A Fiber Optic Intersection Traffic Control System Based on a Competitive Cumulative Momentum Model

Chung Yu, Ph.D.
Principal Investigator

Sheldon Muir
Co-Principal Investigator

Urban Transit Institute
Transportation Institute
North Carolina Agricultural & Technical State University

B402 Craig Hall
1601 East Market Street
Greensboro, NC 27411
Telephone: (336) 334-7745   Fax: (336) 334-7093
Internet Home Page: http://www.ncat.edu/~traninst

Prepared for:
U.S. Department of Transportation
Research and Special Programs Administration
Washington, DC 20590

January 2004
Final Report

DISCLAIMER

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. DTR293-G0018	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A FIBER OPTIC INTERSECTION TRAFFIC CONTROL SYSTEM BASED ON A COMPETITIVE CUMULATIVE MOMENTUM MODEL		5. Report Date January 2004 6. Performing organization Code
7. Author(s) CHUNG YU, Ph.D. SHELDON MUIR		8. Performing Organization Report No.
9. Performing Organization name and Address Urban Transit Institute/Transportation Institute NC A&T State University, Greensboro, NC 27411		10. Work Unit No. (TRAIS) 11. Contact or Grant No. DTRS93-G-0018
12. Sponsoring Agency Name Address US Department of Transportation Research and special programs Administration 400 7th Street, SW Washington, DC 20590-0001		13. Type of Report and period Covered Final Report 01/01/2003-12/31/2003 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report outlines the need for an enhanced methodology to reduce the number of traffic accidents and administer a smarter solution from traffic impact studies so to palliate the issue of sprawling in urban areas. We have demonstrated that such a methodology will provide this solution, by the implementation of a Cumulative Momentum Model (CMV) for intersection traffic management. This proposed CMV is designed to allow traffic at the intersection to negotiate the right of way. This proposed traffic system will assign priority to heavy vehicles such as buses, emergency vehicles and commercial trucks. The CMV model automatically favors these heavier vehicles, which normally ply the main streets. The Market and Dudley beta site was the focused area for the CMV demonstration, and the layout and data analysis were used for refinement and optimization of detection zone design, and for traffic pattern simulations. Based on the raw (input) data, collected from Greensboro DOT for the Market and Dudley Intersection, the resultant simulated-data was used to study the impact for a given signature traffic pattern. The end product can have wide application in urban intersection traffic management. We have initiated a search of existing patents related to the proposed CMV methodology. So far, such a methodology merits further development for a potential patent application.

17. Key Words Traffic Management, Fiber sensor, Momentum, Competitive		18. Distribution Statement	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Page 26	22. Price

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. PROBLEM STATEMENT

The increase in traffic density is demanding new ways to optimize traffic flow and to obtain information for long-term planning of transportation infrastructure. There are many studies that have outlined issues with urban traffic congestion and its impact on fuel consumption, pollution, noise, and public transit ridership. The United States promotes growth, and with growth, these issues become more complex and severe. This is why urban traffic intersection management is an important matter. Advanced traffic management and intelligent transportation systems have been proposed and developed to deal with these issues. Effective solutions depend on accurate and quick data acquisition and processing of critical parameters. Acquisition and processing shall take place at each major intersection zone or traffic artery. We have proposed to specifically address urban intersection traffic control where these issues have the greatest impact.

Accidents	JAN	FEB	Total
Rural	9,227	7,900	17,127
Urban	9,948	9,156	19,104
Total	**19,175**	**17,056**	**36,231**
Killed Rural	77	50	127
Killed Urban	38	14	52
Total	**115**	**64**	**179**
Injured Rural	4,712	4,295	9,007
Injured Urban	5,022	4,767	9,789
Total	**9,734**	**9,062**	**18,796**

Table 1: *State-Wide Survey of Total Vehicle Accidents Between Jan. and Feb. 28, 2003*
Source: *North Carolina DOT*

According to a survey preformed by the North Carolina Department of Transportation (NCDOT), there were a total of 36,321 accidents recorded between the months of January and February 2003, for rural and urban areas. As a result of these accidents, 179 individuals were killed and 18,796 were injured. If we dared to guess as to what the end- of-year total would be, then we could base our assumptions on the law of averages. We would then conceive that 217,368 accidents would have occurred and of those accidents, 1,074 deaths would be recorded. At this time, there were no year-end reports available to compare our predictions to actual year-end results. Nevertheless, the data for January and February are significant and should send a clear massage of urgency to provide a solution to combat these numbers.

In addition, due to the amount of growth in the US urban communities, there is an increased concern with sprawling. There are studies that link sprawling to significant increases in highway deaths, air pollution, and traffic congestion. The report entitled *Measuring Sprawl and its Impact* is based on a three-year investigation conducted by professors at Rutgers and Cornell Universities. The report highlights three significant findings: (1) The daily distance driven per person is ten miles more in the cities with most sprawling than in those with least sprawling, resulting into 40 more miles of automobile travel each day for a family of four: (2)"The ten most sprawling places average 36 traffic deaths for every 100,000 people, while the least sprawling average 23 deaths per 100,000;" and (3) "Ozone pollution levels are as much as 41 parts per billion higher in the most sprawling areas, which can mean the difference between safe, "code green" and "code red" unsafe air quality."

The study also indicates that sprawling is a leading cause of increased congestions in low traffic volume area because there were fewer routes available that lead to a major thoroughfare. Table 2 provides an outline of the metropolitan region involved in the study and the overall Sprawl Index Score for the region.

Metropolitan Region	Overall Sprawl Index Score
Riverside-San Bernardino, CA PMSA	14.2
Greensboro-Winston-Salem-High Point, NC MSA	**46.8**
Raleigh-Durham, NC MSA	**54.2**
Atlanta, GA MSA	57.7
Greenville-Spartanburg, SC MSA	58.6
West Palm Beach-Boca Raton-Delray Beach, FL MSA	67.7
Bridgeport-Stamford-Norwalk-Danbury, CT NECMA	68.4
Knoxville, TN MSA	68.7
Oxnard-Ventura, CA PMSA	75.1
Fort Worth-Arlington, TX PMSA	77.2

Table 2: *Metropolitan Region vs. Overall Sprawl Index Score*
Source: *Smart Growth America's Website at www.smartgrowthamerica.org*

Again, advanced traffic management and intelligent-transportation systems have been proposed and developed to address these issues. However, the current solutions for detection and control are at best only adequate. Two common traffic system applications available are the Induction Loop detector and Overhead Cameras. The Induction Loop detector is accurate and robust and widely preferred based on performance, reliability and cost. However, the type of data collected (vehicle count and presence) do not reflect on vehicle weight essential for green priority at intersection for buses and trucks. The Overhead Camera is capable of acquiring more complex data (speed, vehicle classification); hence cost and lower reliability are a major set-back. Furthermore, vehicle identification is not really necessary, and effects of weather and lighting are severe on such a system.

We intended to develop (but not limited to) the ability to mitigate traffic patterns in sprawling urban areas as well as rural areas with aggressive growth. To satisfy these requirements, the system shall be capable of acquiring impact data (presence, count, speed, vehicle weight classification). Also, the system shall be able to learn from the smart data collected and implement simultaneous solutions, thereby adapting for skewing in a given traffic pattern. This system shall also be competitive with regard to price, reliability, and performance.

