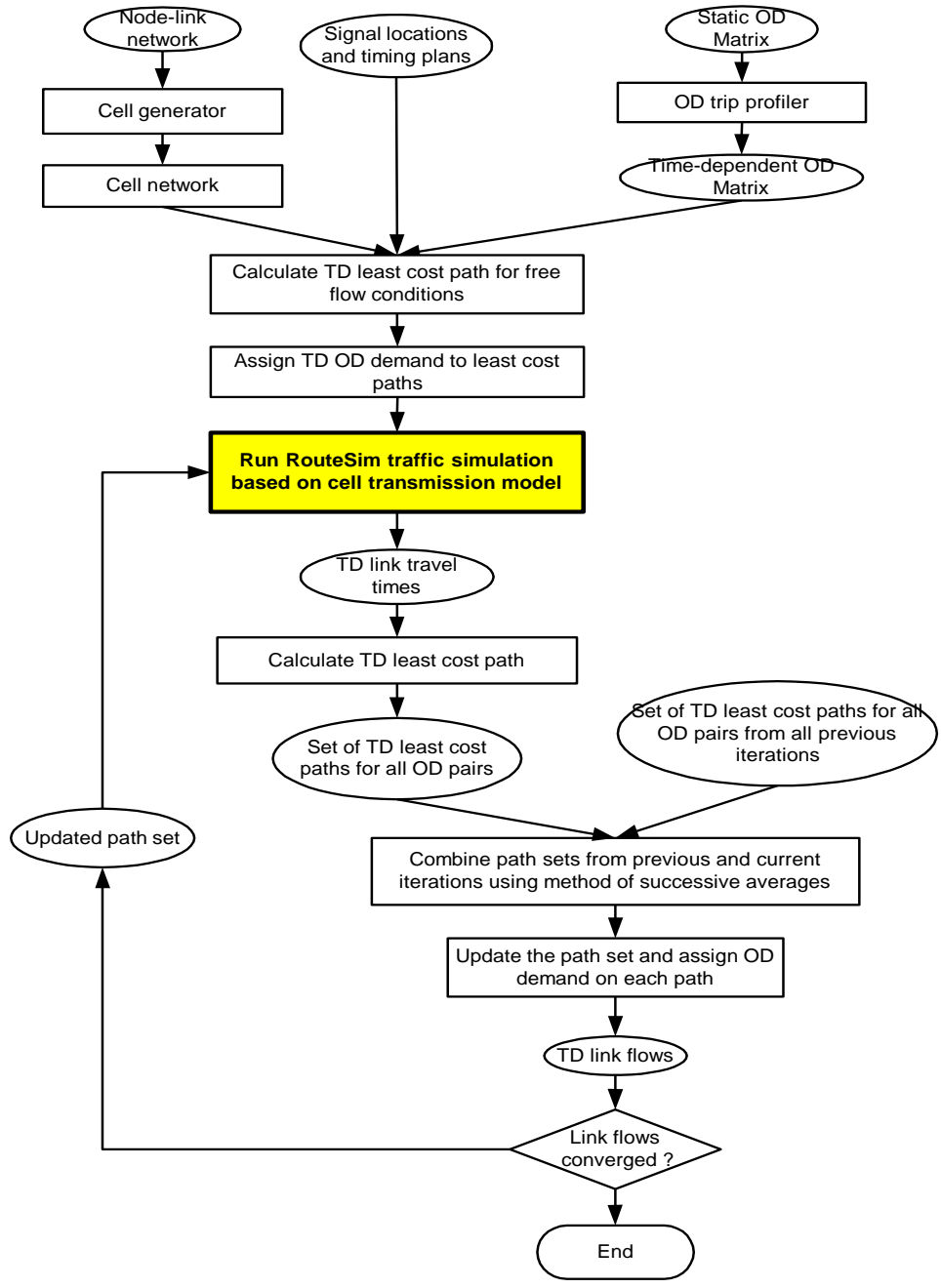


Figure 3-1. VISTA module flow chart for dynamic traffic assignment (Mouskos, et al. 2006).

Study Methodology

Approach

This portion of the research project studied oversaturation on an arterial network and ways to address it. Emphasis is placed on the optimization of signal timing through traditional simulation and DTA procedures. The DTA capabilities of VISTA, along with ITS applications

such as VMS, can be useful in the evaluation of system performance as well as the development of guidelines for employment of traffic signal optimization at TMCs to mitigate the problem of recurring and non-recurring congestion and oversaturation. The basic steps considered for the accomplishment of these research goals are as follows:

1. Selection of study test bed.
2. Data acquisition and model development.
3. Model validation.
4. Identification of closure site.
5. Development of testing scenarios.
6. Simulation of testing scenarios.
7. Analysis of results.
8. Synthesis of conclusions and recommendations.

Selection of Study Test Bed

The case study focused on the regional transportation network of the city of Tuscaloosa in the state of Alabama. The network is comprised of an interstate highway, an interstate spur and other multilane highways, along with other arterials and collector facilities. A map of the major facilities in the network is shown Figure 3-2.

The two major facilities serving this area are Interstates 20/59 and 359. Along with these, state highways US-11 and US-82 pass through the study network. I-20/59 is a facility serving east/west traffic that provides great mobility of people and goods in the state of Alabama. I-359 is a short spur, extending in a north/south direction, which links I-20/59 with US 69 and US 43, providing downtown Tuscaloosa with high-speed access to the Interstate. US 11 runs parallel to I-20/59 and serves the east/west direction of travel, whereas US 82 runs in the north/south direction.

Highway US 82 is also known as McFarland Boulevard, a major north-south arterial corridor connecting the University of Alabama in Tuscaloosa with I-20/59 to the south. It, along with the I-359 spur, provides the majority of north-south travel in Tuscaloosa.

McFarland Boulevard is the specific study site for the study. It was shown previously as Figure 1.1 of this report.

There are congestion choke points at several signalized intersections along the corridor. Local studies have confirmed that McFarland Blvd. operates under oversaturated conditions on a recurring basis and is subject to non-recurring congestion due to special event traffic (such as University of Alabama football games). For this reason, it is an ideal test bed for this research and was selected as main test corridor for this study.

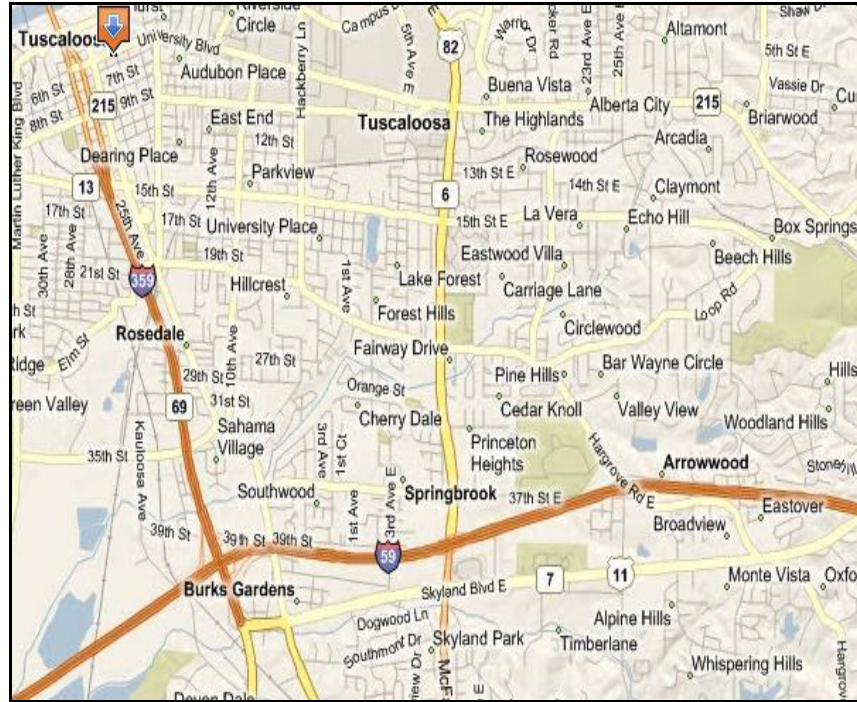


Figure 3-2. General map of the study network.

Data Acquisition and Model Development

Data acquisition is a very important part in any study, as the quality of data directly correlates with the outcomes of analysis, and the simulation model inputs should be of good quality and well tested. The data requirements and the data source for the VISTA simulation model are discussed next.

Network Data VISTA is a simulation model that runs online through a web interface and a client interface. While the user can operate the model through both interfaces, it is not possible to create a network on a web interface but only in the client interface or Postgre Structured Query Language (PSQL) (Vista Transport Group, 2005). Alternatively, VISTA can incorporate the network of Transportation Planning (TRANPLAN) software and CORSIM. This process of creating the network is simpler than the previous one. Files from TRANPLAN and CORSIM can be directly imported to VISTA, and the conversion tool provided there can build the VISTA network.

The VISTA study network development for this study was created using the TRANPLAN file for the city of Tuscaloosa, AL, which was made available to our study group through the Tuscaloosa DOT. The VISTA network was checked for errors and manual refinement was performed, as needed, to correct inconsistencies and improve model accuracy. The VISTA Tuscaloosa network developed in this study is represented by 2,780 nodes 1,856 of which are mesoscopic nodes and 924 are centroid nodes. The network contains 3,395 links, of which 2,233 are mesoscopic links and 1,162 are centroid links. The final network created on VISTA is depicted in Figure 3-3.

Demand Data VISTA generates demand through origin-destination (O-D) trip matrices. The program also allows users to input dynamic demand. O-D trip tables from TRANPLAN were used as demand data in the Tuscaloosa VISTA model. Initially the model was developed for 24 hours, and demand was also for the same 24-hour period. Since the study concentrated on peak hours (when oversaturated conditions are most likely to occur), the demand was adjusted to the evening peak (i.e., from 4 PM to 8 PM). The four-hour time block considered in this study meets the analysis requirement for peak hour congestion. During the simulation the O-D demand loaded 128,765 vehicles into the network, which generated 16,485 trips during the hours considered.

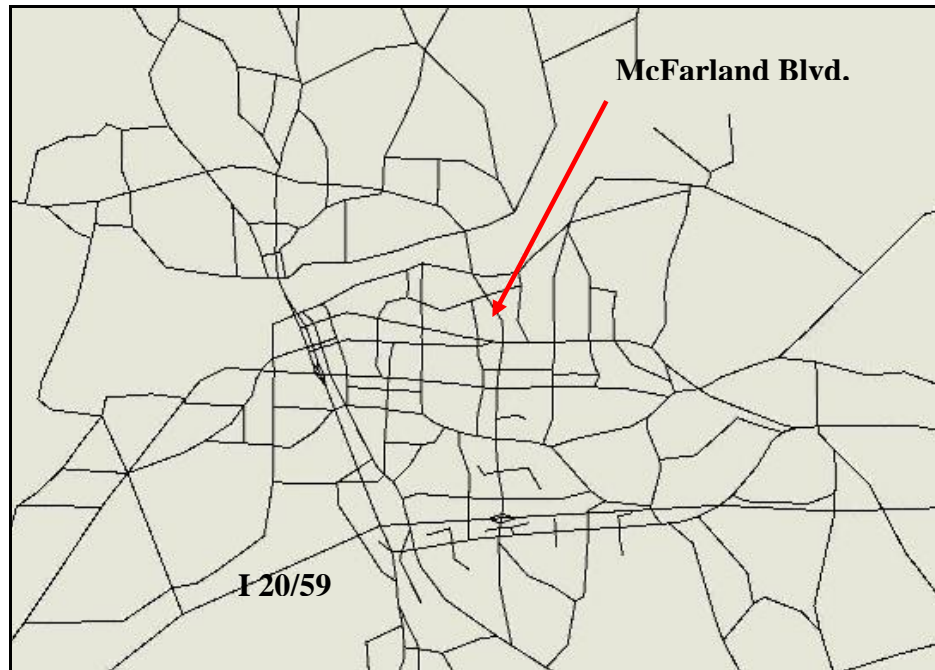


Figure 3-3. Basic Tuscaloosa network developed in VISTA.

Control Data As this study mainly focused on signal timing optimization, control data are an important part of the study. The Synchro signal timing file for the McFarland Blvd. was obtained from the city of Tuscaloosa and inputted in the VISTA network. The inputted signal timing plans covered 10 intersections, i.e., from the intersection of McFarland Blvd. and Skyland Blvd. (which is just south of I-20/59 interchange) to 13th Street East (one intersection south of University Blvd.). The intersections considered for signal timing optimization and study analysis purposes are shown in Figure 3-4.

Data for Model Validation Validation is a major step in the simulation model process. After performing the simulation runs through VISTA, results obtained from the simulation must be compared with the actual data, and adjustments should be made, as needed, to refine the model prior to use. For this purpose peak period traffic counts for McFarland Blvd. were obtained from the city of Tuscaloosa and Alabama Department of Transportation (ALDOT). Limited site visit were performed to observe travel times along McFarland Blvd.

