

Fiber Optic Implementation of a Cumulative Momentum Model for Natural Urban Intersection Traffic Management

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ABSTRACT

We propose an agile and cost-effective urban intersection traffic management model based on the competitive cumulative momentum (CCMV) of vehicles. It is to be implemented by an in-ground fiber optic load sensor system. The model will address congestion relief, bus and truck signal priority in order to reduce excessive bus and truck idling and delays, and the prevention of red light running. The cumulative momentum (CMV) values of traffic in cross streets at an intersection are compared, and the higher CMV value commands the GREEN. A related static cumulative mass or weight (CM) model will be employed to manage vehicle traffic in left turn lanes at intersections with two-way traffic, and also pedestrian crossing traffic. The combined CCMV and CM model replicates precisely the way a traffic cop manages intersection traffic. The GREEN will lower the CMV of a street, while traffic in the cross street continues to build. Naturally, when those two discrete values are cross then so will the command of the Green. This competitive process allows traffic flow to alternate at an intersection based on traffic volume. The CM model will determine when cumulative weight in left turn lanes and at the curb of pedestrian crossings should trigger the Green. We also propose a kinetic energy ($KE = MV^2/2$) model to emphasize speed-controlled traffic signal in the case of speeding vehicles that may run a red light. The proposed fiber optic load sensor systems are commercially available. They are capable of performing axle detection and counting, speed measurement, gap measurement, vehicle classification and recognition. These in-ground systems can be readily installed flush with 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.

Key words: fiber optics—traffic management—traffic signal

PROBLEM STATEMENT

The inevitable increase in traffic density with urban growth is demanding new ways to monitor, manage, control and optimize traffic flow, and to obtain information for long term planning of transportation infrastructure. Many impact studies have been reported on urban traffic congestion, fuel consumption, pollution, noise and public transit rider-ship woes. Advanced traffic management and intelligent transportation systems have been proposed and developed. Urban Traffic Intersection Management is the essential issue. The task lies in accurate and quick data acquisition and processing of critical parameters at the intersections of traffic arteries. We have proposed to specifically address urban intersection traffic control.

Current traffic signaling technology at intersections in the Triad cities is mainly based on inductive loops, embedded in the pavement at intersection approaches. The loop creates a magnetic field, and when disturbed by a vehicle moving through it, sends a signal to the control box. The system has a short range, and performs mainly vehicle counting. In terms of software, these traffic signals run on fixed clock cycles, so that often traffic in a busy lane is being held up by the "Red", while the low traffic lane has the "Green", creating a potential red light running situation by frustrated drivers.

It appears that public transit in cities of the size of Winston-Salem and Greensboro faces steady decline in rider-ship, to the point that such city service is constantly running in the red. The cause lies in the glaring disparity in convenience between personal and public transportation. In addition, due to frequent stops, public transit buses often miss the green at clocked intersections, leading to excessive travel delays. This further discourages rider-ship. Idling of city and school buses and heavy vehicles at urban intersections also contributes to air pollution and waste of fuel. North Carolina ranked fourth nationally in the number of smog days in year 2000 among industrial states, such as Pennsylvania, Ohio, Maryland, New Jersey. The EPA has just announced a National Clean School Bus Act to reduce pollution of diesel engine emissions.

PROPOSED APPROACHES

To improve urban intersection traffic management, we have proposed an "intelligent" traffic signaling system actuated on demand, patterning after the traffic management style of a "traffic cop" at an intersection. The "cop" must have sufficient vision to view approaching traffic for a rough estimate of traffic flow in cross streets. He/she then made a decision normally to let the lane with heavier traffic volume go first. This process would then alternate according to land demand. Long range detection can be above ground, or in the roadbed. In addition, the algorithms for traffic management must be cost effective, and hence "smart", requiring minimum data acquisition and processing. Much deliberation has been given to the selection of traffic flow parameters to be monitored so as to arrive at a high performance and cost effective system. It must also include Green Preference for public transit and heavy vehicles. Several of these algorithms are now commercially available. However, all these must be preprogrammed into the systems, and hence differ significantly from the on- the-spot free management style of the traffic cop. We have proposed a natural algorithm that mimics the mind of the cop as he/she views the traffic picture at an intersection and makes appropriate decisions. This has resulted in a "Claim to Green" formula. It was an attempt to quantify the traffic cop's thought process. Initially, the formula was based on vehicle length, representing vehicle weight, vehicle speed and vehicle distance from the intersection. The determining factor used for claim to green was the kinetic energy or vehicle length x (speed)².