2. DESCRIPTION OF APPROACH

To address the enhancement of a traffic management system, we are proposing "A Fiber Optic Intersection Traffic Control System Based on a Competitive Cumulative Momentum Model." The intent of this approach is to provide a solution that would satisfy the required objectives, as outlined in the problem statement. This system is designed as a stand-alone, zone-traffic control system. The detection zone is a monitored area where approaching and exiting vehicles are evaluated and the Cumulative Momentum Value (CMV) naturally enables the command for the green, hence preventing congestion at that intersection. The management of such a system takes into account expected volume with respect to the detection area, in order for the results to be effective. One can argue that the larger the detection zone, regardless of traffic volume, the more accurate the system should be. However, cross street traffic volume is a competing factor, so that vehicle idling time in each street must be carefully prescribed, according to traffic-volume data. Hence, for each site a layout of the detection zone would have to be evaluated and the management system adjusted for a predetermined volume.

This proposed traffic system should incorporate a CMV, which will enhance traffic system negotiation for intersection right of way. The embedded CMV algorithm provides a logic that is dependent on traffic volume. This logic allows for intelligent negotiation for a given intersection resulting in reduction of traffic idling and congestion. The traffic volume at a given intersection is compared, and the higher CMV requisitions the GREEN. The street with the green will naturally have its CMV lowered, while said value of the cross street continues to increase. At some point in time, their CMV numbers will cross, and the green command changes hand. This competitive process causes the green signal to react intelligently, like a traffic cop.

The proposed fiber optic system will consist of two fiber optic strips, one embedded at a designated distance from the traffic light or intersection, and the other very close to the traffic light. This is the detection zone. The former is used to monitor vehicles entering the detection zone, and the latter, those exiting the zone. Algorithms will be written such that the entering strip registers only “positive” CMV numbers and the exit strip, only negative CMV numbers. Vehicles entering the monitored zone will have their weight and speed measured and their momentum calculated and summed. There is a similar system near the traffic light, where the same vehicles can be detected and their MV subtracted from the previous cumulated number to indicate exit of the vehicles from the zone. For example, if 100 vehicles enter the zone and then exit the zone, then the CMV should be zero. Similarly, if 100 enter the zone and only 50 make their exit, then the original CMV will be halved. During this period, vehicles in the cross street have not exited, so the CMV number continues to build. The proposed scheme will compare the two CMV numbers and set a cross over point for traffic light to switch the green. Once the green is switched, the cross street CMV will begin to drop when the number is subtracted by a similar exit detection system. It is clear that the detection zone size plays a key role in the traffic light switch decision. This parameter varies form intersection to intersection, dependent on prevailing traffic volume. Thus, heavily traveled intersections must have short detection zones, so that CMV numbers will remain within manageable limits. The CMV cross-over point must also be so determined to allow the fastest intersection traffic flow and least congestion.

We intend in the next budget year to carry out the following systematic study:

a. Vehicle counting using the IRD system;
b. Vehicle speed and weight measurements by the IRD system;
c. Vehicle count by weight, e.g., A vehicles of twice the weight of an ordinary sedan will be counted as two vehicles, etc;
d. Conversion of the CMV model to the Vehicle count model;
e. Competitive CMV model is transformed to Competitive Vehicle Count Model;
f. Laboratory simulation and field implementation.

We are in the process of assessing DOT supplied traffic volume data, so as to arrive at an optimum design for the beta site. This design will then be simulated in the lab for fine tuning. It will then be field tested on campus before we negotiate its installation at the beta site for actual city demonstration.

This proposed traffic system assigns priority to buses and trucks. This approach automatically favors heavier vehicles, such as transit buses and commercial trucks, which normally ply the main streets. The focused Beta Site, Market and Dudley St., has been analyzed and rider ship was a major concern due to significant growth rate. A major transfer center is located on Davie Street, close proximity to the beta site, which all routes pass through on the hour. To date there are 27 bus route, most operating from 5:15 A.M. to 9:00 P.M. This fleet consists of 27 35-foot buses that can seat 35 passengers. The GTA forecast rider ship along Market Street would peak over 3500 passengers per day. This projected value would present a significant need for a traffic management system to control traffic delay. Our proposed system would provide a solution to this anticipated boom of transit passengers.

The proposed traffic findings would provide additional research data for fiber optic load sensors to be used for traffic applications. The proposed fiber optic load sensor system is commercially available. It is capable of performing axle detection and counting, speed measurement, gap measurement, vehicle classification, and recognition. This in-ground system can be readily installed flush with the road surface, so as to protect against road hazards. The embedded fiber sensor is vibration proof, has high sensitivity, high elasticity, flexibility and durability, and is non-metallic and thus EMI proof. However, this type of technology is not used in majority of the traffic applications. Our findings are intended to be shared with the traffic community.

3. METHODOLOGIES

3.1 CMV Model Implementation

The CMV model measures (detecting and classifying) vehicle types (speed and weight) over a detection zone. Figure 1 is a layout of a 3-lane, one-way intersection, one of the simpler patterns to manage. Traffic only flows in two directions, southbound and westbound. There is no left turn signal or complex signal phase/timing considered. The detector at the far end simply applies the CM value for the vehicles entering the intersection. At precisely the same time, the cross-artery is monitoring vehicle flow (with regard to speed and weight) the other artery is monitoring vehicle delay. This is the first (simplistic) iteration used to establish a baseline for the CMV model.

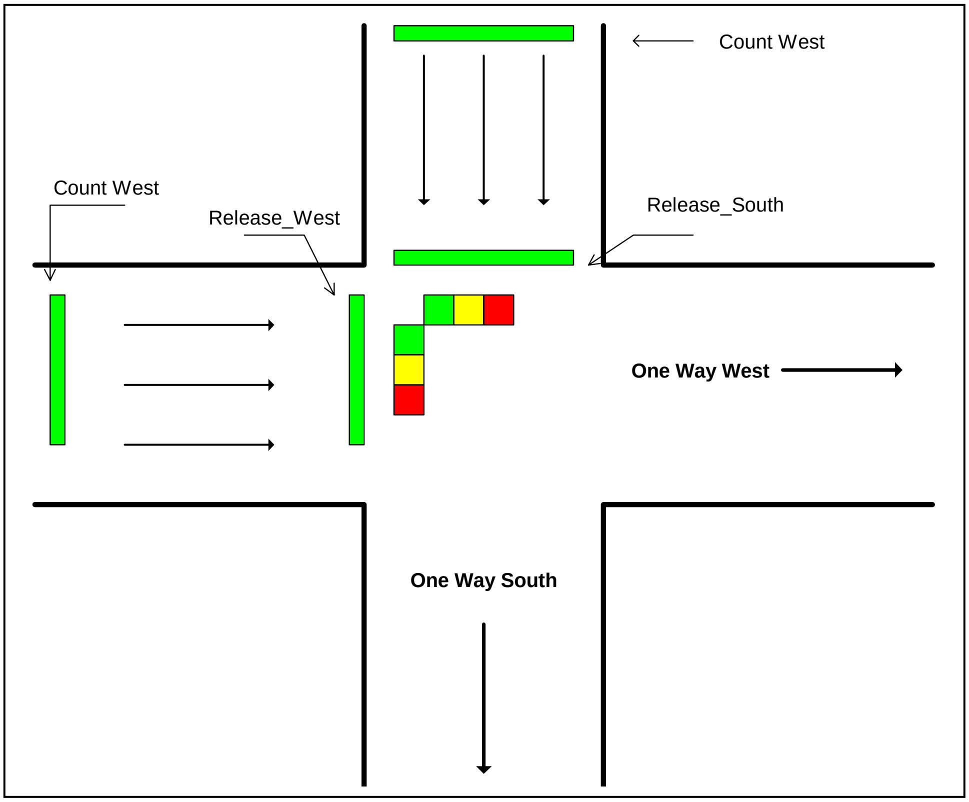

Figure 1: *One-Way Intersection*

Condition (sec.)	South Bound G	South Bound Y	South Bound R	West Bound G	West Bound Y	West Bound R
T1 (65)	1	0	0	0	0	1
T2 (10)	0	1	0	0	0	1
T3 (5)	0	0	1	0	0	1
T4 (65)	0	0	1	1	0	0
T5 (10)	0	0	1	0	1	0
T6 (5)	0	0	1	0	0	1
T7 (65)	1	0	0	0	0	1
T8 (10)	0	1	0	0	0	1
T9 (5)	0	0	1	0	0	1

The data below Figure 1 illustrates fixed signal conditions (T1, T2, T3…T9) and variable time setting. The signal conditions are fixed and include all the possible combinations for the signal to properly manage intersection traffic safely (data excludes flash mode). The time sequences are variable because these values can be adjusted to meet the demand for the green. This demand is determined by the highest CMV assigned to the arterial section approaching the intersection. Conditions T1 through T6 completes one cycle and the management control is dependent on CMV demand for green, sequence and timing for each respected sequence. This is aligned with extending the yellow for speeding vehicles, extending the green for heavy vehicles, and extending the green for uneven traffic patterns.