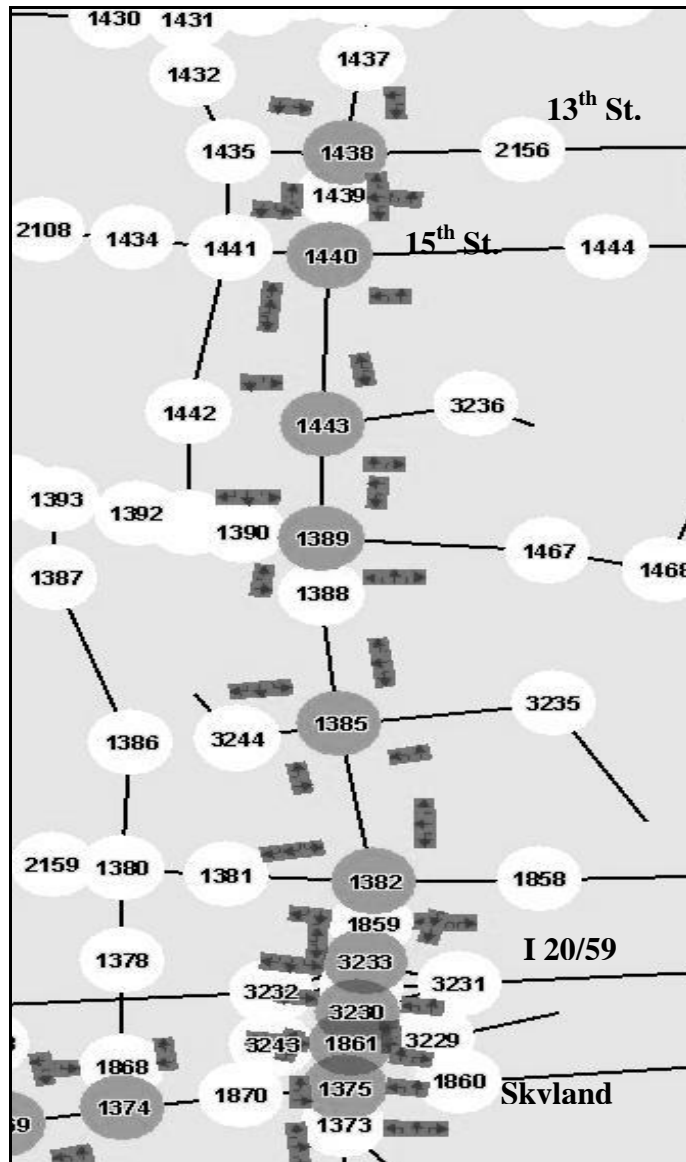


Figure 3-4. Signals considered in the study.

Model Validation

As a part of the model verification procedure, traffic count along the McFarland Boulevard were acquired from ALDOT and the city of Tuscaloosa and compared with the simulation counts. The traffic counts obtained from those agencies were for two evening peak hours from 4 PM to 6 PM. Actual traffic counts from 4 PM to 5 PM were compared with simulation counts for the same period. The comparison was done by plotting observed counts and simulated counts on the X-axis and the Y-axis, respectively. Each point on the graph represents the volume of one link of the study corridor. Figure 3-5 below shows the distribution of observed and simulated counts for the transportation system of the city of Tuscaloosa. The overall difference in the observed

counts and simulated counts along the McFarland corridor is about eight percent. A better fit can be obtained through the calibration of O-D demand, and of simulator.

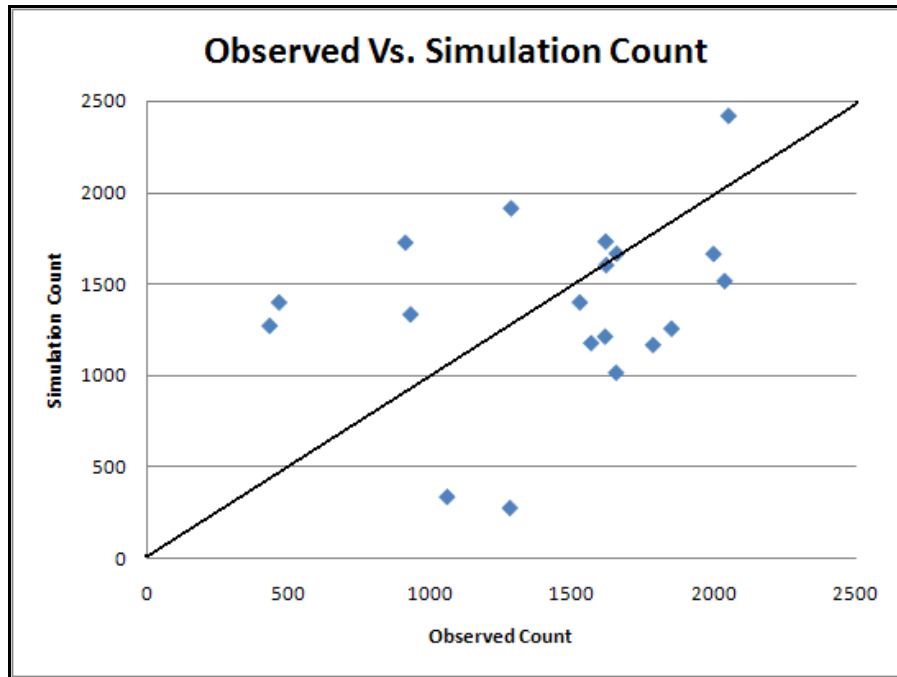


Figure 3-5. Observed vs. simulation counts.

Identification of Closure Site

The southbound section of McFarland Blvd. extending from the intersection with 13th Street in the north and the intersection with the Skyland Boulevard on the south was treated as the potential closure zone for this study. The major purpose of creating this zone was to determine the effect of congestion flow when an arterial has decreased capacity at regular demand. Changes in corridor travel time were used as a MOE for this intersection. In addition, the effect that closing some lanes on the study corridor has on system performance was evaluated. The closure zone created in this study is depicted in Figure 3-6.

Development of Testing Scenarios

As a part of the study, various test scenarios were considered to study traffic congestion along McFarland Blvd. and ways to alleviate it. Some scenarios assumed capacity reductions along the study corridor and other demand increases. More specifically, Scenarios 1 through 6 assumed 0, 1, and 2 lane closures with and without information provision. A sensitivity analysis was performed, with the degree of lane closure severity changing in each of the scenarios from 15 minutes to 60 minutes in increments of 15 minutes. Three more scenarios (scenarios 7 through 9) were increased in demand for the whole network was assumed where there was 30 percent increase with an increase in demand. A brief listing of scenarios is presented in the following section and a description of each in the next chapter.

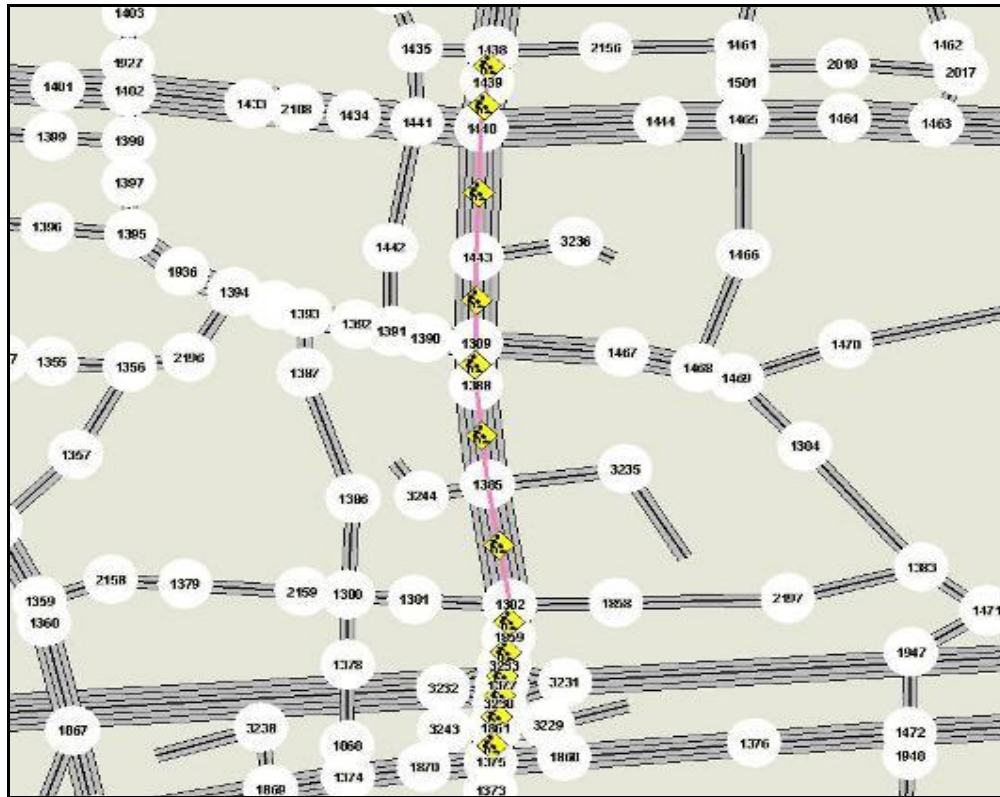


Figure 3-6. Selection of closure site.

1. Base case – No closure and drivers are aware of situation on network.
2. Incident case 1 – One-lane closure for different durations; no information provided to road users.
3. Incident case 2 – Two-lane closure for different durations; no information provided to road users.
4. Incident case 3 – Two-lane closures for different durations; optimal signal timing and no information provided to road users.
5. Incident case 4 – Two-lane closures for different durations; information provided to road users.
6. Incident case 5 – Two-lane closures for different durations; optimal signal timing and information provided to road users.
7. Increased demand case – Existing signal timing plan on corridor.
8. Increased demand case – Optimized signal timing plan on corridor.
9. Increased demand case – Optimized signal and information provided to road users through VMS.

Table 3-1 presents the summary of all scenarios considered for this study, with details on each scenario.

Table 3-1. Summary of Scenarios Tested

Scenario	Lanes closed	Incident Duration (min)	Information Provided	Signal timing	Driver Response (%)
1	0	0	NA	Existing	All
2	1	15,30,45,60	No	Existing	No
3	2	15,30,45,60	No	Existing	No
4	2	15,30,45,60	No	Optimized	No
5	2	15,30,45,60	All	Existing	All
6	2	15,30,45,60	All	Optimized	All
7	0	Increased demand	NA	Existing	All
8	0	Increased Demand	NA	Optimized	All
9	0	Increased Demand	VMS	Optimized	All

Results of Simulation

Base Case

The base case scenario simulated the existing geometric, control, and demand conditions of the corridor. No incident scenario was incorporated in this case. The traffic assignment procedure used for this case was the DTA. The analysis focused on travel time and delay for the study corridor and the Tuscaloosa network as a whole.

Table 3-2 provides detailed information on the system performance obtained from the VISTA simulation for the base case. This table highlights the number of vehicles loaded in the system during simulation, total VMT, travel time, delay, and the standard deviation for travel time and delay for the system

Table 3-2. Base Case System Performance Results

Loaded Vehicle	Total Travel time (hr)	Average Travel Time (min)	TT STD (min)	VMT (miles)	Total Delay (hr)	Average Delay (min/vehicle)	Delay STD (min)
128,660	40,755	19.01	17.79	1,591,969	1,565.36	0.73	1.03

Similarly, Table 3-3 provides the existing condition of the selected corridor on a normal day. This table also provides the information on corridor length, free flow travel time, simulation travel time, total delay, and average delay for the corridor.

Table 3-3. Base Case Corridor Performance Results

Corridor Links	Corridor Length (miles)	Free Flow Travel Time (min)	Simulation Travel Time (min)	Total Delay (min)	Average Delay (min/mile)
252,254,256,259,263,240,238,236,235,3385,3381, 3379,3341,66	2.58	4.10	4.12	0.02	0.01

Incident Case 1 – One-Lane Closure for Different Durations; No Information Provided to Road Users

This study case examined the effect of a one-lane closure on the operation of the study corridor with existing traffic control, i.e., without any adjustment in signal timings. Various degrees of lane closure severity were tested by adjusting the duration of the closure. It was further assumed that road users are not aware of the situation and thus could not change their routes to optimize travel time. The duration of closure ranged from 15 minutes to one hour with a 15-minute increment. Hence the system and corridor performance were tested for 15 minutes, 30 minutes, 45 minutes and 60 minutes for a one-lane closure. Table 3-4 provides the simulation results for this case on the response of system as a whole.

Table 3-4. One-Lane Closure System Performance Results

Loaded Vehicle	Closure Duration (min)	Total Travel Time (hr)	Avg. Travel Time (min)	TT STD (min)	VMT (miles)	Total Delay (hr)	Average Delay (min/veh)	Delay STD (min)
128,660	15	40,764	19.01	17.79	1,591,969	1,565.36	0.73	1.05
128,660	30	40,793	19.02	17.79	1,591,969	1,586.30	0.74	1.09
128,660	45	40,835	19.04	17.80	1,591,969	1,629.69	0.76	1.16
128,660	60	40,894	19.07	17.81	1,591,969	1,694.02	0.79	1.26

The impact of a one-lane closure on the selected corridor for different duration is summarized in Table 3-5.

Table 3-5. One-Lane Closure Corridor Performance Results

Corridor Links	Closure Duration (min)	Corridor Length (miles)	Free Flow Travel time (min)	Simulation Travel Time (min)	Total Delay (min)	Average Delay (min/mile)
252,254,256,	15	2.58	4.10	4.15	0.05	0.02
259,263,240,	30	2.58	4.10	4.27	0.17	0.07
238,236,235,	45	2.58	4.10	4.43	0.33	0.13
3385,3381,3379,334,66	60	2.58	4.10	4.68	0.58	0.22

Incident Case 2 – Two-Lane Closure for Different Durations; No Information Provided to Road Users

This case is similar to the case presented in Incident Case 1, except that an additional lane was closed in this scenario to analyze an even worse situation with existing signal timing plans and without any informational provision to drivers. The severity of two lane closures was tested for durations of 15 minutes, 30 minutes, 45 minutes and 60 minutes. Tables 3-6 and 3-7 summarize the results obtained for a two-lane closure related to corridor and system performance, respectively.

