Determining Surface Street LOS Using Existing Detector Infrastructure: Monitoring Commuter Congestion on Surface Streets in the Salt Lake Valley

Dr. Peter T. Martin PhD, Associate Professor
Joseph Perrin PhD, PE, PTOE

Research Assistant:
Brad Coleman,

University of Utah

Prepared for the Utah Department of Transportation

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LIST OF ACRONYMS

TOC – Traffic Operations Center

UDOT – Utah Department of Transportation

UTL – Utah Traffic Lab

LOS – Level-of-Service

HCM – Highway Capacity Manual

ICONS – Integrated Control of Traffic Networks

ATMS – Advanced Traffic Management Systems

RLR – Red Light Runner

NETSIM – NETwork SIMulation

FRESIM – FREeway SIMulation

cg – cumulative green time

5-min Cap – 5-minute Capacity

v/c – Volume to capacity ratio

g – Green-time

C – Cycle length

CCA – Commuter Congestion Algorithm

FAPO – Floating Average Percent Occupancy

EXECUTIVE SUMMARY

The Utah Traffic Operation Center (TOC) currently monitors freeway congestion using speed detectors spaced 800 meters apart. The speed information for each section of the freeways is returned to the TOC and the information is displayed on an electronic map. TOC operators can determine quickly where congestion occurs based on speeds of the vehicles on the freeway. There is a strong interest in developing a similar map for the arterials. The purpose of this research is to develop an algorithm that enables TOC operators to monitor commuter congestion along the surface street arterials. This research requires using the existing hardware or hardware which is planned to be used in the Salt Lake Valley.

The Utah Department of Transportation (UDOT) is installing system detectors at intersections along the major arterials. These detectors are linked to traffic signal controllers and can communicate volume and occupancy information in five-minute intervals. At some locations, separate speed and left turn queue detectors have been installed. The TOC uses ICONS for its signal management system. ICONS is the acronym for integrated control of networks. It provides a centralized, integrated platform for traffic signal system control, information management, and graphical data display. It polls each controller for signal timing information every second. The goal of this research is to determine if the TOC can monitor surface street commuter congestion using existing data collection from available field devices. Some devices have constraints placed on the data collection, i.e. flow in five-minute intervals, occupancy in five-minute intervals, and signal timing (green time and cycle length) in one-second intervals.

The University of Utah Traffic Lab (UTL) researched Arterial Level-Of-Service (LOS) to see if a similar algorithm had been developed for real-time commuter observation. Arterial LOS is widely understood to be an average travel speed along an arterial and a standard for traffic planning and evaluation tool. Current research is focused primarily on using Arterial LOS for planning. Many researchers have altered certain variables required for the Arterial LOS calculations, as defined in the Highway Capacity Manual (HCM), to obtain more exact estimates of local traffic conditions. Research addresses the ability to use Arterial LOS as a commuter-monitoring device or using the Arterial LOS for real-time calculations.

Research is constrained by available information that makes using direct calculation of the Arterial LOS as defined in the Highway Capacity Manual (HCM) infeasible. Arterial LOS requires that vehicles be timed as they travel at least one mile on an arterial. This approach could be automated by installing cameras that can track specific vehicles through every intersection of the corridor. This may be possible through some of the visual image processing efforts ongoing at Utah State University. However, this does not fit in constraints given to the UTL.

Arterial LOS is strongly influenced by intersection operations. Intersections typically are capacity constraints for a corridor and congestion will first occur at these points, then progress along the arterial. By identifying congested intersections, the TOC operators can watch for excessive delays and increased hazards.

Hardware constraints focus the research to arterial intersections and their proficiency. The traffic simulation program CORSIM was used to simulate a model of a traffic signal under several traffic conditions. This model used detectors to record volume, occupancy, and the signal throughout the simulation. The model recorded occupancy in 0.1-second intervals, the signal (as red "R" or green "G") in 1-second intervals, and a cumulative vehicle count.