The second iteration is an illustration of a 4-way intersection. This illustration does not include left turning lanes. This makes the analysis simpler with regard to running traffic pattern simulations. The conditions and timing pattern are processed similarly to the 3-line one way intersection layout. The difference would be the addition of a north bound and east bound traffic. The detection method is implemented for the said additions.

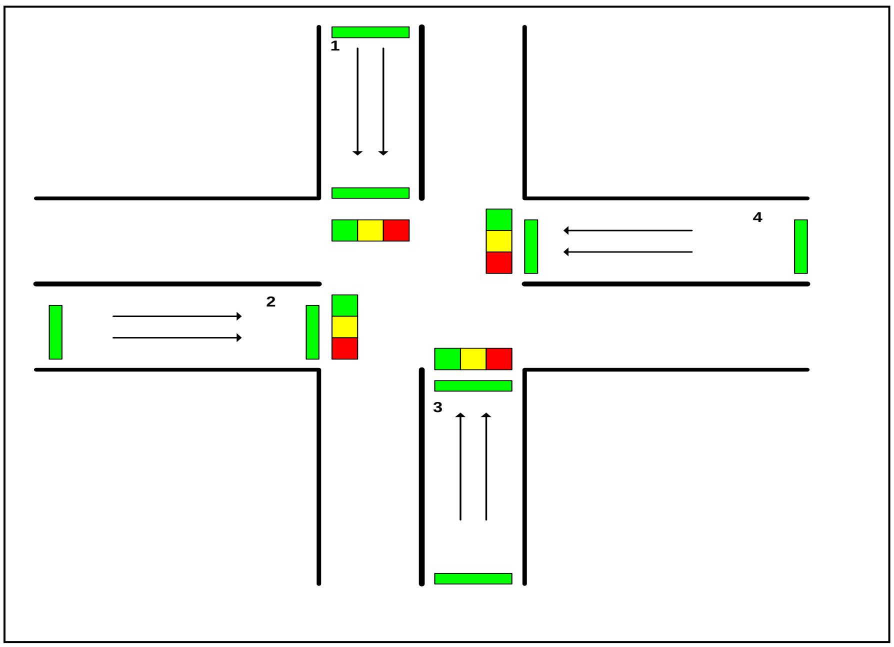

Figure 2: *4-Way Intersection, No Left Turns*

Timing	South			North			East			West		
(sec.)	G	Y	R	G	Y	R	G	Y	R	G	Y	R
T1(65)	**1**	0	0	**1**	0	0	0	0	1	0	0	1
T2(10)	0	**1**	0	0	**1**	0	0	0	1	0	0	1
T3(5)	0	0	**1**	0	0	**1**	0	0	1	0	0	1
T4(65)	0	0	1	0	0	1	**1**	0	0	**1**	0	0
T5(10)	0	0	1	0	0	1	0	**1**	0	0	**1**	0
T6(5)	0	0	1	0	0	1	0	0	**1**	0	0	**1**
T7(65)	1	0	0	1	0	0	0	0	1	0	0	1
T8(10)	0	1	0	0	1	0	0	0	1	0	0	1
T9(5)	0	0	1	0	0	1	0	0	1	0	0	1

Figure 3 is an illustration of a 4-way intersection with turning lanes. The detection process is the same as the first 2 iterations. There are more signal conditions to consider and increased delay due to the additional condition. The time constraint will be based on the CMV given to turning lanes vs. through traffic delay and through traffic flow. For example, if there is a low CMV at a turning lane or no vehicle detected, then the controller would move to the next condition. Therefore, at each condition there is an evaluation that is performed at the arterial.

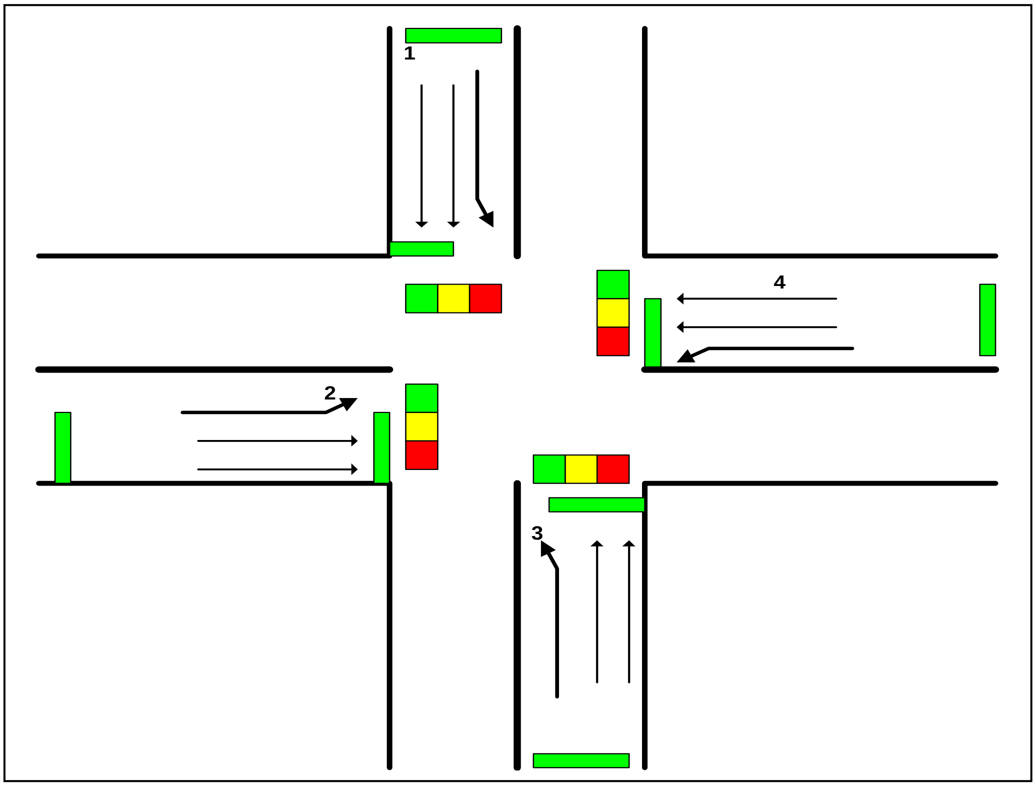

Figure 3: *4-Way Intersection with Left Turning Lanes Enabled*

Timing (sec.)		**N**			**NT**			**S**			**ST**			**E**			**ET**			**W**			**WT**	
	G	**Y**	**R**	**G**	**Y**	**R**	**G**	**Y**	**R**	**G**	**Y**	**R**	**G**	**Y**	**R**	**G**	**Y**	**R**	**G**	**Y**	**R**	**G**	**Y**	**R**
T1(30)	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	1	0	0	1
T2(10)	0	0	1	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	1	0	0	1
T3(5)	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
T4(65)	1	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
T5(10)	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
T6(5)	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
T7(30	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0
T8(10)	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	1	0	0	0	0	0	1	0
T9(5)	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	1
T10(65)	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1
T11(10)	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	0	0	1
T12(5)	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1