Table 3-6. Two-Lane Closure System Performance Results

Loaded Vehicle	Closure Duration (min)	Total Travel Time (hr)	Avg. Travel Time (min)	TT STD (min)	VMT (miles)	Total Delay (hr)	Average Delay (min/veh)	Delay STD (min)
128,660	15	40,843	19.05	17.81	1,591,969	1,651.13	0.77	1.21
128,660	30	41,122	19.81	17.90	1,591,969	1,929.90	0.90	1.94
128,660	45	41,586	19.39	18.09	1,591,969	2,380.21	1.11	3.06
128,660	60	42,597	19.89	18.50	1,591,969	3,388.04	1.58	4.79

Table 3-7. Two-Lane Closure Corridor Performance Results

Corridor Links	Closure Duration (min)	Corridor Length (miles)	Free Flow Travel time (min)	Simulation Travel Time (min)	Total Delay (min)	Average Delay (min/mile)
252, 254, 256, 259, 263, 240, 238, 236, 235, 3385,3 81, 3379, 3341, 66	15	2.58	4.10	4.50	0.40	0.15
	30	2.58	4.10	5.36	1.26	0.49
	45	2.58	4.10	6.20	2.10	0.81
	60	2.58	4.10	7.03	2.93	1.14

Incident Case 3 – Two-Lane Closure for Different Durations; Optimal Signal Timings and No Information Provided to Road Users

Existing signal timing was optimized using the VISTA optimization tool for the two-lane closure condition. The network is again simulated to get the effect of optimized signal setting. The effect of both system and corridor performance was obtained through simulation and is presented in Tables 3-8 and 3-9, respectively.

Table: 3-8. Two-Lane Closure with Optimized Signal System Performance Results

Loaded Vehicle	Closure Duration (min)	Total Travel Time (hr)	Avg. Travel Time (min)	TT STD (min)	VMT (miles)	Total Delay (hr)	Average Delay (min/veh)	Delay STD (min)
128,660	15	40,415	19.01	17.79	1,591,969	1,222	0.57	0.94
128,660	30	40,467	19.02	17.89	1,591,969	1,265	0.59	1.01
128,660	45	40,835	19.04	17.80	1,591,969.	1,351	0.63	1.21
128,660	60	40,894	19.07	18.81	1,591,969	1,480	0.69	1.50

Table 3-9. Two-Lane Closure with Optimized Signal Corridor Performance Results

Corridor Links	Closure Duration (min)	Corridor Length (miles)	Free Flow Travel time (min)	Simulation Travel Time (min)	Total Delay (min)	Average Delay (min/mile)
252,254,256,259,263,240,238,	15	2.58	4.10	4.13	0.03	0.01
236,235,3385,3381,3379,3341,66	30	2.58	4.10	4.32	0.22	0.09
	45	2.58	4.10	4.54	0.44	0.17
	60	2.58	4.10	4.75	0.65	0.25

Incident Case 4 – Two-Lane Closure for Different Durations; Information Provided to Road Users

In this scenario, a two-lane closure was assumed again; however, all drivers were fully aware of the situation via information dissemination technologies, such as VMS and other media. With information being provided to all drivers, DTA methodologies were employed to evaluate the system as well as corridor performance where drivers had the option to optimize their travel time accordingly. The results of DTA on system performance and corridor performance in this case are listed in Table 3-10 and 3-11, respectively.

Table 3-10. Two-Lane Closure with DTA System Performance Results

Loaded Vehicle	Closure Duration (min)	Total Travel Time (hr)	Avg. Travel Time (min)	TT STD (min)	VMT (miles)	Total Delay (hr)	Average Delay (min/veh)	Delay STD (min)
128,749	15	40,362	18.81	17.71	1,583,806	1,459	0.68	1.09
128,749	30	40,364	18.81	17.73	1,584,708	1,502	0.70	1.19
128,749	45	40,432	18.84	17.73	1,585,436	1,502	0.70	1.07
128,749	60	40,691	18.96	17.73	1,584,653	1,781	0.83	1.51

Table 3-11. Two-Lane Closure with DTA Corridor Performance Results

Corridor Links	Closure Duration (min)	Corridor Length (miles)	Free Flow Travel Time (min)	Simulation Travel Time (min)	Total Delay (min)	Average Delay (min/mile)
252,254,256,259,	15	2.58	4.10	4.27	0.17	0.06
263,240,238,236,	30	2.58	4.10	4.29	0.19	0.07
235,3385,3381,3379,3341,66	45	2.58	4.10	4.39	0.29	0.11
	60	2.58	4.10	4.55	0.45	0.17

Similarly, optimized signal performance on the corridor with an informational provision was also carried out. This analysis shows the best result for corridor performance with a 0.01 minute delay for two-lane closure for 60-minute duration. No delays experienced with the closure durations of 45, 30, and 15 minutes.

Increased Demand Case – Existing Signal Timing Plan on Corridor

Under normal conditions Average Annual Daily Traffic (AADT) on McFarland Blvd. is approximately 51,000 vehicles, according to ALDOT. However, a 30 percent traffic increase

along McFarland Blvd. is estimated when there is a football game at the University of Alabama; therefore, the original traffic on the system was increased by 30 percent and evaluated. In this scenario, the signal timing plan for McFarland corridor was assumed to be similar to the existing signal timing plan. The traffic assignment procedure used was DTA. System performance measures for the increased demand are shown in Table 3-12.

Table 3-12. Increased Demand System Performance Results

Loaded Vehicle	Total Travel time (hr)	Average Travel Time (min)	TT STD (min)	VMT (miles)	Total Delay (hr)	Average Delay (min/vehicle)	Delay STD (min)
167,394	94,394	33.83	30.16	2,257,787	38,110	13.66	23.8

Unlike the lane closure conditions studied earlier, where congestion was generated only in one direction, the increased demand scenario considered here generates more demand in both directions. Hence for corridor performance on McFarland Blvd. both northbound and southbound traffic are considered for this scenario. The performance measures for McFarland Blvd. for the increased demand are presented in Table 3-13.

Table 3-13. Increased Demand Corridor Performance Results

Corridor Links	Corridor Length (miles)	Free Flow Travel time (min)	Simulation Travel Time (min)	Total Delay (min)	Average Delay (min/mile)
253,255,257,264,241,239,237, 234,288,3384,3382,3380,3378, 3338, 63 (Northbound)	2.58	4.10	14.72	10.62	4.13
252,254,256,259,263,240,238, 236,235,3385,3381,3379,3341,66 (Southbound)	2.58	4.10	8.22	4.12	1.60

Increased Demand Case – Optimized Signal Plan on Corridor

In this scenario, the signal timing on McFarland Blvd. was optimized using the VISTA signal optimization tool, and the traffic condition of increased demand was again simulated with optimized signal plan. The system travel time and delay were obtained through simulation, and the results are presented in Table 3-14.

Table 3-14. Increased Demand with Optimized Signal System Performance Results

Loaded Vehicle	Total Travel Time (hr)	Average Travel Time (min)	TT STD (min)	VMT (miles)	Total Delay (hr)	Average Delay (min/vehicle)	Delay STD (min)
167,394	93834	33.63	30.04	2258208	37524	13.45	23.7

The corridor performance with optimized signal timing was also evaluated. The results obtained from the corridor performance are summarized in Table 3-15.

Table 3-15. Increased Demand with Optimized Signal Corridor Performance Results

Corridor Links	Corridor Length (miles)	Free Flow Travel time (min)	Simulation Travel Time (min)	Total Delay (min)	Average Delay (min/mile)
253,255,257,264,241,239, 237,234,288,3384,3382, 3380,3378,3338,63 (Northbound)	2.58	4.10	16.62	12.52	4.86
252,254,256,259,263,240, 238,236,235,3385,3381,3379,3341,66 (Southbound)	2.58	4.10	12.12	8.02	3.11

Increase Demand Case – Optimized Signal and Information Provided to Road Users Through VMS

The results from the previous scenario indicate that the signal optimization on the McFarland corridor increases the delay along the corridor as it tries to balance the increased demand on the cross streets. Hence, a VMS was considered on 15th Street east of the intersection with McFarland Blvd. The VMS was designed to improve the northbound delay on McFarland Blvd. by diverting northbound traffic from 15th Street to 6th Avenue East to University Blvd. It should be noted that except from McFarland Blvd. and 15th Street, all other parallel facilities or routes are of one lane in each direction. Considering capacity constraints, a lower compliance factor of 0.25 was selected for the VMS design. The overall effect of VMS on the system as well as the northbound section of McFarland corridor is presented in Tables 3-16 and 3-17, respectively.

Table 3-16. Increased Demand with Optimized Signal and VMS System Performance Results

Loaded Vehicles	Total Travel Time (hr)	Average Travel Time (min)	TT STD (min)	VMT (miles)	Total Delay (hr)	Average Delay (min/vehicle)	Delay STD (min)
167,394	93,778	33.61	30.00	2,258,206	37,468	13.43	23.66

Table 3-17. Increased Demand with Optimized Signal and VMS Northbound Corridor Performance Results

Corridor Links	Corridor Length (miles)	Free Flow Travel Time (min)	Simulation Travel Time (min)	Total Delay (min)	Average Delay (min/mile)
253,255,257,264,241,239, 237,234,288,3384,3382,3380,3378,3338, 63 (Northbound)	2.58	4.10	16.49	12.39	4.81

Analysis of Results

One-Lane vs. Two-Lane Closure with Existing Signal Plan

Figure 3-7 shows the effect on system performance of one-lane and two-lane closures with respect to the base operating case. It is apparent from the graph that the one-lane closure has little effect on the system performance, due to the short section of the study corridor, which is just 2.58 miles. The aggregate delay change on the system is not appreciable.

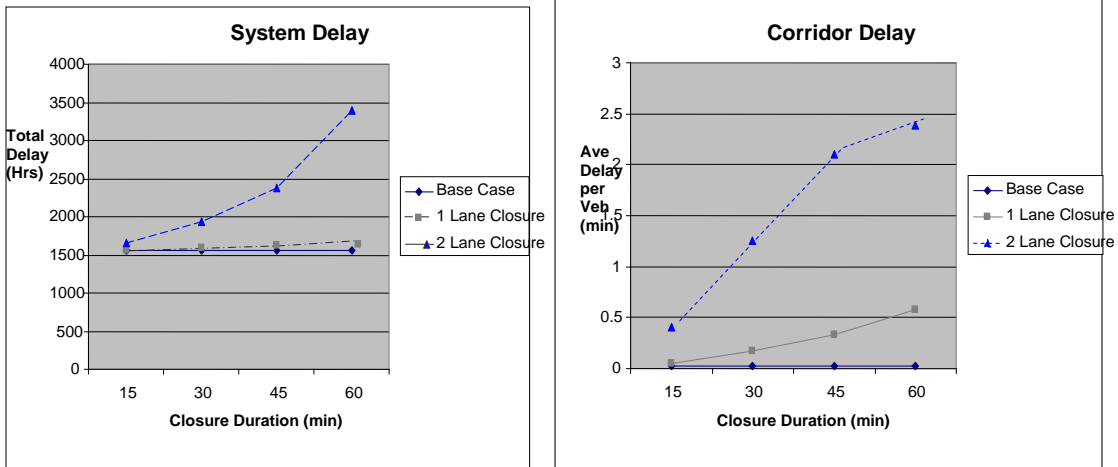


Figure 3-7. One-lane vs. two-lane closure with existing signal timing plan.

For the one-lane closure, the maximum delay for a one-hour one-lane closure along the corridor is 0.58 minutes per vehicle, which indicates that the McFarland corridor offers considerable capacity with existing signal timings. However, the operational condition severely decreases in the case of a two-lane closure. This condition replicates the true scenario of oversaturation along McFarland corridor. Since the study scope is congested conditions, the one-lane closure is disregarded in further analysis and the emphasis is placed on the analysis of the two-lane closures.

Existing vs. Optimized Signal Plan for Two-Lane Closure

The graphs in Figure 3-8 show the changes in delay patterns on both the system and the corridor with the optimal and existing signal plans under a two-lane closure assumption.

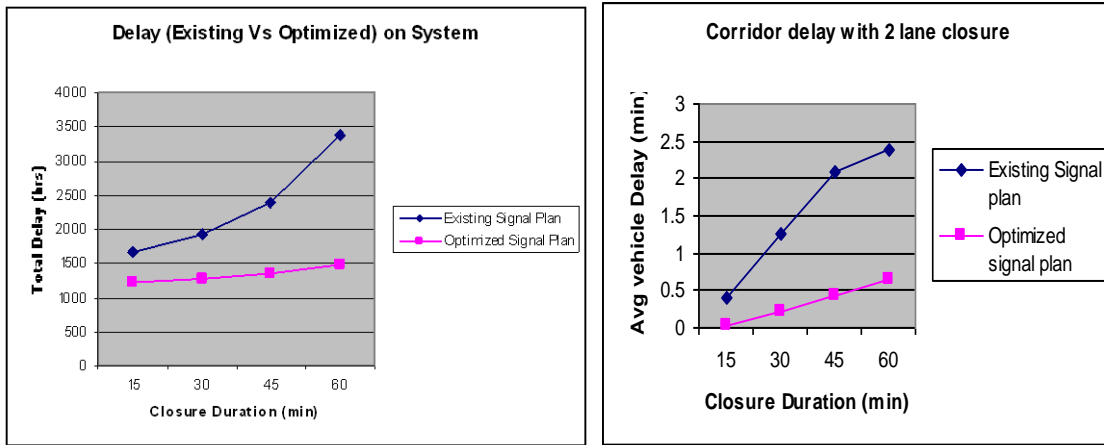


Figure 3-8. Delay comparison for existing and optimized signal plan.

Signal optimization results was compared with the results before optimization for both system and corridor performance. It is apparent from the above graphs that a considerable decrease in

the delay can be experienced through signal optimization along McFarland Blvd. This indicates that it is an effective technique to handle oversaturated conditions along the corridor in the event of recurrent or non-recurrent traffic congestion.

DTA vs. Optimized Signal Plan for Two-Lane Closure

Figure 3-9 shows a comparison of delay in the system and corridor with DTA (existing signal plan) and optimized signal plan for the two-lane closure oversaturation condition.