Green Demand algorithm raises priority as standing vehicle waiting time increase. For moving vehicles farther than 50 ft from the intersection, Green Demand is defined as the ratio of the kinetic energy of each vehicle and its distance from the intersection. The quantity is then summed over each lane. The nearer, faster and heavier the vehicle group, the higher the Green Demand priority. The algorithm will continuously update the Claim-to-Green in each lane, based on cumulative kinetic energy and cumulative elapsed waiting time on approach.

The Green Demand algorithm as postulated above resembles the mindset of the traffic cop at an intersection. The formula has simply quantified his/her thought process. For instance, vehicles far from the intersection would automatically command a lower Green priority due to the limited vision of the cop. He/she can also estimate vehicle weight by its size, although not exactly. Nevertheless, vehicle size does command his attention, thus increasing the Green Claim. It is also unlikely that a human can readily compute kinetic energy mentally, although a sense of vehicle speed comes rather naturally. Furthermore, squaring the speed so as to compute kinetic energy unduly emphasizes vehicle speed more than weight. For instance, a sedan weighing one quarter that of a bus, will have the same kinetic energy if its speed is twice that of the bus. However, if we were to measure momentum, instead of kinetic energy, then both weight and speed are treated equally. In this case, a bus four times the sedan weight traveling at half the speed will still have more momentum than a light sedan, traveling at twice the bus speed.

The momentum concept is taken one step further to include cumulative momentum of all vehicles measured over a designated time period. This departs from the standard vehicle counting systems. As long as the load sensor registers the weight of the passing vehicle or vehicles. Hence, even two or more vehicles pass over the same load sensor; the cumulative weight will be recorded and counted as a single vehicle. If they have different speeds, then they will not pass the second load sensor at the same time. This scenario clearly illustrates the beauty of the system. It needs to monitor only a minimum of traffic parameters, and should thus be most economical and robust. This system allows the cumulative momentum of cross streets to compete: The higher value automatically commands the Green. We have thus arrived at an intersection traffic signal system that implements the claim to Green algorithm naturally.

We therefore propose an agile and cost-effective urban intersection traffic management model based on the competitive cumulative momentum (CCMV) of vehicles. It is to be implemented by an in-ground fiber optic load sensor system. The model will address congestion relief, bus and truck signal priority in order to reduce excessive bus and truck idling and delays, and the prevention of red light running. The cumulative momentum (CCMV) values of traffic in cross streets at an intersection are compared, and the higher CMV value commands the GREEN. A related static cumulative mass or weight (CM) model will be employed to manage vehicle traffic in left turn lanes at intersections with two-way traffic, and also pedestrian crossing traffic. The combined CCMV and CM model replicates precisely the way a traffic cop manages intersection traffic. The GREEN will lower the CMV of a street, while traffic in the cross street continues to build. Naturally, when the two values cross so will the command for the GREEN. This competitive process allows traffic flow to alternate at an intersection based on traffic volume. The CM model will determine when cumulative weight in left turn lanes and at the curb of pedestrian crossing should trigger the Green. We also proposed a kinetic energy ($KE = MV^2/2$) model to emphasize speed-controlled traffic signal in the case of speeding vehicles that may run a red light.

The CMV or cumulative momentum ($MV =$ product of vehicle mass or weight and its velocity or speed) model sums the momentum of N vehicles counted within a certain zone of a street over a certain time period. The CMV's of traffic of all cross streets at an urban intersection are compiled

and compared or "allowed to compete". The street with the higher CMV commands the Green, hence named the competitive cumulative MV or CCMV model. The CMV model automatically favors heavier vehicles, such as buses and trucks, which normally ply the main streets. Hence, main street traffic commands the Green more frequently. Left-turn lane, traffic in two-way streets and pedestrian crossings are included by adding a static cumulative mass (weight) or CM model programmed within the CCMV model. The combined CCMV and CM model replicates precisely the traffic cop, directing traffic at an intersection. The street with the Green will naturally have its CMV lowered, while that of the cross street continues to build. At some point, their CMV numbers will cross, and the Green command changes hand. This competitive process causes the Green signal to alternate naturally and intelligently, since no Green threshold is preprogrammed.