3.2 Embedded Fiber Optic Application for Data Acquisitioning

The design objectives for this traffic-management system includes having the ability to collect the required data set, the ability to accept the algorithm used to interpret the traffic varying conditions, the ability to interface with existing programs, and the design objective of being user friendly. The system should be capable of measuring speed, axial detection, and vehicle-gap data. This information will be used to calculate volume data, and determine lane data and timing. The system shall have acceptable repeatability and accuracy levels once these levels are established. The repeatability and accuracy study shall be established using statistical analysis once data is gathered for the designated test site

The detection method is a major part of this traffic-management approach. This implies careful consideration as to the type of detector being used for the life of the system. For the collection of critical data, we are recommending the use of an embedded fiber optic sensor. In layman terms, optical sensors are nothing more than dielectric wave-guiding devices used to restrict light. The foundation for the application stems from characterization of light, which are monitored in sensing applications by means such as amplitude, polarization, phase, and wavelength. Commercially available optical sensor systems are based on a patented, proven technology. They are made with optical fibers and contain no electrical wires or conductors. They can not conduct a lightning discharge or pick up any electrical noise, thereby reducing the risk of electrical fault or malfunction. The sensors are sensitive to vertical loads and insensitive to adjacent lane vibration. Fiber sensor detects every axle at all speeds including stop-and-go traffic.

The fiber optic sensor product line is designed to interface with a signal processor or a controller. The controller has a preset reference, either factory set or recommended by the OEM's product specification, which is used to compare the levels of the transmitted light source over time and distance. A decrease in lighting results from a wheel load being applied to the sensor thus causing a small amount of light to escape from the fiber. This process is also known as micro-bending. This act causes a differential result with respect to input/out put transmission levels. These results are used to obtain measures for capacity usage and to develop correlation studies for traffic patterns, road usage, and road life over time.

Figure 4: *Fiber Optic Traffic Sensor*

The sensors come pre-assembled within the cabling package. The sensors are within the 0.125 inch thickness as specified by the manufacturer. The assembly seemed relatively easy to install (plug and play) for use with permanent applications. Per the instructions, the sensors require a ¾" conduit to house the sensor (required for field installation testing). Per the application specification for this conduit, it will take approximately one hour to cut the groove and install the sensor. The portable applications conform to the road surface and the construction increases the life of the product, per the data specifications. The sensors are easy to store and setup under extreme environmental conditions. The sensors interface to an opto-electronic unit that contains the electronics and battery. The output is a switch closure or "piezo" voltage pulse. This pulse or switch allows interfacing to existing classification equipment (includes: Counters/Classifiers and Weigh-In-Motion equipment). The sensors employ fiber optic technology, and this technology dampens the probability of unwanted effect due to vibration, electrical noise, lightning, and cross talk between lanes.

We have researched and performed in house laboratory evolutions. Equipment used include a data-acquisition system with a portable fiber optic 2-lane sensor [P/N 340159] purchased from International Road Dynamics, Inc. (IRD). Table 3 contains all the critical components in the system that is essential for the system to function properly. These items consist of:

1. TC/C 540 Manual: for manual operation
2. Trafman software and software instruction manual
3. Battery charger or solar charging panel
4. Sensors assembly
5. Application kit: road adhesion promotion and insulation
6. Computer: serial cable, for standard RS232 serial port interface
7. Modem: modems can be used for long distance control, using phone lines.

Quantity	*Part Number*	*Description*
2.0	170525	Cable Loop Lead 2P-Wires 50 ft.
1.0	100501	TCC-540 Base 68k 4 Ch. F/O Serial Number: 0303-8074
2	100517	Loop Quick-Stick Replacement 3.5 x 6.5 ft 4T.
1	340158	Fiber Optic Pocket Tape 21 ft. long (2 lanes)
1	340159	Fiber Optic Portable Road Top Sensor -2 lanes
1	700156	Fiber Optic Easy Insertion Tool
1	114087	TCC-540 Fiber Interface Box 4 Sensor Input
1	191013	TCC-540 Lp 1-4 Kit w/Cbl. 8-Lp 6′
1	170273	Cable TCC-540 Charger 5P
1	170013	Cable TCC Comm. (9P) 6′

Table 3: *Material List for the Data-Acquisition System*
Source: *International Road Dynamics, Inc.*

The acquisition system was evaluated for vehicle counting and classification. The electronic hardware is encased by 10-gauge welded aluminum (10 ¾″ x 14″ x 7″) and is not physically accessible. There is a key pad on the front panel which allows the setup the type of data to be collected and collection time. We are capable of retrieving (field acquired) traffic data that has been collected by the TCC-540 through the use of a computer. A serial-port connection will allow a computer to interface with the unit's processor. The TCC-540 can also be configured from the serial port connection. That means by the use of a portable computer, the system can be installed in the field for a long period without the need to disconnect in order to extract data. The controller can also be configured to accept commands through a network connection. Therefore, this system can be monitored and manipulated at the office. The TCC-540 has an internal battery cell for portable use. All cables are directly connected to this unit (see Figure 5).

Figure 5: *Side View of TCC-540 Showing Interface Connections*

This unit is capable of performing vehicle count, classification, gap, headway, and speed by axle or length. The unit can also count up to 16 lanes and classify a maximum of 8 lanes. There are two counting modes; these modes collect and store data by user-defined time intervals or by sensor activation stored in memory. There are three classification modes, which include user defined up to 30 speed, 30 axle, 30 headway and 30 gap bins, sensor activation and time of passage to 1/100 second. The TCC-540 has 1Mb of counter memory, and therefore, collect significant amount of count data. The operation temperature for this unit is –40˚F to 165˚F, which will allow for testing in a full range of temperature conditions.

Figure 6: *Front View of TCC-540 Showing Keypad, Power Switch, and Connections*

4. TEST SITE DETECTION ZONE

Figure 4 (Dudley Street and Market Street) shows a complete layout of the traffic signal at the Dudley and Market intersection. The original layout provided by the Greensboro DOT was modified to include the embedded fiber detectors. For this iteration of the layout, the 4-induction loop detectors for all four left turning lanes were not altered. The through lane's induction loops were replaced with fiber detectors. These detectors are located in all four lanes where traffic is approaching the intersection. The detectors are located near the cross walk and 180 feet from the cross walk, near-end and far-end respectively. The positions of the fiber detectors create the stand-alone detection zone. The approach for this layout is to allow the detectors to record the vehicle's presence during idle traffic mode or while traffic is building up. Vehicles are continuously summed starting at the far end. The resultant value is stored and accessed for comparison. The value is not subtracted until the vehicles pass through the near-end detector. For the lanes that command the green, a continuous CMV is applied (within the zone) to those lanes, and compared to the adjacent lanes.