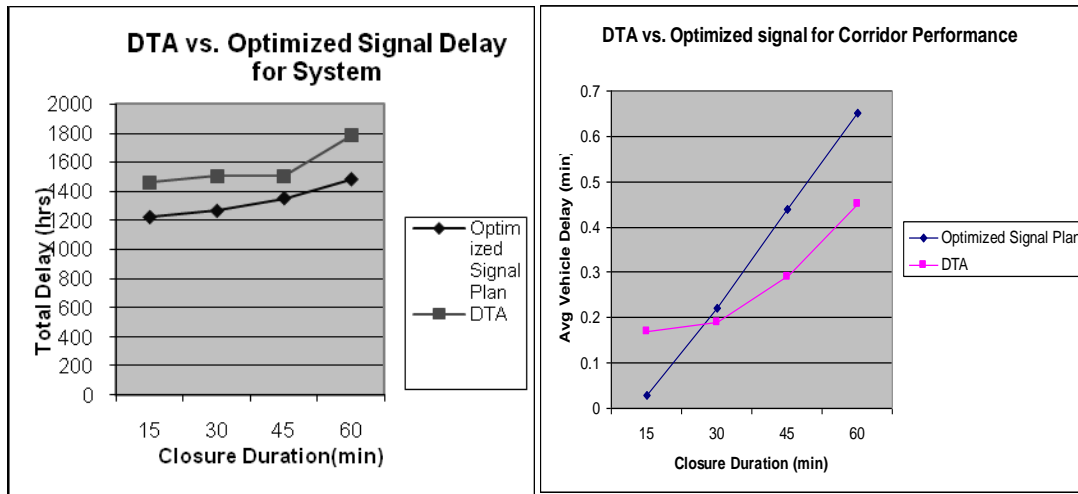


Figure 3-9. Delay comparison for DTA and optimized signal plan.

It can be seen that the transportation network of the city of Tuscaloosa benefits more in terms of delay savings from signal timing optimization along McFarland Blvd., compared with the information provision. On the other hand, corridor performance shows mixed results based on the severity of the closure. For a short closure duration the optimization option results in less delay, whereas the delay decreases with DTA for a closure duration of more than 30 minutes. This is because the drivers are aware of the severity of the closure duration and some of the vehicles are diverted to other routes to avoid the delay caused by the closure or oversaturation generated in the corridor.

Increased Demand Case – Existing vs. Optimized Signal Plan

Figure 3-10 shows a comparison of total and average delay obtained from the system and corridor analysis, respectively, under increased demand conditions with and without signal optimization.

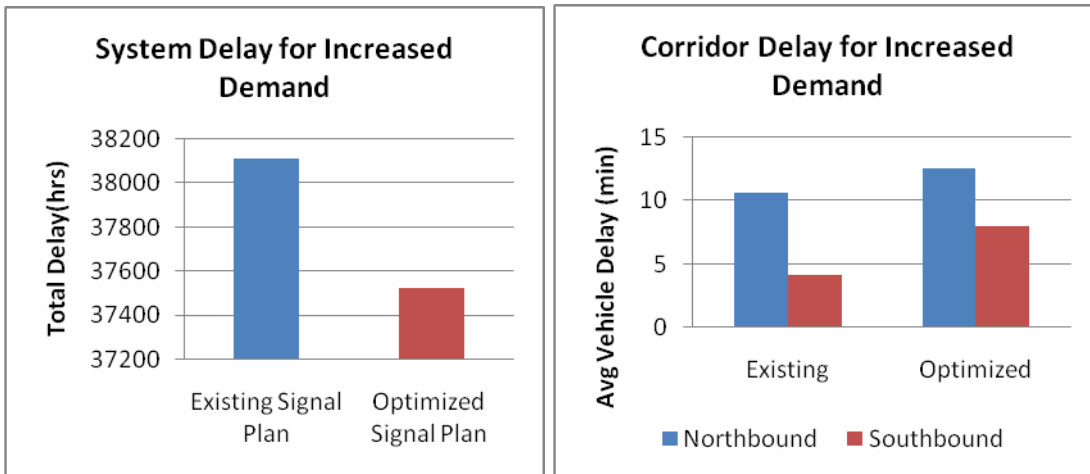


Figure 3-10. System and corridor delay for increased demand case.

The signal optimization process shows both positive and negative results. The overall effect of optimization on the network was positive, as it led to a reduction in total delay of 575 hours. However, the impact of signal optimization on corridor performance is not desirable. It is clear from Figure 3-10 that delays along the corridor increase in both directions along McFarland Blvd. as a result of the increased demand coupled with signal timing optimization. This is because the increase in the demand is assumed in the entire transportation system of the City of Tuscaloosa. As a result, the cross streets along the McFarland corridor get more traffic and thus are assigned more green time at the expense of McFarland Blvd. during the signal optimization process.

Increased Demand Case – VMS Design with Optimized Signal Case

Figure 3-11 shows that there is a very small effect of VMS on the performance of both the McFarland corridor and the city of Tuscaloosa transportation system, reducing system delay by

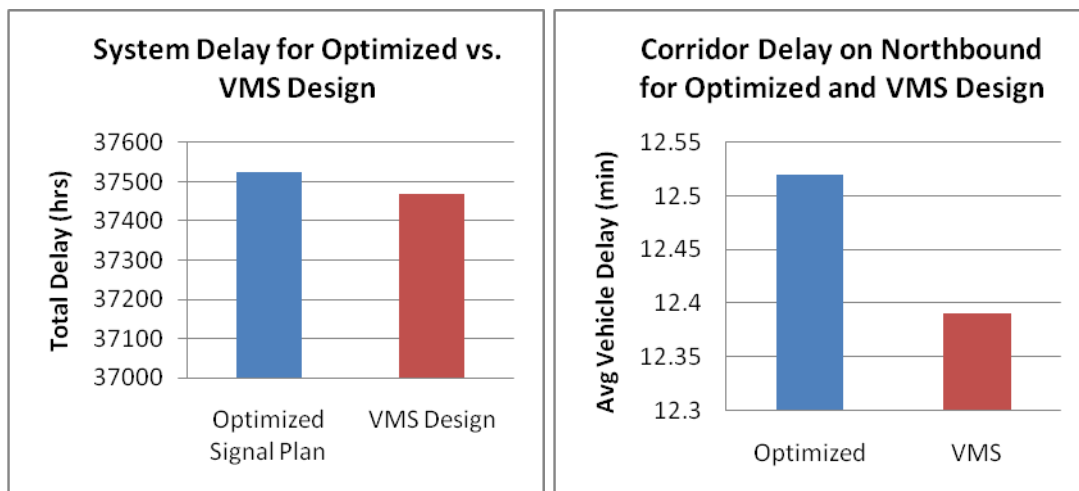


Figure 3-11. Delay for VMS design on system and northbound corridor.

just over 50 hours and average vehicle delay by 0.13 minutes on the northbound of McFarland corridor. These results indicate that the added benefit of VMS will have a minor impact on traffic operations, if the transportation system can achieve DTA successfully. The results show that drivers in the network already optimized their routes according to network conditions, thereby reducing the effect of VMS installed in the network. There is also no major parallel route with sufficient capacity, so the DTA process cannot effectively divert any more traffic onto parallel routes.

Conclusions

This study simulates oversaturated traffic conditions along McFarland Blvd. in the city of Tuscaloosa, AL, through capacity restriction and demand increase. The results obtained from the simulation modeling and analysis presented in this study lead to the following conclusions:

- The VISTA simulation/optimization environment can be used by various transportation agencies for different planning and transportation management purposes, including congestion mitigation, incident management, construction management, signal optimization, and signal preemption.
- The transportation network of city of Tuscaloosa has a large residual capacity available; the network is still sensitive to severe oversaturation along the corridor.
- It is apparent from the study that dynamic traffic assignment could be an appropriate tool in controlling and mitigating congestion in the Tuscaloosa transportation network.
- The existing signal timing on McFarland Blvd. performs well under normal conditions and minor incidents; however, where the corridor is experiencing non-recurring congestion, optimized signal timing plans are recommended to mitigate the congestion.
- Sensitivity analysis should be performed while performing signal optimization for overall network oversaturation. The results show that signal optimization along the corridor for network oversaturation is negative in terms of delay on the corridor but provides positive impact overall on the system.
- VMS has little impact on McFarland corridor and the transportation network of Tuscaloosa in case of entire system oversaturation; however, some benefits in both corridor performance and system performance can be achieved by the use of VMS.

Recommendations

Based on the findings, the following recommendations are offered for future research:

- The availability of actual control data is limited. The actual control data for 10 intersections along McFarland Blvd. are incorporated in the model. Better results are expected if actual control parameters are included for all major signalized intersections in the study network.

- The increased demand scenario that replicates special event conditions can become more realistic by incorporating actual demand profiles that better reflect the variations in traffic demand during special events.
- The VISTA simulation model also does not directly accept the lead-lag phase inputs. Hence, a split in phase was done to incorporate the lead-lag phase while inputting control data on network. While this is still a viable approach, a potential change in VISTA code could address the modeling of this phasing scheme in future studies.
- VISTA has a unique capacity for signal timing optimization and signal warrant at unsignalized intersection but has limited capabilities to model actuated signals. Incorporation of this feature into VISTA is desirable for future research.
- VISTA can easily incorporate the TRANPLAN file. However, some difficulty was experienced while interfacing VISTA with SYNCHRO network. Further work is needed to address this interface problem in the future.

Section 3.0 Appendix

Simulation Model Overview

This appendix provides general information about the types of simulation models commonly associated with transportation simulation, especially as associated with arterial traffic systems and traffic signal systems. This includes a brief overview of

Definition of Traffic Simulation Models

The literature review provides a number of definitions for traffic simulation models. Simulation can be defined as a controlled statistical sampling technique that is used to obtain approximate answers to questions about complex probabilistic models using mathematical formulation. The *HCM* presents the definition as “a computer program that uses mathematical models to conduct experiments with traffic events on a transportation facility or system over extended periods of time” (ITE, 2004). Generally these simulation models are designed to replicate the behavior of the traffic system and integrate these behaviors to obtain highly detailed description of system performance in terms of qualitative measures (*HCM*, 2000). The measure of effectiveness (MOE) could be travel time, intersection delay, fuel consumption, level of service (LOS), etc. The simulation models considered for the appropriate model selection for this study are Highway Capacity Software (HCS+), Corridor Simulation (CORSIM), Synchro, Advanced Interactive Microscopic Simulation for Urban and non-urban Networks (AIMSUN), VISTA, and other DTA-based simulation models.

Simulation Advantages

Simulation can analyze the traffic conditions better than conventional mathematical procedures. Some of the major advantages of using simulation models are as follows:

- Simulation models can model the entire street network or facility and observe the effects on an entire system in a controlled environment of a change in some parameters in one part of the network (Rathi, et al. 1992).
- Simulation models allow for the testing and evaluation of alternative design and control options without the disruption of traffic.
- Simulation models offer the potential to model queuing phenomena in case of congestion (ITE, 2004).
- Simulation models exhibit the ability to model all kinds of geometrics and control characteristics, such as signal preemption, roundabouts, and pedestrians (ITE, 2004).

- Animation abilities of simulation models can provide real-time movements, which enables non-technical people to understand the scenarios and the consequences of changes in traffic parameters (ITE, 2004).
- Simulation models are capable of modeling unusual arrival and service patterns that do not follow traditional mathematical distribution (ITE, 2004).

Simulation Reservations

Despite all the advantages that simulation models possess, some reservations still remain with respect to their use for analysis. They include the following:

- Simulation is the representation of the reality, the accuracy of which depends on the complexity of the model and the accuracy of the assumptions made.
- It may not be worth it to try to perform simple analysis by a simulation model when it can be done easily with a mathematical computational process.
- Simulation models are more data intensive, and the quality of input data correlates with the value of output data (ITE, 2004).
- Many simulation models provide default values for user convenience. However, it is of great importance for the models to be verified by calibration and validation. If these things are overlooked the models output may have substantial errors (Rathi, et al. 1992).
- Determination of a simulation model's accuracy is a complex task because different simulation models can provide different results for the same data input and consistency between results (ITE, 2004).
- Treatment of simulation models as “black boxes” is a common practice that is risky and should be avoided.

Simulation Types

According to the level of detail in which simulation models represent the traffic system, they can be classified in the following three categories (*HCM*, 2000):

- *Microscopic* simulation presents all system characteristics and the interactions between them in very high level of detail. In such models, the characteristics of each individual vehicle can be traced and their time-space trajectories plotted. In doing so, behavioral models describing acceleration, deceleration, lane changing, merging, passing maneuvers, turning movement execution, gap acceptance, etc., are employed.
- *Macroscopic* simulation presents the overall characteristics of traffic in an aggregate manner. Such models focus on traffic stream characteristics rather than individual vehicles. Generally macroscopic models use flow rates, average delays, and other general descriptors to represent traffic conditions.
- *Mesoscopic* simulation contains some of the characteristics of both microscopic as well as macroscopic models. Generally these models depict the movement of clusters or platoons of vehicles. These models use suitable assumptions and equations to model the interaction between clusters or platoons.

Concept of Traffic Assignment

Traffic Assignment is the fourth step of the traditional four-step travel demand forecasting models. The major purpose of this process is to determine the number of vehicles that use a specific highway or route. Traditionally, this is done by algorithms that determine and assign trips to specified paths to accommodate travel from zone i to zone j using mode m , subjected to some specified optimization criteria of equilibrium. Among these commonly used equilibrium criteria are user equilibrium (UE), system optimal (SO) or stochastic equilibrium.