The model was first used to simulate a two-hour peak period, where volume increases the first hour and decreases the second. Then the model was used to simulate congested conditions for intersections operating with different cycle lengths and green-times. Data from the simulations were analyzed and used to form two equations. The first equation estimates the five-minute capacity of an intersection given the cycle length and a fixed green-time. The second equation, a generalization of the first, estimates the five-minute capacity given the cumulative green-time or the total number of seconds of green-time during the five-minute period. The generalized equation accommodates actuated signals and signal extensions that cause longer or shorter cycles. Therefore, a general equation that requires only cumulative green time estimates capacity for varying green-time more accurately. This complete algorithm is called the Commuter Congestion Algorithm (CCA).

The equation used in CCA predicts the capacity of an intersection in five-minute intervals. The CCA equation is compared with the HCM Capacity Equation and field data from video and detectors. The CCA equation estimates typically are 2-5 vehicles closer to the field data than the Capacity Equation. CCA estimates the five-minute capacity of an intersection movement based on the geometry and cumulative five-minute green time for that movement. This calculated capacity then is compared to the five-minute approach volume and occupancy from the system detectors. This comparison is one way of measuring the level of traffic passing through an intersection approach. The calculated capacity was within 5 percent of the field data.

CCA satisfies requirements of the research by providing a method for estimating congestion on surface streets using the existing or planned UDOT hardware. A small algorithm with the equation is provided to allow system integrators to understand and implement CCA. With CCA, the TOC will be able to monitor commuter congestion along arterials that have system detectors installed. The TOC system integrator will need to route the input components to CCA and interface an arterial map to display the estimated congestion.

The findings of this research were presented at the 81st Transportation Research Board, January 15, 2002, by Dr. Joseph Perrin, and were recommended for publication.

CHAPTER 1: INTRODUCTION

Traffic congestion is a major problem for many U.S. cities. While the Advanced Traffic Management System (ATMS) is a major resource to traffic engineers and informs them of congested locations and accidents, it focuses heavily on freeways for real-time information. The current speed-flow map of the freeways, coupled with complete freeway video coverage has increased response time substantially for accidents and congestion. Signal-timing updates have greatly reduced congestion on the arterials. However, few techniques are available to monitor surface streets in real-time. This research focuses on real-time congestion monitoring, a unique direction, as most other cities focus solely on freeway operations as they are easier to monitor. Once surface street congestion is monitored successfully, recurring problematic locations can be identified, and solutions can be developed, tested, then tracked. The results of this research have the potential to substantially reduce delays.

Many transportation engineers use Level of Service (LOS) as defined in the Highway Capacity Manual (HCM) to measure operating conditions on freeways and surface streets. LOS is delimited by assigning a letter (“A” through “F”) to represent the average traveling conditions; “A” representing uninhibited or “free-flow” traveling conditions and “F” representing congested or gridlock conditions. It is described as being the difference between the actual travel speeds along an arterial relative to the theoretical free-flow speed along the same length.

Utah’s TOC can use LOS to monitor progression on the freeway network in combination with detectors embedded along the freeway and an electronic map of the freeways. Detectors record vehicle speed as they are driven over the detectors. The speeds are sent automatically to the TOC. If the speeds are faster than 51 mph, then the commuter condition is defined as “Green” or free-flowing traffic. However, if the speeds fall between 31 to 50 mph or 0 to 30 mph, the commuter condition is defined as “Amber” (heavy traffic) or “Red” (congested traffic) respectively. Finally, the commuter progression color for each section of highway is projected onto an overhead display map highlighting the particular highway (see Figure 1.1).