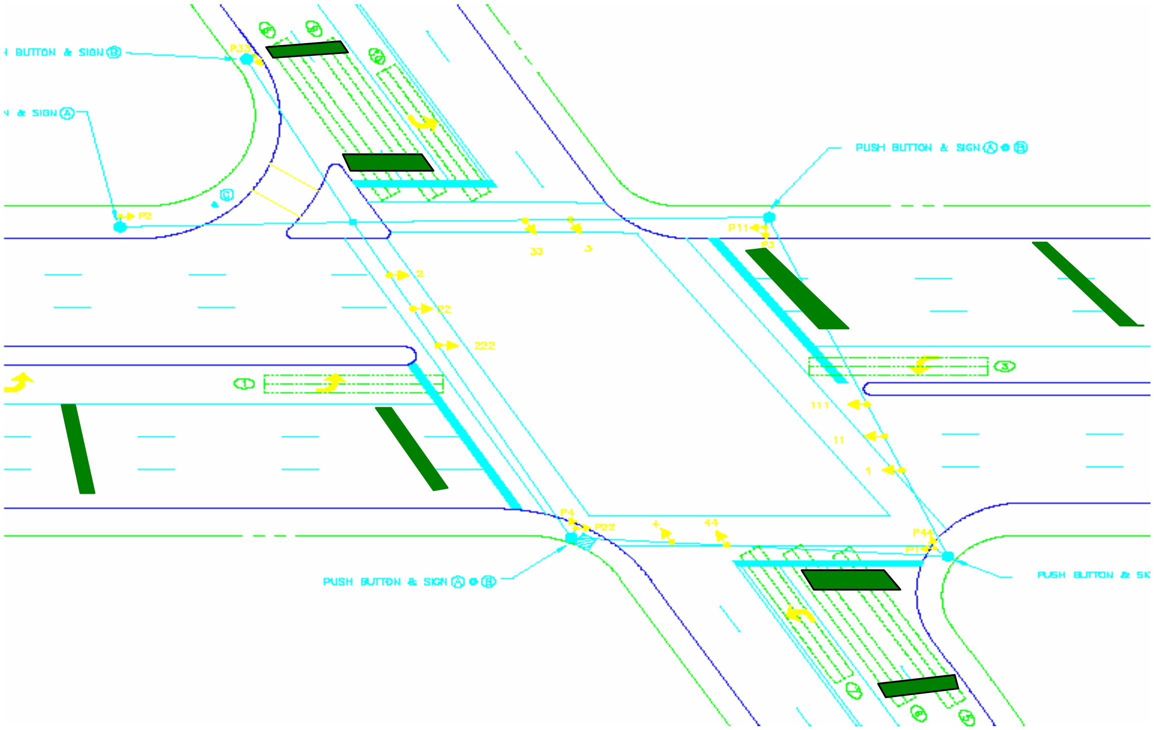

Figure 7: *Dudley Street and Market Street Intersection*

The in-ground induction loops are documented as having three different lengths: 6′ x 30′, 6′ x 50′ and 6′ x 60′. The embedded fiber detector will not require similar lengths for they are placed perpendicular to the induction loops, hence complementary to the current detection method. The overall length of the embedded fiber optic sensor will be determined through site layout and initial road testing. Once this assessment is completed, conditioned, and implemented, then the next step is to detect for an effective distance. This process is to help ensure reliability and justify material cost. These are two major variables that are assessed during the implementation phase. This is also why the proposed system must be competitive price-wise while providing similar reliability points.

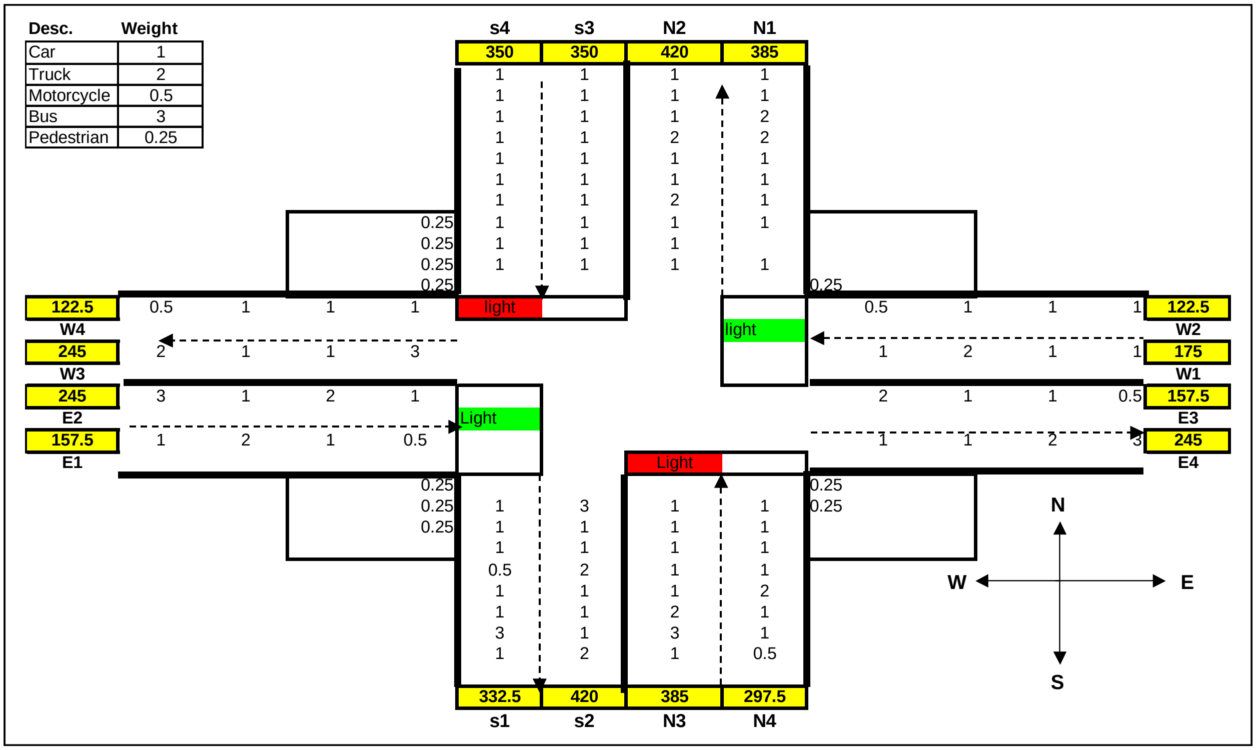

Figure 8: *Intersection Detection Zone*
Data Source: *City of Greensboro, NC DOT*

Figure 8 provides a pictorial of the intersection-detection zone during intended mode of operation. The figure illustrates the CMV process of identifying the vehicle's attributes as it passes through the detection zone. As outreach, our senior design group is designing a hand free pedestrian presence sensor that would be tied in to the CMV claim-to-green. With this implementation the zone will be fully automated. Pedestrian service is a required consideration for it is a means of commuting, and intersections are currently accommodated through the use of a push button device.

In the upper left corner of Figure 8 there is a table with a list of weights with respect to vehicle types such as cars, trucks, motorcycles, buses, and pedestrians. It is our intent to fully identify all vehicles by determining their weight signature and compare their acceleration rate. The detection zone recognizes the presence of each of these vehicles, their location with regard to the intersection and their respective weights. The CMV function is ascertained through a subset of calculations, seen in the yellow. It is this value that is continuously calculated and compared. For each count that the assigned weight appears in the detection zone, that vehicle is being identified for vehicle type and speed. This method is therefore dependent on the CMV and not a timing pattern.

We have proposed zone detection communication for intersections, such as the 10- city blocks beta site, which are significantly close to each other. This means talking between close proximity arterial intersections. The resultant downstream traffic flow from intersection 1 can be used to calculate upstream CMV calculations for intersection 2. This method of predicting or forecasting upstream traffic is an effective way to anticipate congestion relief.

5. Site Data Simulation and Analysis

Traffic input data for the Market and Dudley Street intersection was acquired (see Table 4). This data was used as input to evaluate effects of the volumes at high peak hours through a traffic simulation tool. The software used for the simulation was the Syncor-4. The Synco-4 provides a Simulation Summary Report, which contains summary data runs and simple statistics. The simple (or basic) statistical data is with regard to the measurable quantities resulting from the intersection's volume data and assumptions made for the proposed site. The summary report is very valuable when used to track interval simulation, volume adjustments, and timing plan(s). The typical information provided by the simulation tool (in a report format) contains the following: start time, end time, total time, vehicles entered and exited, total distance, total time, total delay, total stops, and fuel.