Static Traffic Assignment

Static traffic assignment (STA) is a conventional traffic assignment procedure used to determine the routes taken by transportation system users in order to estimate present and future traffic condition on existing or proposed roadways. STA models work on the principle that link flows and link trips remain unchanged over the planning horizon of interest, including that of the peak period. Then a matrix of steady-state origin-destination (O-D) trip rates is assigned to network links, resulting in a link flow pattern that is intended to replicate the peak period flow (Peeta, 1994). This traditional STA is based on various methods, such as all-or-nothing, incremental, volume averaging or capacity restrained approaches (Sisiopiku, et al. 2007).

STA can reasonably predict the volume of traffic for long-term planning purposes. Although this approach is widely used, problems arise when STA is employed for traffic assignment on congested networks. The formulation of STA fails to properly account for the features of traffic congestion (Peeta, 1994). The most prominent shortcoming of STA is its inherent static analysis perspective, which fails to capture the actual dynamics of real-time routing behavior. Especially in peak hours, assumptions of STA regarding external demand inputs do not replicate reality as well as the demand of highly dynamic incident conditions (Sisiopiku, et al. 2007).

The major shortcomings of STA in addressing real-time traffic conditions in oversaturated conditions can be highlighted as follows (Peeta, 1994):

- STA is only realistic for uncongested arterial networks. Because it uses a volume-delay curve to represent congestion that does not incorporate intersection delay. It particularly focuses on link delay, based on trip time and prevailing link flow. This assumption of STA fails to replicate the reality of traffic behavior at high demand conditions and is not able to indicate the location and extent of queue and bottlenecks and delays associated with them, STA is not particularly applicable to peak hour or incident conditions where such phenomenon is usual.
- STA cannot depict the effect of ITS devices on travel behavior. In other words, it has no capability to predict user response due to real-time information or route guidance information such as VMS. Hence it is not able to consider different management strategies, such as, advance traveler information system (ATIS) and advance traffic management system (ATMS).

Dynamic Traffic Assignment

DTA is an evolving concept in the field of transportation engineering and planning. DTA is considered to be a solution to the unrealistic assumptions and shortcomings of STA. Further, the capabilities of DTA to model ITS technologies and evaluate the effects of such systems on traveler choices make it a better choice than other traditional models.

DTA models are able to compute the spatio-temporal variation of traffic flow and realistically model the real-time routing behavior of drivers. Due to this feature, DTA is considered to be closer to reality and can replicate the true dynamics of traffic under congested conditions far better than STA. On the other hand, DTA involves more complex formulations and more intensive data requirements than those traditionally used in STA models. With the ability to model ITS technologies as well as real-time driver routing behavior, DTA can be an appropriate tool in handling oversaturated transportation networks.

Commonly Used Traffic Analysis Tools

Highway Capacity Software

HCS+ was developed by the McTrans group and is based on the concept and methodologies provided in *The Highway Capacity Manual, 2000*. HCS+ is computational software, so unlike other stochastic traffic simulation software, it provides consistent output for a given set of data.

Some of the features of HCS+ are as follows:

- HCS+ directly employs *HCM* procedure and methodologies for computational purposes, and consistency in results is expected.
- It has the capabilities to model all kinds of transportation facilities, including signalized and unsignalized intersections, freeways, multi-lane highways, and arterials.
- It can also model the complex phenomenon of weaving and merging.
- HCS+ is best in simple modeling and capacity and level of service analysis.
- HCS+ is user-friendly software with a simple interface and very fast computational time.

Some of the major limitations of HCS+ are as follows:

- HCS+ is not able to analyze the components of a network when the volume-to-capacity ratio is above one, so it has no capabilities to model for oversaturated conditions.
- HCS+ can only compute the operational measures for a given set of conditions but is not able to introduce randomness as other stochastic simulation packages do.
- HCS+ can analyze the signal settings but has very limited capabilities with respect to signal optimization.

CORSIM

CORSIM is a link node network simulation model developed and maintained by the Federal Highway Administration (FHWA). It is the most widely used simulation program in the United States as well as other countries. This simulation program is the part of the Traffic Software Integrated System (TSIS). CORSIM is a microscopic simulation model that takes into account common characteristics of vehicle and driver behavior to simulate existing and proposed conditions of traffic and control systems. Development of the CORSIM model logic started in the 1970s through the element of two separate programs called NETSIM (for surface streets) and FRESIM (for freeways). Recently these two simulation programs were combined to form single simulation program of CORSIM (Benekohal, et al. 2001).

CORSIM offers very high level modeling features and is used extensively in traffic engineering and modeling processes. It is ubiquitously accepted that CORSIM has specific strengths in the following areas (Sisiopiku, et al. 2004):

- CORSIM can simulate all kinds of geometry possible in the transportation network. It can model combinations of through streets with turning pockets and multi-lane freeway segments with on-ramps and off-ramps. Similarly, all kinds of geometries, including lane-drop and lane-add, can be modeled.
- CORSIM can also simulate various kinds of traffic conditions ranging from very low and moderate demand to very congested traffic conditions. It has the simulation capabilities of incident queue build up to recovery to normalcy.
- CORSIM can simulate nearly all traffic control conditions ranging from simple stop, and yield control to complicated traffic signals and ramp metering. It also can simulate other management strategies, such as high occupancy vehicle (HOV) operations.
- CORSIM has the ability to interface with external logic and programs and two way data exchange via an interface that operates in real time. This feature of CORSIM can be used in evaluating ITS technologies.
- In CORSIM, input data such as geometrics, volume and pattern, surveillance and detecting devices, engineering criteria, run control and output requirements are stored in record types (RTs). This approach provides some ability to model time-varying traffic and control conditions over a period of time.

Although CORSIM is a highly accepted simulation model, it possesses several limitations, including those in the following list:

- CORSIM can model the effects of signal presence and signal coordination; however, it has limited capabilities in terms of signal optimization.
- CORSIM cannot be used in the assessment of strategies of such ITS technologies as VMS signs.
- The model has limited capabilities in terms of DTA. Although dynamic demand can be inputted in CORSIM, the program cannot replicate the true dynamics of demand in congested networks.

- CORSIM also possesses limited capability to model non-motorized facilities as well as perform parking studies.

Synchro

Synchro is traffic modeling and optimization software developed by Trafficware, Inc. It is a macroscopic traffic simulation program that is particularly designed for capacity analysis of signalized intersections based on the procedure specified in *HCM 2000*. Synchro is a Windows-based simulation program, and its user-friendly interface makes it very popular among the users (Benekohal, et al. 2001).

Some of the major features of Synchro simulation are as follows:

- Synchro allows detailed capacity analysis for signalized intersections. It can completely implement the *HCM 2000* procedure for signalized intersections.
- Synchro can generate optimal signal timing plans according to coordination of signals and hence minimize delays on corridors.
- Synchro is one of the few pieces of interactive simulation software with the ability to model actuated signals. It can model skipping and gap-out behavior and apply such information to delay modeling.
- Synchro provides colorful and informative time-space diagrams and allows the user to adjust splits and offsets directly from those diagrams.
- Synchro provides high-level integration with other modeling software packages like SimTraffic, CORSIM, and HCS+. The Synchro network can be exported to these programs to perform further analysis.

Synchro possesses detailed capabilities with respect to analysis of signalized intersections; however, it still has several limitations. They include the following:

- Synchro assumes that traffic is generated at intersections and is not dependent on O-D pairs for traffic generation, therefore, complete travel patterns cannot be modeled using this model.
- Synchro provides MOEs for signalized intersections only. It is not desirable to use this model to find the MOEs at intermediate points between intersections.
- Synchro does not possess the capabilities to model stop-yield control.
- Synchro cannot differentiate between different classes of vehicles.

AIMSUN

AIMSUN is a microscopic simulation model developed at the Department of Statistics and Operational Research in Barcelona, Spain. It can deal with any kind of network extending from freeways, multilane highways, urban networks, non-urban networks, or any combination of these. AIMSUN is an integral part of the GETRAM (Generic Algorithm for Traffic Analysis and Modeling) simulation environment along with the Traffic network Editor (TED) (Xiao, et al. 2005).

Some of the main features of AIMSUN simulation model are highlighted below:

- AIMSUN provides very precise capabilities of modeling traffic conditions. It has the ability to differentiate and classify different vehicle types.
- AIMSUN can model traffic demands based on traffic flow and turning movement ratios as well as O-D matrices with route selection models.
- AIMSUN can model almost every kind of traffic control from fixed time control to actuated control and some adaptive control through the use of the extension application.
- AIMSUN also has the capabilities to model the impact of VMS on traffic operation as well as incident conditions.
- AIMSUN provides dynamic traffic assignment capabilities to some extent. Hence it has features to model the real-time routing behavior of every vehicle and can model the decision change of every driver before and during the trip.

Apart from all of these features, AIMSUN has the following limitations:

- AIMSUN cannot give priority to public transportation vehicles, so, it cannot model transit systems in detail.
- AIMSUN is highly data intensive compared to other similar simulation models, and coding a network in AIMSUN is a very tedious and time-consuming process.

VISTA and Other DTA-Based Simulation Models

VISTA is a micro/mesoscopic traffic simulation. VISTA is relatively new software with multiple features that was developed at Northwestern University. VISTA is a planning model but can be used efficiently for traffic engineering operational analysis. VISTA possesses the ability of dynamic traffic assignment and is capable of modeling ITS technologies, features that make this model very attractive in simulating transportation systems. Some of the major features of VISTA are as follows:

- VISTA uses dynamic traffic assignment capabilities to realistically model the traveler's routing behavior.
- VISTA uses spatial Geographic Information System (GIS) database which can easily interface with other inputs.
- VISTA runs through Internet/Intranet, providing access to multiple users at a time to run the model, query, and change database.
- VISTA bridges between microscopic and mesoscopic models by using meso/microscopic simulator.
- VISTA is capable of modeling the effect of ITS technologies such as Variable Message Signs (VMS).
- VISTA is highly flexible in terms of network size. There is no limitation on the transportation network size, a feature that allows great flexibility.

Besides VISTA, there are other DTA-based simulation models that are in current practice. Of these DTA simulation models, DynaMIT and DYNASMART are popular among users. DynaMIT is developed at Massachusetts Institute of Technology with the support of FHWA, whereas DYNASMART is developed at the University of Texas at Austin. A recent study by Sisiopiku and Li (2006) provides a comparison between DynaMIT, DYNASMART, and VISTA which is summarized in Table 3-18.

Table 3-18. Comparison of DTA-Based Simulation Models (Mouskos, et al. 2006)

Models	DynaMIT	DYNASMART	VISTA
Approach	<ul style="list-style-type: none"> • Heuristic • User equilibrium • Mesoscopic, moving queuing segments • Kalman Filtering methodology • 	<ul style="list-style-type: none"> • Heuristic • User equilibrium and system optimal • OD assignment • Mesoscopic, moving queuing segments • Greenshield-type speed-density relationships 	<ul style="list-style-type: none"> • Exact and heuristic • User equilibrium and system optimal • OD assignment • Mesoscopic • Cell transmission model
Impacts That Can Be Evaluated	<ul style="list-style-type: none"> • Short term infrastructure and operational changes; limited area coverage 	<ul style="list-style-type: none"> • Short-term, long term infrastructure and operational changes; no limitation on area coverage 	<ul style="list-style-type: none"> • Short-term, long term infrastructure and operational changes; no limitation on area coverage
Input Data Required	<ul style="list-style-type: none"> • Geometry, control and demand data inputs • Demand tables need to be arrival and/or departure time based • Text editor to modify input data 	<ul style="list-style-type: none"> • OD trip table, link traffic flows, traffic control and detailed geometry 	<ul style="list-style-type: none"> • OD trip table, link traffic flows, traffic control and detailed geometry • Networks must be created through either the VISTA client or through PSQL with nodes and links • Can define controls, streets, zones, Variable Message Sign positions etc.
Direct Output	<ul style="list-style-type: none"> • Individual vehicle trajectories 	<ul style="list-style-type: none"> • Link occupied by each vehicle at each time step 	<ul style="list-style-type: none"> • Cell occupied by each vehicle at each time step • Vehicle path and travel time
Ease Of Use	<ul style="list-style-type: none"> • Not so easy to implement and use, still at the research community level 	<ul style="list-style-type: none"> • Not so easy to implement and use, still at the research community level 	<ul style="list-style-type: none"> • Moderate training required • Software ready • Web-based
Time Step	<ul style="list-style-type: none"> • 60 sec 	<ul style="list-style-type: none"> • ≥ 6 sec 	<ul style="list-style-type: none"> • 2-6 sec
Quality Of Graphics	<ul style="list-style-type: none"> • Low 	<ul style="list-style-type: none"> • Low 	<ul style="list-style-type: none"> • Medium
Network Size	<ul style="list-style-type: none"> • Medium size 	<ul style="list-style-type: none"> • Medium to large size 	<ul style="list-style-type: none"> • Large to very large size networks; networks with 40,000 nodes developed
Calibration Required	<ul style="list-style-type: none"> • Demand and supply simulators calibration 	<ul style="list-style-type: none"> • Traffic flows and travel time distributions 	<ul style="list-style-type: none"> • Traffic flows and travel time distributions
Strengths	<ul style="list-style-type: none"> • Interfaces with real world • Demand and supply calibration 	<ul style="list-style-type: none"> • Bus movement included • Requires less calibration 	<ul style="list-style-type: none"> • Bus movement included • Requires less calibration
Weaknesses	<ul style="list-style-type: none"> • Computation performance to be tested • Interface is not very user friendly • Bus/transit/background not modeled • Travel time is the only link impedance modeled 	<ul style="list-style-type: none"> • Computation performance remains to be tested • Not modular • Mode and departure time assumed given 	<ul style="list-style-type: none"> • Cannot precisely detect vehicle stops • Less emphasis on driver behavior

4.0 Cell Transmission Model Based Traffic Signal Timing In Oversaturated Conditions

Introduction

Oversaturation occurs when signal networks cannot process all arrivals at the end of the green time. Queues are developed and carried over to the next green time. As the queues grow they may cause blockage and delay at other intersections.