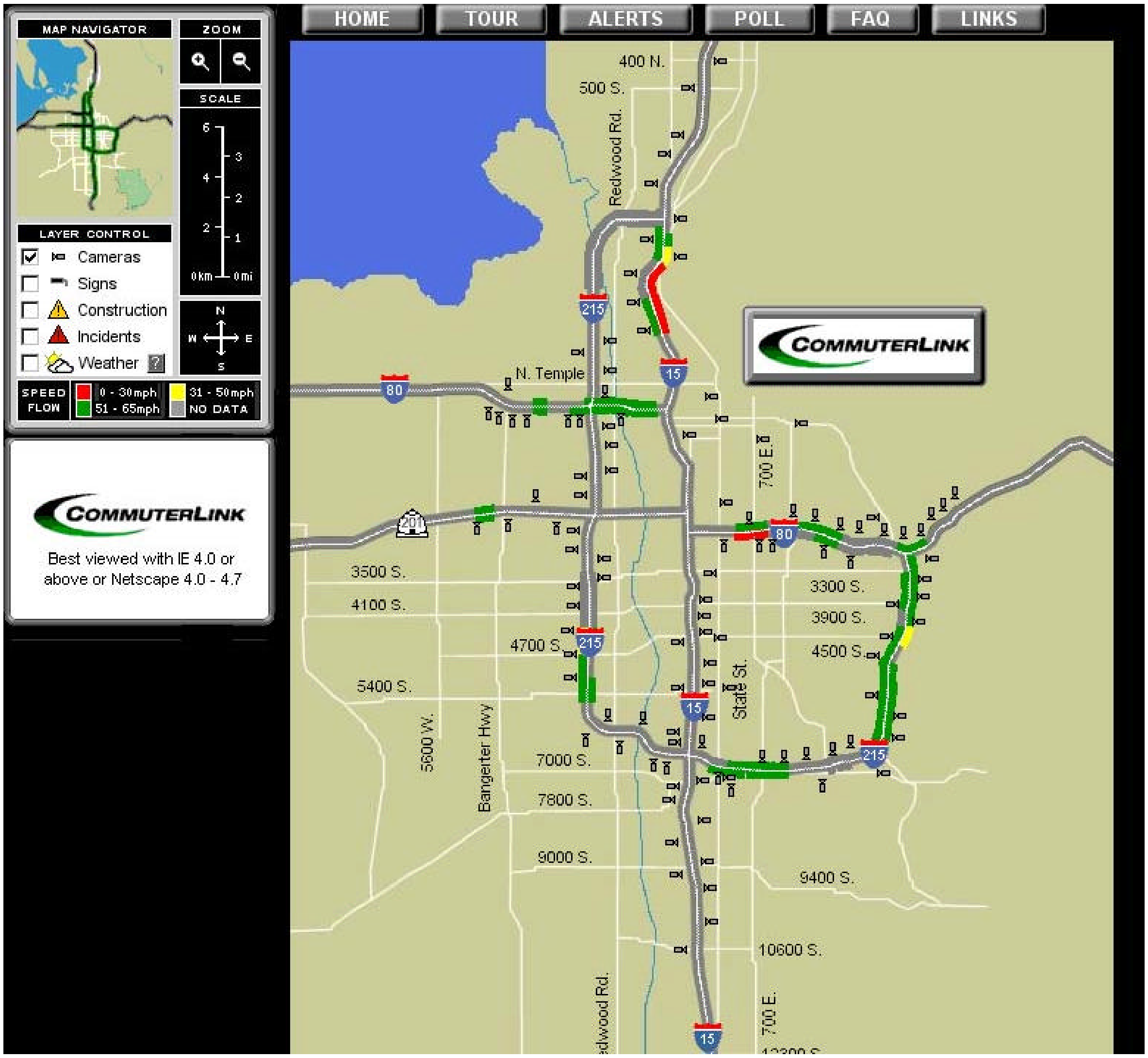


Figure 1.1: TOC Commuter Link Display

UDOT seeks to extend this technology to the major surface street arterials around the Salt Lake Valley to improve public service. However, there has not been any research or development toward real-time LOS or similar monitoring methods measurements for surface streets. This research correlates the system detector information with commuter congestion. If TOC operators can monitor surface street congestion, they may be able to detect incidents, detour traffic to free flowing streets, and indicate travel trends and future signal timing update requirements. This could reduce delays, increase safety, and improve air quality.

This research will focus on real-time congestion monitoring by examining the conventional method of measuring Arterial LOS as given in the HCM, proposed alterations to the HCM method, and the current applications of LOS measurements. It also discusses intersection LOS and its impacts on Arterial LOS. This impact defines the steps this research will take to monitor arterials. Since the term LOS is widely understood to refer to the method given in the HCM, this report will use the term "commuter congestion" instead of LOS or any previously defined Measurement of Effectiveness.

Researchers used the manuals for intersection controllers and the Integrated Control of Networks (ICONS) systems to identify the limits of intersection hardware, intersection software, and TOC system communications. Information received from the manuals and the TOC will determine how detector data can be used to measure commuter congestion. If this research is successful it could initiate further progression in advanced surface street management and observation.