From East on Market St.			
	Right	Straight	Left
8:00	23	330	29
8:15	40	223	27
8:30	24	194	22
8:45	24	229	39
12:15	65	238	53
12:30	26	197	26
12:45	22	178	41
13:00	48	188	48
16:30	41	291	36
16:45	35	256	59
17:00	37	267	64
17:15	33	271	61

From West on Market St.			
	Right	Straight	Left
8:00	25	186	50
8:15	16	199	40
8:30	23	120	32
8:45	27	135	33
12:15	29	214	43
12:30	7	174	38
12:45	24	126	39
13:00	43	162	39
16:30	9	301	40
16:45	21	228	43
17:00	21	297	43
17:15	23	301	55

From South on Dudley St			
Time	Right	Straight	Left
8:00	27	79	43
8:15	22	84	33
8:30	15	63	34
8:45	22	63	21
12:15	18	57	16
12:30	16	73	18
12:45	27	65	15
13:00	32	58	25
16:30	19	77	27
16:45	11	89	26
17:00	14	99	39
17:15	15	102	24

From North on Dudley St			
	Right	Straight	Left
8:00	9	54	12
8:15	10	38	15
8:30	12	47	14
8:45	2	6	45
12:15	30	83	44
12:30	16	64	29
12:45	15	72	30
13:00	31	54	27
16:30	37	118	30
16:45	25	123	23
17:00	19	98	31
17:15	23	118	37

Table 4: *Input Data, Peak Traffic Data for Market and Dudley*
Data Source: *City of Greensboro DOT*

Table 5 contains summary data of the entire run. Each run, denoted by the peak time, was performed individually. The quantifiers on the left side of the table are the measurable factors based on the input data and the assumption made during setup. During the peak hours there were on the average 190 and 170 vehicles entering and leaving the intersection, respectively.

	8:00 AM	8:15 AM	8:30 AM	8:45 AM	12:15 PM	12:30 PM	12:45 PM	1:00 AM	4:30 AM	4:45 AM	5:00 AM	5:15 AM
Vehs. Entered	194	168	147	150	210	148	152	166	239	221	243	249
Vehs. Exited	172	152	131	133	190	133	137	149	212	199	218	224
Ending Vehs.	22	16	16	17	20	15	15	17	27	22	25	25
Travel Distance (mi)	117	101	87	90	127	85	87	97	143	130	144	146
Travel Time (hr)	4.6	3.8	3.3	3.4	4.9	3.2	3.3	3.7	5.6	5	5.7	5.7
Total Delay (hr)	0.6	0.4	0.4	0.4	0.5	0.4	0.3	0.4	0.8	0.6	0.8	0.8
Total Stops	96	75	74	69	102	78	75	98	122	107	124	126
Fuel Used (gal)	6.3	5.2	4.4	4.7	6.8	4.5	4.5	5.3	7.6	6.9	7.8	8

Table 5: *Summary of Entire Run*

The average number of stops was 95 and the total average delay was 0.5 hours. The average amount of fuel consumed over the total run was 6 gallons.

A growth factor can be used to modify the traffic volumes. Volume data is multiplied by the growth factor when calculating Adjusted Volumes and Lane Group volumes. As a rule of thumb, the growth factor is 0.5 to 3.0. Current volumes can be adjusted to reflect future volumes and how accurate the results depend on front-end, trend analysis and assumptions. The use of this Growth Factor can provide insight into predicting potential results of future traffic attributes. The simulator can calculate a growth factor based on a growth rate over several years.

Calculation (A), Source: Synco-Simulation Manual

GF = (1+r)^Y = Growth Factor
r = Growth Rate
Y = Number of years

For example the growth factor for 2% growth over 5 years is:
GF = (1 + 0.02) ^ 5 = 1.104

	Delta		
Delta (VAGF-Initial run)	Min.	Max.	Average
Vehs Entered	0	0	-2.77
Vehs Exited	0	0	-2.56
Ending Vehs	0	0	-0.20
Travel Distance (mi)	0	0	-1.56
Travel Time (hr)	0	0	-0.06
Total Delay (hr)	0	0	-0.01
Total Stops	0	0	-1.05
Fuel Used (gal)	0	0	-0.08

Table 6: *Growth Factor Comparison (Final-Initial)*

Table 6 provides a growth factor comparison. This factor was used in the simulation and to compare the final against the initial run. The results yielded no significant differences between today and 5 years from now. Based on the input data and the assumptions made, one would make the recommendation to hold off any planning with regard to this site. Again, if used in conjunction with a trend analysis preformed over a period of time and assumptions made from city development planning data, this application would help to provide a well thought out plan for the future.

Delays and fuel emission were evaluated for the various peak times. SimTraffic reports two kinds of delays, total delay and stopped delay. Stopped delay is an amount of time that the observed vehicle is halted or traveling less than 10 ft/s. Total delay is the difference between the true travel time and the period it would take to clear a channel without any signals, signs, other vehicles, etc. If the analysis period increases, then the delays will also increase. Therefore, each run interpreted will have different assumptions with regard to what happens during congestion. Hence, our accuracy is reduced by some factor when comparing delays for congested movements. The results of the delay analysis are contained in Table 7a-d.

East Bound	8:00	8:15	8:30	8:45	12:15	12:30	12:45	1:00	4:30	5:00	5:15
Total Delay (hr)	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.2
Delay / Veh (s)	8	6.8	6.8	7.2	6.9	6.6	6.2	7.1	9.2	9.5	7.6
Total Stops	38	27	29	29	43	30	28	38	50	52	36
Travel Dist (mi)	28.4	21.5	21.7	22.3	31.5	19.4	20.1	22	31.8	31.4	29.4
Travel Time (hr)	1.1	0.8	0.8	0.9	1.2	0.8	0.8	0.9	1.3	1.3	1.2
Avg Speed (mph)	25	26	26	25	25	26	26	25	24	24	25
Fuel Used (gal)	1.4	1	1	1	1.5	0.9	0.9	1	1.5	1.5	1.5
HC Emissions (g)	3	2	2	2	4	2	2	2	4	4	4
CO Emissions (g)	49	42	39	41	63	31	34	42	55	61	62
NOx Emissions (g)	8	7	6	7	11	5	6	7	9	11	11
Vehicles Entered	88	67	66	68	97	60	62	68	97	96	90
Vehicles Exited	81	60	63	63	90	56	57	63	91	90	84
Hourly Exit Rate	347	257	270	270	386	240	244	270	390	386	360

Table 7a: *East Bound Performance Traffic Simulation Results*

West Bound	8:00	8:15	8:30	8:45	12:15	12:30	12:45	1:00	4:30	5:00	5:15
Total Delay (hr)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3
Delay / Veh (s)	8	8.8	7	7.1	7.8	7.3	7.6	7.4	10.5	10.1	11.2
Total Stops	38	28	21	23	29	22	23	32	42	45	47
Travel Dist (mi)	28.4	21.7	15.3	17.7	24.4	15.7	16.8	20.1	29.3	31.6	32.9
Travel Time (hr)	1.1	0.9	0.6	0.7	1	0.6	0.7	0.8	1.3	1.3	1.4
Avg Speed (mph)	25	24	25	25	25	25	25	25	23	24	23
Fuel Used (gal)	1.4	1.1	0.7	0.9	1.2	0.7	0.8	1	1.4	1.5	1.6
HC Emissions (g)	3	2	1	2	3	1	2	2	3	3	4
CO Emissions (g)	49	43	23	30	47	24	26	34	58	60	71
NOx Emissions (g)	8	7	3	5	8	4	4	5	10	10	12
Vehicles Entered	88	58	40	47	65	41	44	53	79	85	88
Vehicles Exited	81	54	39	45	61	40	43	51	72	78	81
Hourly Exit Rate	347	231	167	193	261	171	184	219	309	334	347