Traffic signal timing plays an important role in dealing with oversaturated conditions. However, comprehensive guidelines are not yet available for the design of traffic signal timing plans to handle oversaturated conditions. The reasons lie in three issues. First, it is difficult to model traffic flow in oversaturated conditions, since queue spillback is likely to appear when the system is oversaturated. When green times for some approaches are not sufficient to process traffic demand, queue spillback to upstream intersections is common in heavily loaded networks, especially when intersections are closely spaced (Chow, et al. 2007). The traffic queue at a downstream intersection may spill back to an upstream intersection. The consequence of this will influence the outflow from the upstream intersection, and in turn the inflow to the downstream intersection. Sometimes, turning movements are blocked by extended queues. Two spillback situations for left-turns are used as an example in Figure 4-1.

- Overflow of left turn vehicles blocks the through lane entrance.
- Overflow of through vehicles blocks the left turn entrance.

For both situations, all flow is restricted if either the left turn lane or through lane is unable to accommodate its allocation of flow (Kikuchi, et al. 2007). The cell transmission model (CTM) can capture this by using cells, which are the building blocks of CTM and represent homogeneous segments of the traffic network. So a vehicle that cannot exit its “cell” will prevent the movement of all vehicles behind it. A model is needed to capture such phenomena.

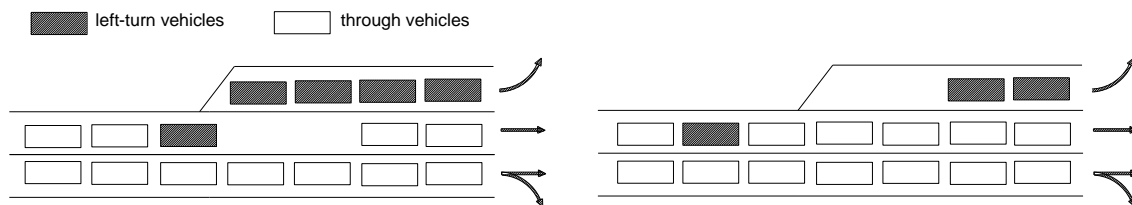


Figure 4-1. Overflow blocks lane entrance.

Second, oversaturated flow conditions are not steady state. At any time that traffic demands are more than the system can provide, conditions are a function of traffic arrival/departure and signal

control during a time period (signal cycle), plus the conditions of the previous time. So in oversaturation, the signal control scheme should account for conditions during the previous cycle as well as conditions during the current cycle. The problem is much more complicated than steady state conditions where usually one cycle is optimized and then repeated over the entire period.

Third, an efficient optimization tool for traffic signal timing is not yet available. Oversaturated conditions need time-dependent traffic signal timing, which can be computationally demanding.

The three issues above make traffic control for oversaturation conditions more complex and difficult than normal conditions. Therefore, representation of traffic flow, dynamic signal plans and an optimization tool are three ingredients to handle oversaturation. The objective of this paper is to develop an approach to represent traffic flow in oversaturation conditions and to search for a dynamic traffic signal timing to minimize the delay.

Literature Review

Existing Research for Oversaturation

Two valuable studies on signal timing for oversaturated networks were performed by Abu-Lebdeh (Abu-Lebdeh, et al. 2000) and Lieberman (Lieberman, et al. 2000). Abu-lebdeh's method produces real time signal timings that manage the formation and dissipation of queues, and it considers current and projected queue lengths. In this method, different priorities are assigned to arterial and cross street traffic flows for a given queue management strategy. He considered the prevention of de facto red to be the selected strategy of queue management. The computation of green time at intersections depends on the green phase at downstream intersections. The objective function consists of two terms, i.e., a control algorithm that maximizes the number of vehicles processed by the signal network, and a disutility function that specifies the relative importance of an arterial and cross streets for a given strategy of queue management. This research is limited to single arterials as well as a simple two phase signal timing without turning movements. Although the simplistic nature of this research limits its applicability, expanding the concept to signal systems of complex intersections and extensive turning movements could make a breakthrough.

Lieberman (Lieberman, et al. 2000) utilized the concept of maintaining the growth of queues on every saturated approach. Signal coordination was designed to meet the objectives of maximizing traffic throughput, fully using storage capacity and providing an equitable service for major and cross street traffic. A mixed integer linear program tableau is formulated to yield optimal values of signal offsets and queue length for each approach. The notion of modifying traffic density to the optimum level is not included.

Existing Traffic Signal Optimization Software

The most popular traffic signal optimization software models are TRANSYT and Synchro. TRANSYT is a macroscopic optimization and simulation tool developed in the United Kingdom. TRANSYT-7F is the US version of TRANSYT developed by the University of Florida. TRANSYT-7F uses a disutility index as the objective function to optimize. TRANSYT-7F measures delay by periodically counting the number of vehicles queued at a signal and integrating counts over time. Uniform and residual delays are computed based on the area under the uniform queue profile. Increment delay is computed by using the *HCM* equation. Although TRANSYT 7F has been modified to deal with congested conditions, it was developed for undersaturated conditions. So it still is not an ideal method to handle the oversaturated condition.

Synchro optimizes traffic signal timings by minimizing a parameter called percentile delay. The percentile delay is the weighted average of a delay corresponding to the 10th, 30th, 50th, 70th, and 90th percentile volumes. Synchro uses a quasi-exhaustive search in offset optimization.

None of the existing traffic signal timing software models considers the fundamental flow-density relationship. Nor are they otherwise configured to handle oversaturated flow.

Optimization Tool for This Portion of the Project

Genetic Algorithms (GA) have previously been applied in traffic signal timing as an optimization tool. Park (Park, et al. 2000) developed a procedure that uses GA to optimize all traffic control parameters simultaneously, including cycle length, green split, offset, and phase sequence. Delay is used as the fitness function for the optimization process. In his case study, GA was implemented at two closely-spaced signalized intersections within 100 meters of each other. The GA optimizer generated 250 generations with a population size of 10 per generation, a crossover probability of 0.4 and a mutation probability of 0.03. An elitist method was used for the GA selection process. Three different demand volume levels were tested: low, medium and high demands. The results indicate that the GA optimizer works better than TRANSYT-7F for this two-signal test case, as evaluated by a CORSIM simulation program.

Enhancements were then provided to a previously developed GA for traffic signal optimization for oversaturated traffic conditions. Three different optimization strategies (throughput maximization, average delay minimization, and modified average delay minimization with a penalty function) and different intersection spacing (100, 200, and 300 meters) were tested. An arbitrary arterial system consisting of four intersections was selected in order to test the GA based program. Of the three objective functions, the delay minimization strategy is applicable to both undersaturated and oversaturated conditions. The GA based program and TRANSYT-7F timing plans were compared in terms of queue time, and GA generated less queue time.

Abu-Lebdeh (Abu-Lebdeh, et al. 2000) presented a dynamic traffic signal control algorithm (DSCA) to optimize traffic signal control and queue management for oversaturated arterials. DSCA is a vary-varying dynamical system optimized using micro-Genetic Algorithms. They

were shown to converge to near optimal solutions within a very short time, making them available for use on line. The solutions varied with changes in the values of the genetic parameters and with the type of genetic operators.

Chow and Lo (Chow, et al. 2007) presented a novel sensitivity analysis of signal control with physical queues. They derived a set of travel delay derivatives with respect to the signal control elements. The contribution of these derivatives is that they explicitly take the effects of physical queuing into account, including queue spillback and blockage. They developed a derivative based heuristic algorithm for dynamic traffic control.

Girianna and Benekohal (Girianna, et al. 2002) developed an algorithm to design signal coordination for networks with oversaturated intersections. The basic concept of signal coordination applied to oversaturated single arterials was extended for a grid network of arterials, which involves greater analytical and computing complexity. In this algorithm, signal coordination was formulated as a dynamic optimization problem. The micro-genetic algorithm was used to solve the signal optimization problem.

Although this literature review showed that GA optimization has made advancements in the methodology of traffic signal timing in oversaturated conditions, there are no known GA models that can handle more than a small signal system and there are none in popular use. For the research discussed in this project, GA is being used for optimization purposes for the CTM modeling approach.

Methodology

CTM is a simplified macroscopic model that describes the movement of traffic flow over time and space by dividing the transportation network into homogeneous cells.

It is known that for convenience, CTM assumes several constant parameters that may not capture the random variations in traffic flow and consequently cannot lead to a precise estimation of performance of a traffic network (Alecsandru, et al. 2007). Hence, this research attempted to enhance the original form of CTM to increase its accuracy of traffic flow representation. The enhanced cell transmission model will accurately simulate traffic flow in oversaturated conditions and search for an optimal traffic signal timing plan using GAs.

The proposed methodology overcomes several issues in oversaturated conditions. First, the proposed version of CTM will automatically accommodate all traffic conditions from light flow to oversaturation and can capture all phenomena such as queue spillback and left turn blockage which often appears when the system is oversaturated. Second, because flow conditions are not steady state, queues that develop at intersections during a green time cannot be eliminated in one signal cycle and are carried over to the next cycle. The proposed methodology will provide a dynamic signal plan to adjust to the change in traffic demand and signal capacity during different cycles. Third, oversaturated conditions require time-dependent traffic signal timing and a fast-computing capability server. Genetic algorithms are powerful optimization tools to handle

multiple parameters. They can converge to near optimal solutions within a short time such that their implementation for time-dependent traffic is possible. The accommodation of the proposed methodology for oversaturated conditions is shown in Figure 4-2.

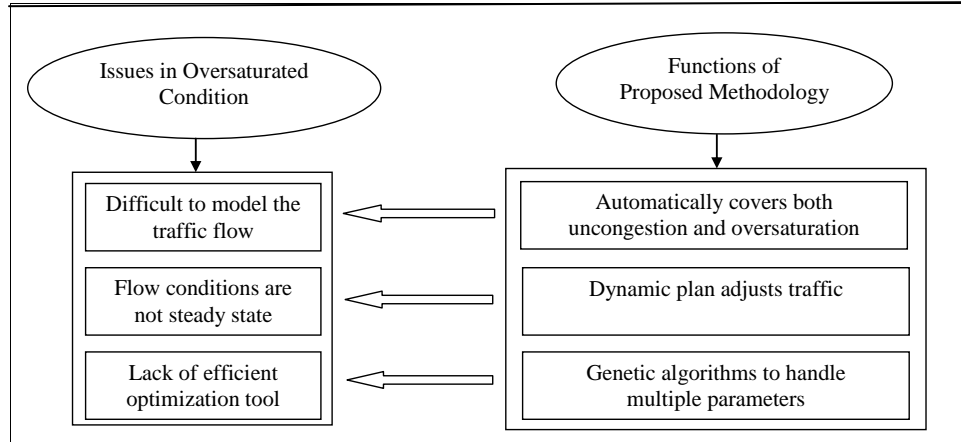


Figure 4-2. Relationship between oversaturated condition and proposed methodology.

Cell Transmission Model

The Lighthill and Whitham and Richard (LWR) model can be stated by the following two conditions:

$$\frac{\partial f}{\partial x} + \frac{\partial k}{\partial t} = 0 \text{ and } f = F(k, x, t) \quad \text{Equation 4-1}$$

- Where, f = traffic flow;
- k = density;
- x = space variable;
- t = time variable;
- F = function relating f and k .

Daganzo (Daganzo, 1994) simplified the solution by adopting the following relationship between traffic flow, f , and density k , which he called the CTM.

$$f = \min \{ kV, Q, W(k_{jam} - k) \} \quad \text{Equation 4-2}$$

- Where, k_{jam} = jam density;
- Q = inflow capacity;
- V = free flow speed;
- W = speed of backward shock wave.

CTM assumes that the network can be divided into a set of equal length cells. The length of each cell is equal to the distance that a single vehicle travels in one time step at the free flow speed. When there is no congestion, a vehicle would travel from one cell to another at each time step. If

there is congestion, a vehicle cannot travel to the next cell and would stay at the same cell in which delay will occur. In each time step, the number of vehicles traveling into cell i at time t is the minimum among: (a) the number of vehicles waiting to enter cell i , (b) the maximum number of vehicles that can enter cell i in a given time step, and (c) the available space in cell i (Lo, 1999). The equation follows:

$$f_i(t) = \min \{ n_{i-1}(t), Q_i(t), W/V [N_i(t) - n_i(t)] \} \quad \text{Equation 4-3}$$

Where, $n_{i-1}(t)$ = number of vehicles in cell $i-1$ at time t ;

$n_i(t)$ = the number of vehicles in cell i at time t ;

$Q_i(t)$ = the inflow capacity of cell i at time t ;

W = shock wave speed;

V = free flow speed;

$N_i(t)$ = vehicle holding capacity of cell i .

The effect of the signal timing plan on traffic flow can be represented via the inflow capacity $Q_i(t)$. If time t falls in a green time period, we set the inflow capacity of the cell to saturation flow rate. If time t falls in a red time period, we set the inflow capacity of the cell to zero. Mathematically, this can be written as:

$$Q_i(t) = \begin{cases} s & \text{if } t \in \text{green time} \\ 0 & \text{if } t \in \text{red time} \end{cases}$$

$N_i(t)$ is the vehicle holding capacity of cell i as determined by the following equation:

$$N_i(t) = k_{jam} L$$

Where, k_{jam} = jam density (veh/km);

L = the length of cell (km).

L is the product of free flow speed and the length of the time step.

$$L = V \times t$$

The network can be updated at every time step.

$$n_i(t+1) = n_i(t) + f_i(t) - f_{i+1}(t) \quad \text{Equation 4-4}$$

Where, i = Cell i ;

$n_i(t)$ = number of vehicles in cell i at time t ;

$f_i(t)$ = actual flow into cell i at time t ;

$f_{i+1}(t)$ = actual flow into cell $i+1$ at time t .