ADOPTED DETECTOR TECHNOLOGY AND ITS IMPLEMENTATION

A portable IRD fiber optic load traffic sensor system will be purchased and tested first at a test site on campus under well-controlled conditions. This is aimed at checking out the system hardware and software for axle counting and speed measurement. System software and hardware must then be modified or reconfigured for momentum measurement. Known test conditions and parameters are established: number and type of vehicles, their speeds and weights and wheel and tire sizes, site layout, and sensor installation issues. System capability must be further upgraded for cumulative momentum or CMV data acquisition and processing. This may involve integration and modification of the IRD fiber optic sensor hardware, and writing our own software or algorithms. After these preliminary tests are completed successfully, then additional components will be purchased to constitute two pilot systems for CCMV model testing at the A & T Intersection or ATI site. This site is selected for pilot system testing since we will incur minimum disruption to city traffic due to remoteness of site from downtown, and proximity to the campus. The IRD optoelectronic interface TCC 540 is capable of binning data by number of axles and spacing classification, binning individual vehicle speed, and overall length, gap between vehicles from the tail of the leading vehicle to the nose of the following vehicle, and binning headway by the time of vehicles going in the same direction, from the nose of the leading vehicle to the nose of the following vehicle. The interface must be integrated with current traffic control systems. Existing control systems run mainly on clocks, and are not intelligent systems. Substantial collaboration is planned between this group and the twin-city DOT's in interfacing sensors with existing traffic signal controls.

TEST SITE DATA AND DESIGN

To implement this model, we have chosen 10 blocks of downtown Greensboro along Friendly Avenue and Market Street and the East Market-Bennett intersection (henceforth named the A & T Intersection or ATI) as the two test sites. Downtown with a major city bus hub and daily traffic volume of 20,000 per intersection is ideal for testing the impact of bus signal priority on busy intersections along the two major thoroughfares. The ATI site has two-way traffic and left turn lanes. Pedestrian crossings are present at both sites.

Bus route preliminary analysis has identified 10 intersections with 10 traffic lights along the 10 blocks. There are three bus tops along Friendly, as buses depart the hub, and 10 stops along Market, as buses return to the hub. Bus route schedules and delays due to frequent stops must be analyzed and actual data gathered. They will be to arrive at average bus speeds between intersections and the impact of bus signal priority on overall traffic flow in downtown Greensboro

during rush hours. The CCMV + CM Intersection traffic management model will be first simulated for the chosen test sites using the Synchro 4 software package.

An International Road Dynamics (IRD) portable fiber optic load sensor + IRD TCC 540 multi-lane Traffic Counter/Classifier will be purchased and installed for preliminary proof of concept tests on campus grounds. It will be tested for ease of installation, ruggedness against most road hazards, durability, susceptibility to roadbed vibration noise, sensitivity to vehicle weights, calibration of load dependent signals, signal processing and optical to electronic interface for traffic signal control. The system will be tested for MV, CMV, and combined CM + CCMV model implementation.

To implement and test the CCMV model properly, actual test site traffic volume data must be established. Thus, in addition to publicly available traffic data about the sites, more precise and specific data must be sought from the Greensboro DOT. Collaboration similar to that established with Winston Salem DOT is planned. Statistical data on the traffic volumes at each of the 10 intersections along Friendly and Market, especially, during the two rush hour periods, are essential for the design of the capacity of the CCMV model. The amount of bus traffic and the severity of bus delays due to frequent stops for passenger pickup and drop-off along the two main thoroughfares must be known statistically. These numbers will aid us in assigning CCMV capacities to different intersections for optimum traffic flow control along the 10 blocks. Traffic flow data will first be input into the Synchro 4 simulation tool for a direct diagramming of the 10 intersection traffic patterns. This will enable us to have a clearer picture of traffic along the main and side streets and bus traffic, as well. A table of the 10 downtown blocks and bus schedule and potential delays due to stops are tabulated below.