Table 7b: *West Bound Performance Traffic Simulation Results*

North Bound	8:00	8:15	8:30	8:45	12:15	12:30	12:45	1:00	4:30	5:00	5:15
Total Delay (hr)	0.1	0	0.1	0	0	0.1	0	0.1	0.1	0.1	0.1
Delay / Veh (s)	13.7	5	13.8	5.9	5.3	12.9	5.3	12.7	8.9	10.6	8.8
Total Stops	14	7	15	6	12	19	12	18	20	16	22
Travel Dist (mi)	3.5	3.2	3.7	2.6	4.9	5.1	4.9	4.7	7.5	6.1	7.5
Travel Time (hr)	0.2	0.1	0.2	0.1	0.2	0.3	0.2	0.2	0.3	0.3	0.3
Avg Speed (mph)	20	26	20	24	25	20	25	20	23	21	23
Fuel Used (gal)	0.2	0.1	0.2	0.1	0.2	0.3	0.2	0.3	0.4	0.4	0.4
HC Emissions (g)	0	0	0	0	1	1	1	1	1	1	1
CO Emissions (g)	7	5	6	3	9	12	9	13	19	18	18
NOx Emissions (g)	1	1	1	1	2	2	2	3	4	3	3
Vehicles Entered	18	16	19	13	25	26	25	24	38	31	38
Vehicles Exited	17	16	17	13	25	24	25	23	37	30	38
Hourly Exit Rate	73	69	73	56	107	103	107	99	159	129	163

Table 7c: *North Bound Performance Traffic Simulation Results*

South Bound	8:00	8:15	8:30	8:45	12:15	12:30	12:45	1:00	4:30	5:00	5:15
Total Delay (hr)	0.1	0	0	0	0.1	0	0	0	0	0	0.1
Delay / Veh (s)	7.4	6.1	7.4	7	9.2	5.4	7.5	6.4	7	5.8	9.5
Total Stops	16	17	9	11	14	7	12	10	10	11	21
Travel Dist (mi)	4.6	4.5	3.3	3.3	3.1	3.2	3.2	3.2	3.7	4.6	4.9
Travel Time (hr)	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.2
Avg Speed (mph)	21	23	22	23	20	25	22	23	22	23	20
Fuel Used (gal)	0.3	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3
HC Emissions (g)	1	1	1	0	0	0	0	0	1	1	1
CO Emissions (g)	14	8	10	6	9	9	9	9	12	13	16
NOx Emissions (g)	3	2	2	1	2	2	2	2	2	2	3
Vehicles Entered	30	29	22	22	20	21	21	21	25	31	33
Vehicles Exited	30	29	20	21	20	21	21	21	23	29	31
Hourly Exit Rate	129	124	86	90	86	90	90	90	99	124	133

Table 7d: *South Bound Performance Traffic Simulation Results*

Observation Made for Vehicles, Fuel, and Emissions

The majority of fuel is consumed when accelerating from a stopped position to full speed. For stopped vehicles, the emissions and the fuel consumption are less per second when compared to moving vehicles. Because a majority of the vehicle's acceleration occurs after crossing the stop bar, the reporting of fuel consumption can be optimized if the evaluation is performed on the exiting vehicles. By increasing traffic flow, it is then possible to reduce emissions effects from idling vehicles.

6. Patent Review and Assessment of Approach

A patent review search was initiated to evaluate the CMV approach to intersection traffic management. There have been a multitude of patents filed between 1974 to the present. There were some similar approaches. However, the CMV concept is a unique approach, given our methodology, and warrants further research time to draw up a preliminary patent disclosure.

Of the patents filed, there were several patents that address similar aspects of traffic control. The following are a list of patent numbers and descriptions:

- **U.S. Pat. Nos. 4,985,705; 5,041,828; 4,908,615.** Describes methodology to compile and evaluate local traffic data via radar.

- **U.S. Pat. Nos. 5,432,547; 5,041,828; 5,734,337.** Describes methodology to use cameras to monitor traffic violations and record traffic statistics.
- **U.S. Pat. Nos. 5,448,219; 5,572,202, and French Patent No. 2562-694-A.** Describes methodology to detect vehicles approaching an intersection. In addition, describes mythology to warn motorists at intersections of approaching vehicles.
- **U.S. Pat. No. 4,352,086.** Describes methodology to modify traffic control information via circuit arrangements.
- **U.S. Pat. No. 4,370,718**. Describes methodology to control traffic lights based on the conservation of aggregate momentum.
- **U.S. Pat. No. 4,322,801**. Describes methodology to control traffic and traffic signals based on local requests for service.
- **German Patent No. DE 2,739,863**. Describes methodology to control traffic and traffic signals based on the detection of vehicles and pedestrians at an intersection.
- **U.S. Pat. No. 5,257,194**. Describes methodology to control traffic and traffic signals on a local level in conjunction with an area-wide traffic control system.
- **U.S. Pat. No. 5,444,442. U.S. Patent No. 5,444,442.** Describes methodology to use cameras to predict traffic flow rates and to use this information to control local traffic.
- **German Patent No. 2411716**. Describes methodology to control traffic signals by modeling the traffic light phase-splits after stored traffic flow models.
- **U.S. Pat. No. 5,357,436 and Japan Patent No 4-148299**. Describes methodology to control traffic and traffic signals via fuzzy logic algorithms.
- **U.S. Pat. No. 5,696,502. U.S. Pat. No. 5,696,502**. Describes methodology to detect traffic using a fuzzy logic processor.

The above list contains familiar traffic-management systems commercially available and we have not violated the claims outlined in the above patents. For example, **U.S. Pat. No. 4,370,718** describes a methodology to control traffic lights based on the conservation of aggregate momentum. The word "conservation" indicates a different approach from ours. This methodology is based on adaptive control of traffic signal timing, which is similar to our proposed system in that, in order to implement the CMV model and request the Claim-To-Green, we have to evaluate for how long (time) this condition will be maintained. However, signaling is dependent on intersection traffic patterns, not timing patterns. The proposed system will gather data of the intersection and impose timing depending on traffic flow.

The said patent will collect information generated by each sensor and is processed into three running aggregate quantities: aggregate momentum data, aggregate experienced congestion data, and aggregate stopped vehicles data. The CMV system will process only the information needed to make a decision of the approaching traffic and the Claim-To-Green. Therefore, the data collection is limited to the quantifying data, which are a function of the detection zone area, speed, and weight of vehicles approaching the intersection. Our approach is also based on letting the traffic flow control itself.

The said patent aggregate quantities are summed together in combinations determined by the traffic signal condition. The sums are compared with equivalent sums generated by processors associated with the intersecting roadway, generating a difference magnitude which in turn controls an adjustable rate clock, depending on existing signal conditions. In addition, embodiment of this invention uses vehicular length as equivalence to mass. Again, the CMV is evaluating a product of speed and vehicular weight of opposing accumulation and the aggregate quantifiers are not equal to the said claim. There are significant studies that have been put to the test as far as timing is concerned. The only timing aspect that is considered is the signals (Red, Yellow, Green) transitioning for the Claim-To-Green.

The aforesaid patent is similar, conceptually, to the CMV methodology. Further inspection of the full version of this patent report must me acquired and reviewed in order to unequivocally determine if the CMV concept is a viable patent. Only when this process is complete will there be an opportunity to request a submission for filing or review the CMV concept for refinement, thereby claiming an original concept.

7. CONCLUSIONS

The increased traffic volume has seriously changed the traffic patterns in growing urban areas, leading to increased traffic accidents, congestion, delays and a higher level of pollution (noise and air). Many approaches have been attempted, but cost is prohibitive if systems must be installed at many intersections. This report provides a clear-cut reason for improving existing intersection traffic controllers. It is urgent because injury and death factors due to traffic accidents are rapidly climbing, especially in the State of North Carolina. These facts provide the logical reasoning as to why providing a smarter solution is necessary.