The goal of this work is to determine a method for monitoring commuter congestion using the equipment installed by UDOT in the Salt Lake Valley. To accomplish this task, the algorithm must satisfy the following objectives:

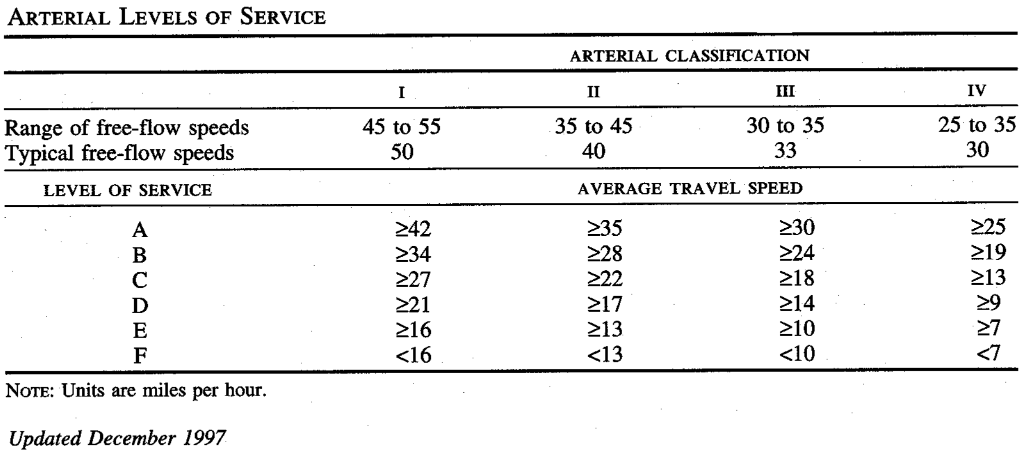
- Establish a relationship between detector data and commuter congestion
- Provide a model that can estimate commuter congestion
- Instill confidence in the modeling procedure and the model output through field tests

CHAPTER 2: LOS BACKGROUND

Literature Review

This literature review covers relevant literature surrounding Arterial LOS. The scope of the review includes journal articles, conference papers, books, and standards. The standard method of determining Arterial LOS is found in the HCM (TRB 1997). This review discusses the HCM method, its limitations, and modifications proposed by previous research. Records of previous real-time Arterial LOS measurements could not be found, so this review will examine the HCM method and corresponding studies for their application to real-time Arterial LOS calculation.

Arterial LOS is a measure of the operating conditions on a surface street. This equation requires the arterial classification, free-flow speed, delay from signaled intersections, and level of coordination to calculate the Arterial LOS. HCM identifies Arterial LOS by the speed ranges given in Figure 2.



ARTERIAL LEVELS OF SERVICE

	ARTERIAL CLASSIFICATION			
	I	II	III	IV
Range of free-flow speeds	45 to 55	35 to 45	30 to 35	25 to 35
Typical free-flow speeds	50	40	33	30
LEVEL OF SERVICE	AVERAGE TRAVEL SPEED			
A	≥42	≥35	≥30	≥25
B	≥34	≥28	≥24	≥19
C	≥27	≥22	≥18	≥13
D	≥21	≥17	≥14	≥9
E	≥16	≥13	≥10	≥7
F	<16	<13	<10	<7

NOTE: Units are miles per hour.

Updated December 1997

Source: (1)

Figure 2.1: Arterial Level Of Service (LOS)

Average travel speeds can be estimated or measured directly. Estimations are made using running time and intersection delay calculations or by using assumptions of arterial intersection delay characteristics given in Chapter 16 of the HCM. (1) A planning analysis by the HCM method requires several input values, listed in Table 2.1. Using this information, the planning analysis yields Arterial LOS. Travel speeds can be measured directly by driving the arterial and taking the distance traveled (miles) divided by the duration (hours).