Equation 4-4 states that the number of vehicles in a cell at time $t+1$ is equal to the number of vehicles in that cell at the prior time t , plus the number of vehicles that entered and minus the number of vehicles that exited.

The equation automatically accommodates different traffic conditions from light flow to oversaturation (Lo, 2001). This is the advantage of CTM.

$$f_i(t) = \begin{cases} \min \{ r_{i-1}(t) & \text{light traffic} \\ \min \{ c_i(t) & \text{bottleneck between cells} \\ \min \{ W/V [N_i(t) - n_i(t)] & \text{oversaturated traffic} \end{cases}$$

Hence, CTM provides a simplified approximation to the hydrodynamic or kinematic wave model developed by LWR. CTM transforms the partial differential equations of LWR into simple difference equations at the cell level (Alecsandru, et al. 2007).

The original CTM is widely used because of its simplicity and relatively accurate representation of traffic flows. It assumes that all parameters including arrival rate and saturation flow rate are constant. This assumption may limit accuracy and flexibility of the model, because random variations in traffic flow play a significant role in the representation accuracy (Sherif, et al. 2006).

For instance, arrival rate is a random parameter, as the number of vehicles entering the network at each time step is different. Variations in arrival rate will affect the status of each cell and consequently affect the traffic flow performance of the whole network. Arrival rate depends on many factors and can be higher or lower than the assumed arrival rate. Random arrivals would be Poisson distributed when traffic is relatively light. For oversaturated conditions, the Normal distribution is applicable. Arrival rate in this study will be randomly generated by assuming a probability distribution for the mean arrival rate.

Saturation flow rate is another important input factor in CTM and is defined as the maximum number of vehicles per hour. Mathematically, this can be written as:

$$s = \frac{3600}{h}$$

Where, h = saturation headway, (s/veh);
 s = saturation flow rate, (veh/hr).

Saturation headway is achieved by a saturated stable moving queue of vehicles, and determines the saturation flow rate. For convenience, in CTM saturation flow rate is assumed to be constant for the whole network. However, the random behavior of drivers causes random variations in the saturation headway, which can be slightly higher or lower than the assumed headway. This can be randomly generated by using a probability distribution for the mean minimum headway.

This study uses randomly distributed saturation flow rates and arrival rates instead of average saturation flow rate and arrival rate to increase CTM's accuracy and the realism of traffic flow representation.

As mentioned above, when there is no congestion, a vehicle would travel from one cell to another at each time step. Otherwise, a vehicle cannot travel to the next cell and must stay at the same cell, occurring delay of one time step. Delay here is defined as the addition time beyond

the normal time when a vehicle travels at free flow speed and is determined by the Equation 4-5 (Lo, 2001):

$$d_i(t) = n_i(t) - f_{i+1}(t) \quad \text{Equation 4-5}$$

This equation states that the delay of cell i at time t is equal to (one model time step) \times (the number of vehicles in it minus the number of vehicles flowing into next cell $i+1$). The delay of the whole network is obtained by aggregating all cells during the time horizon.

$$\text{Delay} = \sum_t \sum_i d_i(t)$$

Genetic Algorithm (GA)

This portion of the report provides a brief review of GA, which is a widely used random search optimization method based on the mechanics of natural selection and evolution. GA works with a population of points. Each point is a possible solution with an assigned fitness value depending on how close the solution is to the expected value. This involves the following three steps:

- **Initialization.** Initialization is a way to create a pool of points. For the optimization problem in this report, we generate a population of 10 points. This means the population size is 10. Each point is a traffic signal timing plan, represented by a binary string. The length of the string depends on the desired precision. Each point will have a fitness value.

Traffic signal timing plan parameters include cycle length, phase duration and offset for each intersection. So each string has these three decision variables. Figure 4-3 illustrates the string structure for intersection i .

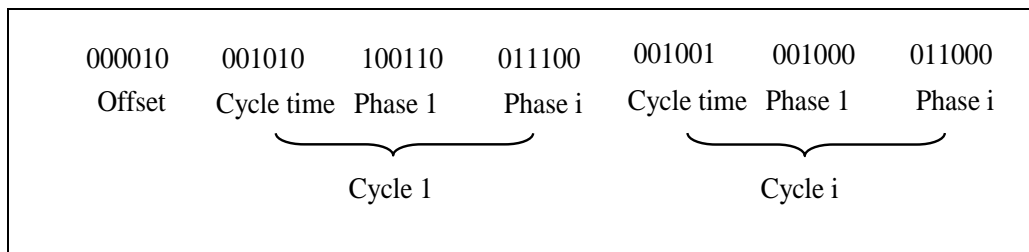


Figure 4-3. String structure for one intersection.

- **Evaluation.** To evaluate every point, i.e., each traffic signal timing plan, we give every point a fitness function. In this project, fitness function is the delay per vehicle in the network under a traffic signal timing plan. Obviously, the less the delay, the better the traffic signal plan and a higher fitness value is given to the plan.

The natural objective function is the fitness function F . If the objective is to maximize the objective function, GA works toward maximizing the objective function. But in this case, minimizing the delay function D is the objective. To overcome this, the minimization problem is transformed into a maximization problem by modifying the fitness function.

- **Generation.** A new generation is created through three operators: selection, crossover, and mutation. Points in the current generation with a higher fitness value will have more opportunities to be selected and be mated to create new points in the new generation. In the baseline, we assume that the probability of crossover is equal to 0.7, the probability of mutation is equal to 0.07, and the number of generations is 50.

To illustrate the procedure of GA, the creation of Generation 1 is shown in Figure 4-4. The same is true for the following generations.

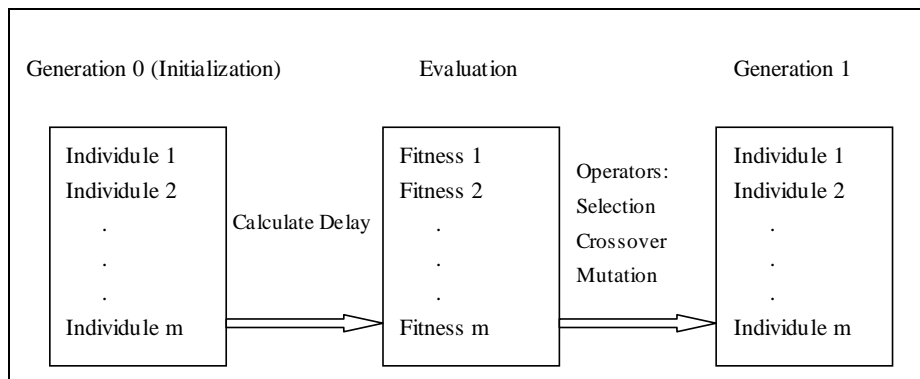


Figure 4-4. The procedure for Generation 0 to Generation 1.

Implementation

MATlab 7.0 coding was used for the proposed traffic signal timing methodology. The steps for the program coding follow:

1. Load the traffic demand to the network. Generate the arrival rate from a normal distribution.
2. Generate a signal timing plan for the network including cycle length, offset, and phase time for each intersection.
3. Simulate the traffic flow movement on the network using the enhanced CTM model step by step. Calculate each actual flow between cells at each time step t . For the cell just downstream of the signal, the capacity is set to the saturation flow rate if t falls into the green time. Otherwise, it is set to zero. For the cell at the end of network, the holding capacity is set to infinite.

4. Use enhanced CTM to update the whole network step by step. Calculate the number of vehicles in each cell at the end of each time step t .
5. Calculate delay for each cell and aggregate all cells during the time horizon. Divide the delay of whole network by the number of affected vehicles to obtain average delay per vehicle.
6. Compare the delay value with expected delay value. If it converges to the expected value, stop the program. The current signal timing plan is regarded as the optimal plan. Otherwise, go to step two to generate next signal timing plan.

Case Study

Case Description

In order to demonstrate the properties of the model and test its performance, an example is given. Although the model can be used in a larger network, the case study consists of two intersections. The parameters of this traffic network are as follows:

- Free flow speed: 50 km /h
- Backward shock wave speed: 40 km /h
- Jam density: 120 vehicles /km
- Time step: 10 s
- Minimum green and red time: 10 s
- Maximum green and red time: 40 s
- Modeling horizon: 20 time intervals
- Saturated flow rate - Saturation flow rate is obtained from saturation headway. In this study, saturation headway was drawn from a normal distribution assuming a 2 second mean and 0.1 second standard deviation. So the average saturation flow rate is 1800 vehicles/ h (5 vehicles/time step).
- Arrival rate - In this report, arrival rate was drawn from a normal distribution assuming 1800 vehicles/h (5 vehicles/time step) mean and 1 vehicle/time step standard deviation.

To track the movement of traffic over time and space using the CTM, we divided the transportation network into homogeneous cells shown in Figure 4-5. Cells where vehicles enter the network are denoted as OR and cells where vehicles leave the network are denoted as DE.

Case 1-A – Comparison of Original and Enhanced CTM

For evaluation purposes, the performance of the enhanced CTM was compared to the performance of the CTM in terms of travel time. The same traffic demand and signal timing plan was used for both models. Simtraffic was used as an unbiased evaluator to compare them based on the simulation results. The literature review indicated that eight replications are frequently used for CTM and that value was adopted for this research, using different random number seeds. A 15-minute simulation time was used for every simulation trial. The results are shown in Table 4-1.

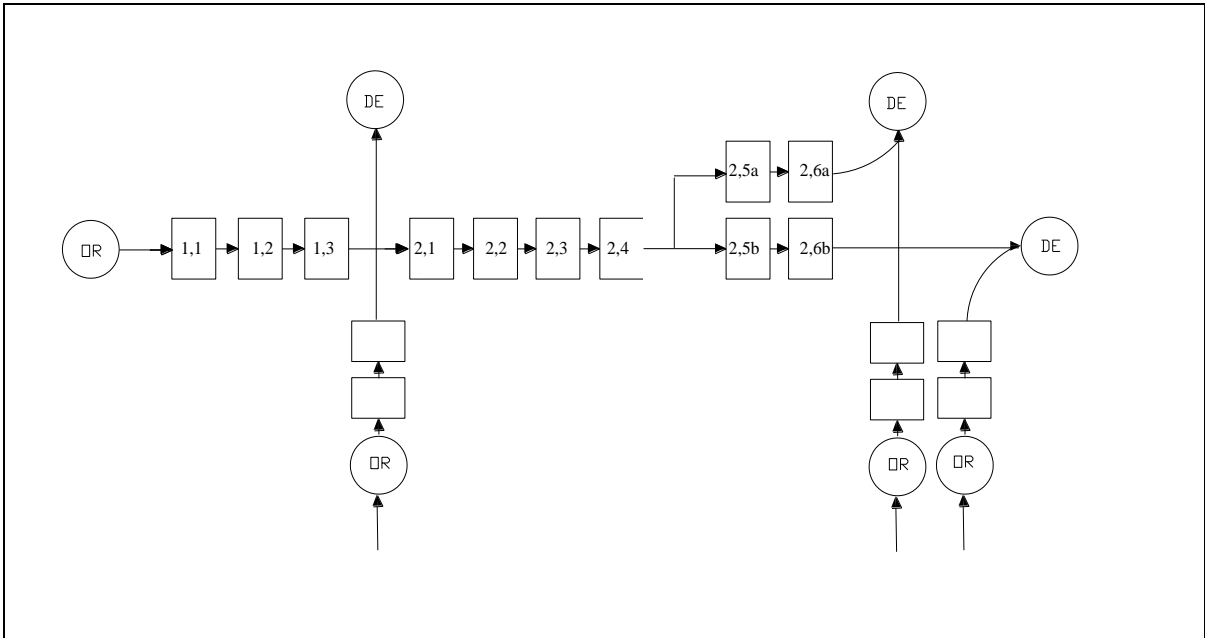


Figure 4-5. Cell representation of network.

Table 4-1. Case 1-A, Travel Times for CTM, Enhanced CTM and Simtraffic (sec/veh)

CTM	Enhanced CTM	Simtraffic
136	178	183

Using Simtraffic as the standard, it is seen that the original CTM underestimated the travel time by 25 percent, while the enhanced CTM underestimated by only three percent. This is because the enhanced CTM considers the random variations in saturation flow rates and arrival rates to increase its accuracy of traffic flow representation. The results of this simple comparison for a simple case study point toward a possible dramatic improvement in accuracy of modeling using the enhanced CTM.

Case 1-B – Evaluation of Fixed Time and Dynamically Timed Signals

The enhanced model was used to search for the best signal timing for the network. For comparison, the performance of a fixed signal timing plan was compared to that of a dynamic signal timing plan. The average delays for the network are shown in Table 4-2. Due to the space limitations of this paper, results are shown in Table 4-2 for only the major links using a fixed time signal, but are representative of all links for both the fixed time and dynamically timed signals.

Table 4-2. Case 1-B, Average Delay of the Fixed Plan and Dynamic Plan (sec/veh)

Signal timing plan	Average delay of network	Average delay of major corridor
Fixed	78	88
Dynamic	72	79

In Table 4-3, column 1 shows the number of time steps. Columns 2, 4, 6, 9, 11, 13, 15, 17, 19, and 22 show the numbers of vehicles in each cell at each time step. Columns 3, 5, 7, 10, 12, 14, 16, 18, and 20 show the number of inflowing vehicles at each time step. Columns 8 and 21 show the status of the signal. The letter G means green time and the letter R means red time.

A close analysis of Table 4-3 shows that CTM captured traffic flow phenomena in oversaturation conditions. For example, at time step 15, there was a forward wave through cell (1, 3), cell (2, 1), cell (2, 2), cell (2, 3) and cell (2, 4). A time step 6, there is another forward wave through cell (2, 4), cell (2, 5b) and cell (2, 6b). At time step 4, there is backward wave through cell (2, 4), cell (2, 3) and cell (2, 2). This demonstrates CTM's accurate representation of traffic flow.