TABLE 1: Test Beta Site

East Bound	Miles	North/South Bound	West Bound
Market St.	0	Murrow Blvd.	Friendly Ave.
Market St.	0.12	London Street	Friendly Ave.
Market St.	0.1	S. Church St.	Friendly Ave.
Market St.	0.12	N. Davie St.	Friendly Ave.
Market St.	0.08	N. Elm	Friendly Ave.
Market St.	0.07	N. Green St.	Friendly Ave.
Market St.	0.06	Commerce Place	Friendly Ave.
Market St.	0.08	N. Eugene	Friendly Ave.
Market St.	0.12	N. Edgeworth	Friendly Ave.
Market St.	<u>0.07</u>	N. Spring St.	Friendly Ave.
Total Miles	0.82		

Source: 2002 Yellow Pages

Friendly and Market along the 10 downtown blocks have only one way traffic without left turn lanes, but do have pedestrian crossings, This test site is ideal for the demonstration of the CCMV model. On the other hand, the ATI test site has two-way traffic on both East Market and Bennett/Yanceyville, four-left turn lanes and pedestrian crossings. However, since this is an isolated intersection in this area with sufficient traffic volume and proximity to A & T, it serves as an ideal site for testing the CCMV + CM model.

DEFINING THE BETA SITE

Physical Layout

Figure 1 (Dudley St. and Market St.) shows a complete layout of the signal application for the Dudley and Market intersection. There are a total of 4 push button devices, 4-induction loop detectors for all 4 left turning lanes, and induction loop detector for all lanes approaching the intersection on Dudley Street. There are no induction loop detectors for through traffic detection approaching Market Street, at the intersection. The detectors are located 180-feet from the stop bar on Market Street. The detectors record vehicle’s presents while approaching the intersection,

and during idle traffic mode or while traffic build up.

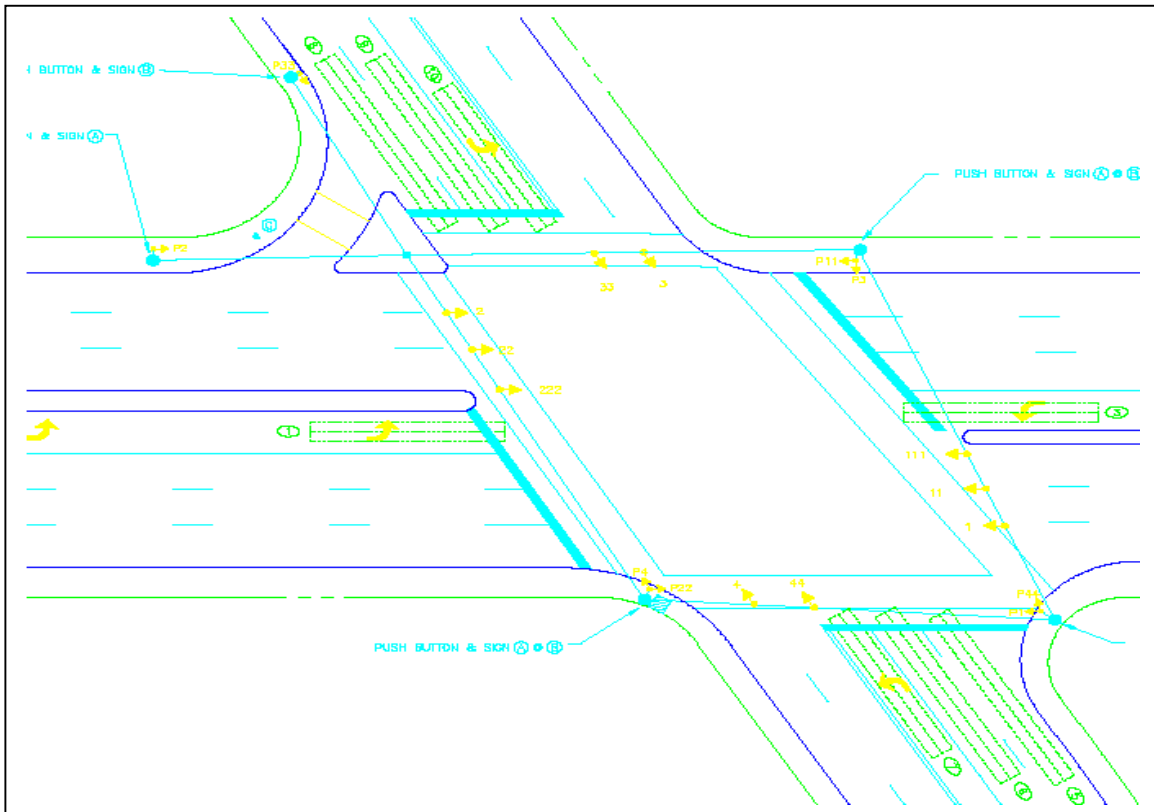


FIGURE 1: Dudley St. and Market St. Intersection (ATI Site)