Table 2.1: LOS Input Requirements

Traffic characteristics:	Roadway characteristics:	Signal characteristics:
Annual average daily traffic (AADT),	Number of through lanes (N),	Arrival type,
Planning analysis hour factor (K),	Free-flow speed,	Signal type,
Directional distribution factor (D),	Arterial classification,	Cycle length (C),
Peak hour factor (PHF),	Medians,	Effective green ratio (g/C)
Adjusted saturation flow rate,	Left-turn bays or exclusive left-turn lanes	
Percentage of turns from exclusive lanes		

Previous research focused on validating, challenging, or modifying the HCM method, input parameters, or arterial definition for local traffic conditions. Fambro and Rouphail (2) modified the HCM method to account for actuated control, over saturation and variable demand. Li, et al. (3) adjusted the delay model to account for the heavy platoon effect that occurs during high-volume hours. Chang and Lung (4) redefined arterial definition, LOS measurements, and considered the effect of motorcycles on LOS for traffic conditions in Taiwan. Yan (5) modified the HCM method by replacing the HCM arterial definition with the American Association State Highway and Transportation Officials' (AASHTO) definition of an arterial (see Table 2.2). The previous research does not consider using LOS as a real-time monitoring device.

Table 2.2: AASHTO's Typical distribution of urban functional systems.

	Range	
	Travel Volume	**Length**
Systems	**(%)**	**(%)**
Principal arterial system	40-65	5-10
Principal arterial plus minor arterial street systems	65-80	15-25
Collector street system	5-10	5-10
Local street system	10-30	65-80

Source: (6)

The scope of the HCM method is limited in several ways. First, it assumes that all arterial and the traffic conditions conform to assumptions of the method. Second, its main purpose is to evaluate existing conditions or predict congestion and delay as road use increases. Finally, it is primarily a static measurement; a planning tool used to predict future expansion. Because of the data required for calculation, the HCM equations are not intended to measure Arterial LOS in real-time.

As stated in the HCM, average travel speed "is strongly influenced by the number of signals per mile and the average intersection control delay … such factors as inappropriate signal timing, poor progression, and increasing traffic flow can substantially degrade arterial level of service" (1). Since the current infrastructure does not allow individual intersections or detectors to measure progression (signal coordination) this algorithm will use intersection congestion to indicate arterial congestion.

Econolite Controllers

Econolite produces a wide variety of traffic management devices. These devices include distributed/closed loop traffic control systems, actuated and pretimed controllers, arterial masters, wide area video vehicle detection systems, advanced traffic management systems, traffic control cabinets and traffic signal display equipment. Econolite has more than 2,000 arterial systems controlling at least 15,000 intersections and 2,500 wide area video vehicle detection systems operating in intersection and freeway applications. It developed the first digital controller, introduced the first microprocessor-based controller, and created several detection systems (7).

Econolite controllers operate signal timing for the majority of intersections in the Salt Lake Valley. These controllers can collect volume, occupancy, and speeds if the detectors are configured properly. Volume is recorded as a number of vehicles per lane per time interval. Occupancy is recorded as percent per detector per time interval. The minimum time interval for volume and occupancy data is five minutes.

Detectors

Detectors used by the UDOT fall into two categories: stop bar detectors (intersection detectors) and system detectors. Intersection detectors usually are used as presence detectors. If the detector is occupied, then the controller will extend the green-time for that direction.

The detectors are connected to controllers through cells. The controller is then programmed to get specific information from each cell during operation of the intersection. Many arterials in the Salt Lake Valley have two or three detectors per lane at the intersections, called stop bar detectors. During the assembly, the stop bar detectors in each lane were connected in series to the controller, effectively making the three detectors act as one large detector (Figure 2.2). In this configuration, neither occupancy nor volume can be measured because the controller will receive an “occupied” signal if any of the detectors are occupied. For example, if a vehicle is detected by the first sensor and before it exits the detector area another vehicle enters the area of the second sensor, the controller will only “see” one vehicle with a time of occupancy equal to the time required for the first vehicle to enter detection zone one and the second vehicle to exit detection zone two. In this scenario, the detector will count only one vehicle, giving an erroneous measurement.