In Table 4-3 the overflow of left turns can be seen to block the through lane, which is a normal phenomenon in oversaturation conditions. In cell (2, 4), the number of vehicles is 12. The inflow to cell (2, 5a) and (2, 5b) is determined by their available spaces. All flows are restricted if either of them is unable to accommodate its allocation of flow. Because cell (2, 5a) has 15 vehicles and is fully occupied, all flows are restricted, although cell (2, 5b) still has five vehicles spaces available. This matches what happens in reality. Left turn vehicles block the entrance of the through lane although there is some space in the through lane. This causes spillback. We can observe spillback at time step 2, where signal A is green but there is no flow. This is called defacto red – vehicles are blocked by the queue in front even though the signal is green. Using this process, a fixed timing plan was compared to a dynamic timing plan (Table 4-2).

The dynamic plan is much better than the fixed plan in terms of average delay. For example, in the major corridor the average delay is 88 sec/veh for the fixed plan and 79 sec/veh for the dynamic plan. The difference is substantial so the superiority of dynamic signal timing is obvious.

As with Case 1-A, it is not realistic to draw sweeping conclusions based upon one simplistic case analysis. But an important point is that the two cases replicate current logic regarding oversaturated flow at traffic signals. As such the concept might make important contributions to traffic signal timing in oversaturated conditions. However, much refinement and testing of the model must be done before its specific contributions can be established.

Table 4-3. Case 1-B, Vehicles in Each Cell: Fixed-Time Signal Timing Plan

TIME STEP	CELL (1,1)	f2	CELL (1,2)	f3	CELL (1,3)	f1	Signal A	CELL (2,1)	f2	CELL (2,2)	f3	CELL (2,3)	f4	CELL (2,4)	f2,5a f2,5b	CELL(2,5a) CELL(2,5b)	f2,6a f2,6b	CELL(2,6a) CELL(2,6a)	f(LF) f(T)	Signal B	CELL (3,1)
1	72	4	10	5	10	3	G	12	3	12	3	12	3	12	0	15	0	15	3	G	0
2	68	4	9	3	12	3	G	12	3	12	3	12	0	15	0	15	3	12	3	G	5
3	64	5	10	3	12	3	G	12	3	12	0	15	0	15	2	12	3	12	0	R	10
4	59	3	12	3	12	0	R	12	0	15	0	15	5	10	4	0	0	10	0		10
5	56	3	12	0	15	3	G	12	0	15	5	10	5	10	2	12	3	12	3	G	15
6	53	0	15	3	12	0	G	15	4	10	5	10	5	10	4	4	4	9	5		15
7	53	3	12	0	15	4	G	11	4	9	5	10	5	10	2	11	3	12	0	R	20
8	50	0	15	4	11	0	R	11	4	8	5	10	5	10	4	4	4	7	0		20
9	50	4	11	0	15	6	G	7	4	7	5	10	5	10	2	11	3	12	3	G	25
10	46	0	15	5	9	6	G	9	4	6	5	10	5	10	4	4	4	9	5	R	30
															4	4	4	8	0		30
															4	4	4	11	5		30

Table 4-3 (Continued). Case 1-B – Vehicles in Each Cell: Fixed Time Signal Timing Plan

TIME STEP	CELL (1,1)	f2	CELL (1,2)	f3	CELL (1,3)	f1	Signal A	CELL (2,1)	f2	CELL (2,2)	f3	CELL (2,3)	f4	CELL (2,4)	f2,5 a f2,5 b	CELL(2,5a) CELL(2,5b)	f2,6 a f2,6 b	CELL(2,6a) CELL(2,6a)	f(LF) f(T)	Signal B	CELL (3,1)
11	46	4	10	5	8	4	G	11	4	5	5	10	5	10	2	9	3	12	3	G	
12	42	4	9	5	9	0	R	11	4	4	4	10	5	10	4	4	4	10	5	R	35
13	38	4	8	1	14	6	G	7	4	4	4	9	5	10	2	4	4	8	0	G	40
14	34	4	11	5	9	6	G	9	4	4	4	8	5	10	4	4	4	12	5	G	40
15	30	4	10	5	8	4	G	9	4	4	4	7	5	10	2	8	3	12	3	G	45
16	26	4	9	5	9	0	R	11	4	4	4	6	5	10	4	4	4	10	5	R	50
17	22	4	8	1	14	6	G	7	4	4	4	5	5	10	2	5	0	15	3	G	50
18	18	4	11	5	9	6	G	9	4	4	4	4	4	10	4	4	3	12	5	G	55
19	14	4	10	5	8	4	G	9	4	4	4	4	4	10	2	6	3	12	0	R	60
20	10	4	9	5	9	0	R	11	4	4	4	4	4	9	4	4	4	9	0	G	60
															2	3	0	15	3	G	60
															4	4	3	13	5		60
															4	5	5	10	5	G	65

Conclusions

This chapter outlines a potential methodology to optimize traffic signal timing in oversaturated conditions. It adopts CTM to simulate the traffic flow in oversaturated conditions, estimates the average delay, and uses Genetic Algorithms as an optimization tool to minimize the average delay for the network. To improve the ability of CTM to represent oversaturated traffic flow, this project uses randomly distributed saturation flow rates and arrival rates instead of the constant values associated with CTM.

Simtraffic was used to evaluate the performance of the enhanced CTM versus the original CTM in two case studies. Both studies used the same, two-signal system, but different MOEs were used.

Case study 1-A demonstrated that the proposed methodology gave an accurate representation of traffic flow and captured some phenomena in oversaturated conditions such as forward waves, spillback and lane entrance blockage. CTM underestimated travel time by 25 percent when compared to Simtraffic, while the enhanced CTM underestimated travel time by only three percent. Case study 1-B evaluated optimization of a dynamic signal timing plan as compared to a fixed-time plan. The MOE used for this analysis was average delay. In this case the enhanced CTM had the flexibility to adjust the phase time according to the traffic flow.

This report has provided a strong statement about the inability of existing signal timing models to demonstrate fundamental flow-density relationships.

The authors recognize that it is not possible to draw sweeping conclusions based upon two simplistic case analyses. It is important to note, however, that the two cases replicate and support current logic regarding oversaturated flow in traffic signal systems. As such the concept might make important contributions to traffic signal timing in oversaturated conditions. Nonetheless, much refinement and testing of the model must be done before its specific contributions can be established.

Many additional enhancements can be made to the model. A possible future work is to calibrate the distribution of parameters in CTM, and to conduct a sensitivity analysis of the parameters. Another obvious extension is to investigate increased signal system size and complexity. It would be informative to use field data to calibrate the distribution of free flow speed used in the model. Similarly, field observations could be used to validate CTM by comparing average delay with that estimated from CTM. Field data could also be used to calibrate the enhanced CTM. The effects of geometric design should be considered as well because of its effect on vehicle flow and speed, turning vehicle storage, and signal timing. Finally, another recommendation is to investigate additional optimization strategies. For example, maximization of throughput is a potential way to optimize single signals and signal systems.

In closing, the authors view the enhanced CTM as a possible stepping stone in accurately simulating the effect of oversaturation on traffic signal systems. They intend to continue its development and testing to firmly establish it a new contribution to this field.

5.0 References

- Abro, A. M. *Traffic Signal Preemption for Transit Operations*. Master's Thesis, The University of Alabama at Birmingham, 2007.
- Abu-Lebdeh, G., and R. F. Benekohal. Genetic Algorithms for Traffic Signal Control and Queue Management of Oversaturated Two Way Arterials. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1727*, Transportation Research Board of the National Academies, Washington, DC, 2000, pp. 61-67.
- Alecsandru, C, and S. Ishak. *Accounting for Random Driving Behavior and Nonlinearity of Backward Wave Speeds in the Cell Transmission Model*. CD-ROM. Transportation Research Board of the National Academies, Washington, DC, 2007.
- Benekohal, R.F., Elzohairy, Y. M., and J. E. Saak. *Comparison of Delays from HCM, Synchro, PASSER II, PASSER IV and CORSIM for an Urban Arterial*. Traffic Operations Laboratory, Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, 2001.
- Chow, A. H. F., and H. K. Lo. Sensitivity Analysis of Signal Control with Physical Queuing: Delay Derivatives and an Application. *Transportation Research Part B*, Vol. 41, No. 4, 2007, pp. 462-477.
- Daganzo, C. F. The Cell Transmission Model: A Simple Dynamic Representation of Highway Traffic. *Transportation Research Part B*, Vol. 28, No. 4, 1994, pp. 269-287.
- Dixon, M., Kebab, W., and A. Abdel-Rahim. *Field Measurement of Approach Delay at Signalized Intersections Using Point Data*. CD-ROM. Transportation Research Board, National Research Council, Washington, DC, 2007.
- Girianna, M., and R. F. Benekohal. Dynamic Signal Coordination for Networks with Oversaturated Intersections. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1811*, Transportation Research Board of the National Academies, Washington, DC, 2002, pp. 122-130.
- Highway Capacity Manual 2000*. Transportation Research Board of the National Academies, Washington, DC, 2000.
- Institute of Transportation Engineers (ITE), California Border Section, Highway Capacity Task Force. *Report on the Use of Traffic Simulation Models in the San Diego Region*. 2004.

- Kikuchi, S., Kronprasert, N., and K. Masanobu. *The Length of Turn Lanes on Intersection Approaches: the Case of Three-Branch Fork Lanes*. CD-ROM. Transportation Research Board, Washington, DC, 2007.
- Lieberman, E. B., Chang, J., and E. S. Prassas. Formulation of Real Time Control Policy for Oversaturated Arterials. In *Transportation Research Record: Journal of the Transportation Research Board, No.1727*, Transportation Research Board of the National Academies, Washington, DC, 2000, pp. 77-88.
- Lo, H. K. A Novel Traffic Signal Control Formulation. *Transportation Research Part A*, Vol. 33, 1999, pp. 433-448.
- Lo, H. K. Dynamic Network Traffic Control. *Transportation Research Part A*, Vol. 35, 2001, pp. 721-744.
- Mousa, R. M. Analysis and Modeling of Measured Delays at Isolated Signalized Intersection. *Journal of Transportation Engineering*, Vol. 128, No. 4, 2002, pp. 347-354.
- Mouskos, K. C., Ziliaskopoulos, A. K., Chien, C., and C. Barrett. Implementing Dynamic Traffic Assignment to Support Incident Management. *Proceeding of the 6th Asia-Pacific Transportation Development Conference and the 19th ICTPA Annual Meeting*, Hong Kong and Macau, China, 2006.
- Overview of Visual Interactive System for Transportation Algorithm (VISTA)*, Release 1.0.1. Northwestern University, Evanston, IL.
- Park, B., Messer, C. J., and T. Urbanik, II. Enhanced Genetic Algorithm for Signal Timing Optimization of Oversaturated Intersections. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1727*, Transportation Research Board of the National Academies, Washington, DC, 2000, pp. 32-41.
- Peeta, S. *System Optimal Dynamic Traffic Assignment in Congested Networks with Advanced Information Systems*. Ph.D. Dissertation, University of Texas at Austin, 1994.
- Quiroga, C. A., and D. Bullock. Measuring Control Delay at Signalized Intersections. *Journal of Transportation Engineering*, Vol. 125, No. 4, 1999, pp. 271-280.
- Rathi, A. K., and E. Lieberman. *Traffic Simulation, " Revised Monogram on Traffic Flow Theory*. FHWA, US Department of Transportation, 1992.
- Schrank, D., and T. Lomax. *The 2005 Urban Mobility Report*. Texas Transportation Institute, The Texas A&M University System, 2005.
- Sherif I, C. A., and D. Seedah. *Improvement of Evaluation of the Cell Transmission Model for Operation Analysis of Traffic Networks: A Freeway Case Study*. CD-ROM. Transportation Research Board of the National Academies, Washington, DC, 2006.

- Sisiopiku, V. P., and X. Li. Overview of Dynamic Traffic Assignment Options. *Proceedings of the Transportation Simulation Symposium Spring Simulation Multi-Conference*, Huntsville, AL, 2006.
- Sisiopiku, V. P., Li, X., Abro, A. M., and R.W. Peters. *University Transportation Center for Alabama (UTCA) Report Number 06202 - Transportation Facilities Management under Emergencies*. UTCA, Tuscaloosa, AL, 2007.
- Sisiopiku, V. P., Abro, A. M., Mouskos, K., Parker, N., and C. Barrett. *Dynamic Traffic Assignment Applications to Transit*. Final Report to the Federal Transit Administration and the Urban Serving Universities Program, 2007.
- Sisiopiku, V. P., Jones, S. L., Sullivan, A. J., Patharkar, S.S., and X. Tang. *University Transportation Center for Alabama (UTCA) Report Number 03226 - Regional Traffic Simulation for Emergency Preparedness*. UTCA, Tuscaloosa, AL, 2004.
- Traffic Congestion Factoids*, 2006. <http://www.fhwa.dot.gov/congestion/factoids.htm>. Accessed 2008.
- US DOT Strategic Plan 2003-2008*. 2003. http://www.dot.gov/stratplan2008/strategic_plan.htm#_Toc52257030. Accessed 2008.
- Vista Transport Group, Inc. *Visual Interactive System for Transportation Algorithm-Software Walk Through*, 2005. <http://www.vistatransport.com>. Accessed 2008.
- Xiao, H., Ambadipudi, R., Hourdakis, J., and P. Michalopoulos. *Intelligent Transportation Systems Institute (ITSI) Final Report - Methodology of Selecting Microscopic Simulator: Comparative Evaluation of AIMSUN and VISSIM*. ITSI, Minneapolis, MI, 2005.
- Ziliaskopoulos, A. K., and S. Lee. A Cell Transmission Based Assignment-Simulation Model for Integrated Freeway/Surface Street Systems. Presented at the 75th Annual Meeting of the Transportation Research Board, Washington, DC, 1996.