Data Source: *Greensboro, NC DOT*

The in-ground induction loops are documented as having 3 different lengths: 6' X 30', 6' X 50' and 6' X 60'. The significance for the variance in length can be an attribute for the need to monitor over a specific distance. There are no initial plans to change the layout for this site. Comparison data will be gathered simultaneously to determine the optimal layout. We may determine that we need a longer detection zone than what the loop detectors provide. This will increase the accuracy for forecasting priority and signal time duration. The fiber optic detector will provide the accuracy and repeatability of similar or better quality, compared to the loop detector.

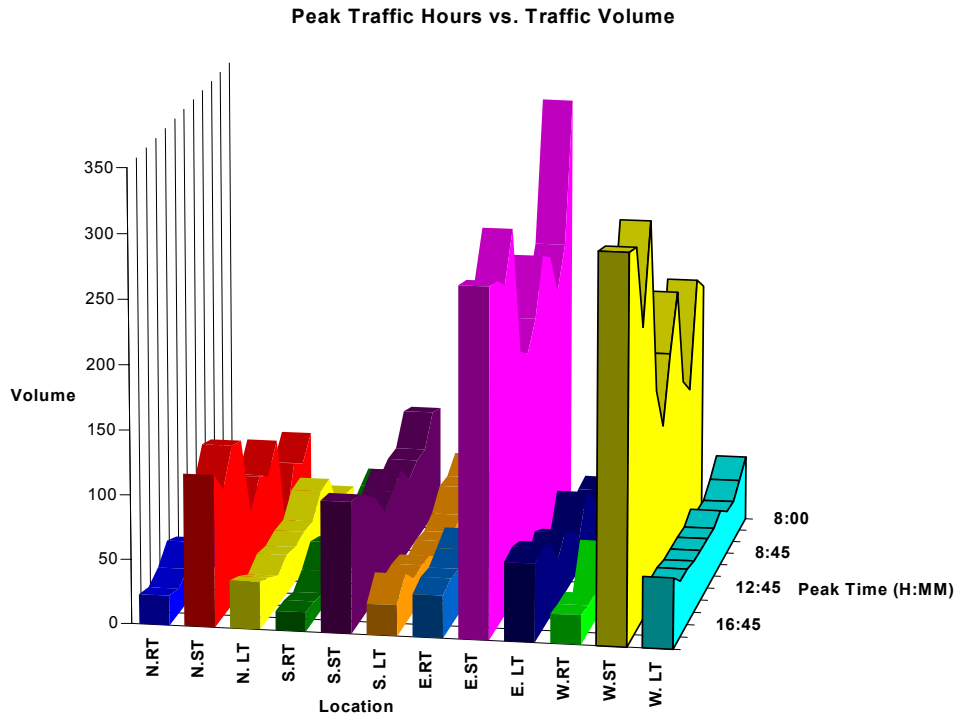


FIGURE 2: Peak Traffic Hours vs. Traffic Volume

Data Source: *Greensboro, NC DOT*

Traffic Volume

Traffic Volume data was furnished by the Greensboro DOT for this beta site. Figure 2 is a 3D graph of the traffic volume vs. location and peak time. The Graph indicates, on the average, east and westbound traffic volume is approximately 3 times more than north and south bound traffic. The left and right turning volumes were not one-to-one, but the delta range is within 67% between East/West and North/South bound traffic.