It is our intent to demonstrate a smarter methodology that will provide a solution to the foregoing problem. The approach that will solve this problem is through the implementation of a Cumulative Momentum Value (CMV) for intersection traffic management control. We have exemplified the methodology of the proposed CMV and have provided a step-by-step process of its capability. This process is designed to enhance traffic negotiation for intersection right of way. We have demonstrated how the proposed traffic system will allow priority to heavy vehicles such as buses and commercial trucks. These features are not yet available in current traffic control systems.

The Market and Dudley (focused beta site) intersection was revisited, the layout and the data analysis were used for further optimization of a detection zone. The layout was modified to accept the embedded-fiber detectors. The layout modification allowed for a new detection scheme. Also, the layout and data were used as input data to perform traffic-pattern simulations. Based on the simulation results, we are able to predict congestion level, vehicle fuel consumption, and emission levels as well as provide a way to measure how successful the CMV model could be prior to installation.

We have initiated a patent search and have compared our findings to the proposed CMV methodology. The initial review was intended to find as my patents that were similar to the CMV concept and to research their claims. A patent review search was initiated to evaluate the CMV approach to intersection traffic management problem. The results of this search presented similar patented concepts that may be aligned with our claims. However, the research was limited to a short text summary of the full document. By reviewing the full document, we will be able to determine if in fact the CMV concept is an original idea. For the ones that were reviewed under this approach, there is enough of a unique approach with our methodology to warrant further research time and allow for refinement of our approach in order to draw up a preliminary patent disclosure.

For future work, our goal is to facilitate the implementation of the proposed stand-alone zone traffic control system. We have assigned additional students from computer science and electrical engineering to this project. These students will have an immediate impact on the project from a development and design standpoint. We will continue to investigate similar patents and depending on our finding, will assess the potential for a patent filing. Also, it is our intent to initiate more frequent communications with the local DOT. Through this communication we hope to determine proper protocol for new product launch, within a government controlled setting. We expect that the relationship maintained with the local DOT will add value to this project, and the guidance of experienced traffic engineers will influence a successful and positive outcome for this project. It is also essential that legal ramifications must be assessed related to the installation of such a system at a city intersection. Thus, thorough planning, laboratory and field testing must be carried out first on campus before any plan is made to negotiate with the city DOT for actual city street installation.

BIBLIOGRAPHY

Reports

- Practical Approach to Managing Intersection Traffic Data for Large Scale Studies; Gerken, Jeff

Simulation Tools

- Syncro-4 Traffic Capacity Software

Websites

- http://hyperphysics.phy-astr.gsu.edu/hbase/ke.html
- http://www.cigreensboro.nc.us/transit

A.T. Ali and E.L. Dagless, "Computer vision for automatic road traffic analysis," in *ICARCV 90, Proceeding International Conference on Automation, Robotics and Computer Vision*, Sept. 19-21, 1990, pp. 875-879.

R. Ashworth, D.G. Darkin, K.W. Dickinson, M.G. Hartley, C.L. Wan, and R.C. Waterfall, "Applications of video image processing for traffic control systems," in *Proceedings 2nd International Conference on Road Traffic Control*, London, U.K., Apr. 14-18, 1985, pp. 119-122.

K.W. Dickinson and R.C. Waterfall, "Video image processing for monitoring road traffic," in *IEE International Conference on Road Traffic Data Collection*, Dec. 5-7, 1984.

M. Fathy and M.Y. Siyal, "An image detection technique based on morphological edge detection and background differencing for real-time traffic analysis," *Pattern Recognition Letters*, Vol. 16, No. 12, pp. 1321-1330, 1995.

N. Hashimoto, Y. Kumagai, K. Sakai, K. Sugimoto, Y. Ito, K. Sawai, and K. Nishiyama, "Development of an image-processing traffic flow measuring system," *Sumitomo Electric Tech. Rev.*, No. 25, pp. 133-137, 1986.

N. Hatsopoulos, F. Gabbiani, and G. Laurent, "Collision-avoidance system based on optical flow," *Proceedings of the IEEE Intelligent Vehicles Symposium*," London, England, pp. 79-84.

N. Hoose and L.G. Willumsen, "Automatically extracting traffic data from videotape using the CLIP4 parallel image processor," *Pattern Recognition Letters*, Vol. 6, No. 3, pp. 199-213, 1987.

M. Kilger, "Video-based traffic monitoring," in *International Conference on Image Processing and its Applications*, Apr. 7-9, 1992, Maastricht, Netherlands.

J.L. Kim, J.-C.S. Liu, P.I. Swarnam, and T. Urbanik, "The areawide real-time traffic control (ARTC) system: A new traffic control concept," *IEEE Transaction on Vehicular Technology*, Vol. 42, No. 2, pp. 212-224.

S. Takaba, M. Sakauchi, T. Kaneko, B. Won-Hwang, and T. Sekine, "Measurement of traffic flow using real time processing of moving pictures,"in *Proceedings of the 32nd IEEE Vehicular Technology Conference*," San Diego, California, May 23-26, 1982, pp. 488-494.

A.D. Worrall, G.D. Sullivan, and K.D. Baker, "A simple, intuitive camera calibration tool for natural image, " in *Proceedings 5th British Machine Vision Conference*," York, U.K., Sept. 13-16, 1994, pp. 781-790.

J. Zifeng, "Macro and micro freeway automatic incident detection(aid) methods based on image processing," in *Proceedings IEEE Conference on Intelligent Transportation Systems*, Boston, Massachusetts, Nov. 9-12, 1997, pp. 344-349.

APPENDIX

Patent Search

5010319	Apr., 1991	Killinger	340/472.
5041828	Aug., 1991	Loeven	340/937.
5161107	Nov., 1992	Mayeaux	364/436.
5164904	Nov., 1992	Sumner	364/436.
5182555	Jan., 1993	Sumner	340/905.
5206641	Apr., 1993	Grant et al.	340/905.
5214793	May., 1993	Conway et al.	455/49.
5257023	Oct., 1993	Furuya	340/995.
5257194	Oct., 1993	Sakita	364/436.
5270708	Dec., 1993	Kamishima	340/995.
5294924	Mar., 1994	Dydzyk	340/908.
5313200	May., 1994	Sone	340/905.
5317311	May., 1994	Martelo et al.	340/905.
5357436	Oct., 1994	Chiu	364/436.
5396429	Mar., 1995	Hanchett	364/436.
5432547	Jul., 1995	Toyama	348/149.
5444442	Aug., 1995	Sadakata et al.	340/916.
5448219	Sep., 1995	Yoshikawa et al.	340/436.
5459665	Oct., 1995	Hikita et al.	364/437.
5493291	Feb., 1996	Bruggemann	340/905.
5504488	Apr., 1996	Henderson	342/115.
5572202	Nov., 1996	Regel et al.	340/917.
5652705	Jul., 1997	Spiess	364/436.
5668717	Sep., 1997	Spall	364/148.
5696502	Dec., 1997	Busch et al.	340/905.
5699056	Dec., 1997	Yoshida	340/905.
5729214	Mar., 1998	Moore	340/905.
5732383	Mar., 1998	Foladare et al.	701/117.
5734337	Mar., 1998	Kupersmit	340/937.
5771484	Jun., 1998	Tognazzini	701/117.

Foreign Patent Documents

80/000009	Jun., 1980	BR.
2 411 716	Mar., 1974	DE.
27 39 863	Sep., 1977	DE.
2 562 694	Oct., 1985	FR.
3-157799	Jul., 1991	JP.
4-148299	May., 1992	JP.