TABLE 2: Peak Traffic Data for Market and Dudley

From East on Market St.				From West on Market St.			
	Right	Straight	Left		Right	Straight	Left
8:00	23	330	29	8:00	25	186	50
8:15	40	223	27	8:15	16	199	40
8:30	24	194	22	8:30	23	120	32
8:45	24	229	39	8:45	27	135	33
12:15	65	238	53	12:15	29	214	43
12:30	26	197	26	12:30	7	174	38
12:45	22	178	41	12:45	24	126	39
13:00	48	188	48	13:00	43	162	39
16:30	41	291	36	16:30	9	301	40
16:45	35	256	59	16:45	21	228	43
17:00	37	267	64	17:00	21	297	43
17:15	33	271	61	17:15	23	301	55

From South on Dudley St				From North on Dudley St			
Time	Right	Straight	Left		Right	Straight	Left
8:00	27	79	43	8:00	9	54	12
8:15	22	84	33	8:15	10	38	15
8:30	15	63	34	8:30	12	47	14
8:45	22	63	21	8:45	2	6	45
12:15	18	57	16	12:15	30	83	44
12:30	16	73	18	12:30	16	64	29
12:45	27	65	15	12:45	15	72	30
13:00	32	58	25	13:00	31	54	27
16:30	19	77	27	16:30	37	118	30
16:45	11	89	26	16:45	25	123	23
17:00	14	99	39	17:00	19	98	31
17:15	15	102	24	17:15	23	118	37

Data Source: Greensboro DOT

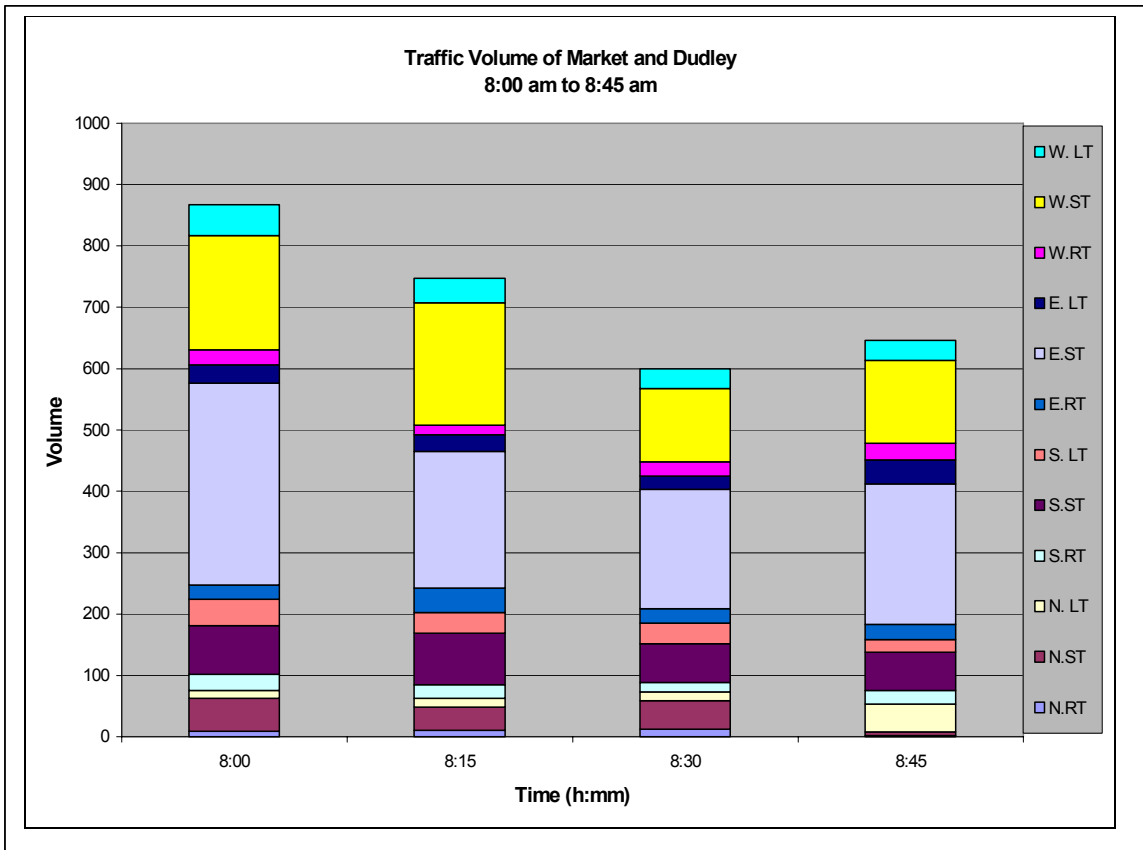


FIGURE 3: Volume Contribution at Intersection
 Data Source: Greensboro DOT

Public Transit Data for Claim-to-Green

The challenge is to demonstrate how rider-ship can be improved not only for passengers but also for all travelers. The bus travel impacts all in its path, for example the multiple stops along a desired bus route has an impact on the vehicles traveling behind it. The effects on normal traffic flow from high KE-vehicles are delays in free flow travel time and queuing. The vehicles’ slower take off at intersections and scheduled bus stops, compare to a smaller vehicle travel, and reduces the traffic flow from point “A” to “B”. When a bus is behind schedule the passenger is potentially behind schedule. All these examples demonstrate the reasoning for improving bus rider-ship.

The model that is presented is derived using 10-city blocks as a beta test site. This site was chosen because it is a major transition (transfer) point for majority of the bus routes in the city of Greensboro. The major through street is Market Street, which is the primary street that buses leave from the transfer terminal-located on Davie Street. From Market Street these 10-cross streets are a prime means for bus transition to their designed routes. According to the Greensboro Transit Authority the minimum average daily traffic volume is greater than 20,000 vehicle on any of the give cross streets. This is a significant and a demanding amount of traffic to manage on a daily basis.

SIMULATION

At this point in the research, field study is performed to gather additional data (volumes, geometry, timing, phasing, etc.) about traffic conditions during peak-and off-peak times. This information will then be input for the simulation. The simulation tool used so far is the demo version of Synchro-4, a package for modeling and optimizing traffic-signal timings. At this time, the software will not allow simulation for ten city blocks, so the full version will be purchased. This tool will allow for modeling actuated signals, skipping and gapping behavior, and applying the information for delay modeling.

CONCLUSION

Two new concepts have been proposed for urban intersection traffic management: the use of vehicle kinetic energy and alternately, momentum, explicitly as a traffic flow parameter, and the traffic management patterned after a traffic cop. The enunciated objective was to relieve urban traffic congestion at urban intersections, thus rendering traffic more environmentally responsible by reducing fuel consumption due to idling, especially by heavier vehicles, and promoting public transit ridership. We believe the proposed scheme should work on paper. By resorting to physics of vehicle motion or kinematics, such as momentum MV or kinetic energy KE in the CCMV model, we have incorporated physics into the geometry of traffic flow. It is almost a scientific axiom that the more elaborate the formulations of a solution scheme to a problem, the simpler the implementation. Therefore, we anticipate a simpler implementation. Since momentum is the essential parameter, vehicle weight measurement must be performed. Present-day above ground detection systems are unable to measure vehicle weight, and hence, rely on studying the geometry for traffic flow. The induction loops, although installed in-ground, detect only inductance change that is unrelated to vehicle weight. Our smart “traffic cop” concept originally proposed required vision of the traffic scene, and naturally pointed to an aboveground system. As the old saying goes: “to see far, you must climb high,” thus aboveground. Our system would have the same limitations as all aboveground systems. In this case, the only means to measure vehicle momentum or the product of weight and speed was to infer weight from vehicle length or size. The speed could be found geometrically by measuring distance covered within a certain period. Our success would have been limited since vehicle weight is not necessarily reflected by its length or size. Even if we did make that correlation, vehicle length measured using overhead cameras would be highly dependent on the aspect or the relative orientation or angle between the vehicle and the camera. Light conditions could potentially affect the accuracy of such measurements as well. We have thus switched to an in-ground fiber optic load sensor, which we found to be much less costly than an Autoscope MVP system. The cost of the latter was beyond our originally proposed budget. However, the downside is that this switch has cost us valuable time. A significant part of the delay was caused by the campus integrated software support policy. Thus, if the campus Center of Information Technology could not support the purchased software, then such software purchase would be allowed. Our TCC 450 software for traffic counter/classifier was deemed to be in that category. After lengthy negotiations, we were able to purchase it. We have however, passed the extended deadline of the project. Fortunately, a follow-up proposal using CCMV model has been founded. So, the implementation phase of the proposed work will continue.

We have also downsized kinetic energy (MV^2) to momentum (MV), so as to treat vehicle weight and speed at par. This also renders velocity or speed measurement linear, thus simplifying data

processing. We plan to emphasize the Claim-to-Green algorithm for public transit and heavier vehicles. This is automatically incorporated in the CCMV model. Thus, the main street, in which most buses and trucks ply, will automatically command the Green. The impact study to work on the Green extension and its impact on cross streets is in progress.

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