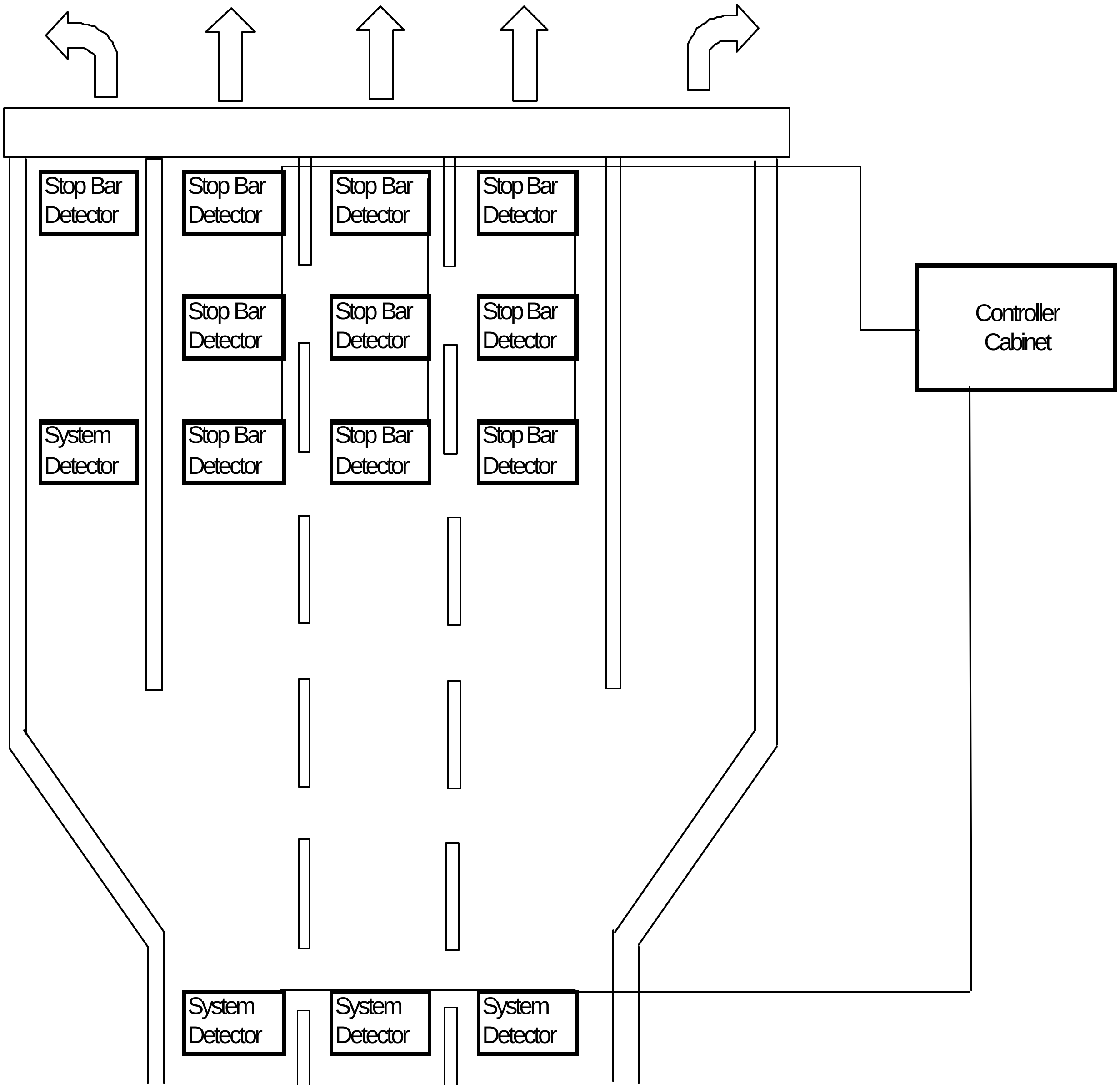


Figure 2.2: Detector Layout

If the controller is used to record accurate information from the stop bar, each detector must be separated from the group and connected to the controller through a separate cell that is programmed to measure occupancy and volume. On the other hand, the system detectors already are connected to the controller through an individual cell enabling them to measure occupancy and volume accurately. However, the system detector is placed before the vehicle reaches the turning lane so it counts the turning and the through vehicles.

Integrated Control of Traffic Networks (*ICONS*) technology

The Integrated Control Of NetworkS (ICONS) is from Econolite's ATMS product line of central systems. It provides a centralized, integrated platform for traffic signal system control, information management, and graphical data display. With ICONS, the operator can assimilate data more rapidly through a map-based graphics display called Aries; thereby improving traffic operation and decision making efficiency.

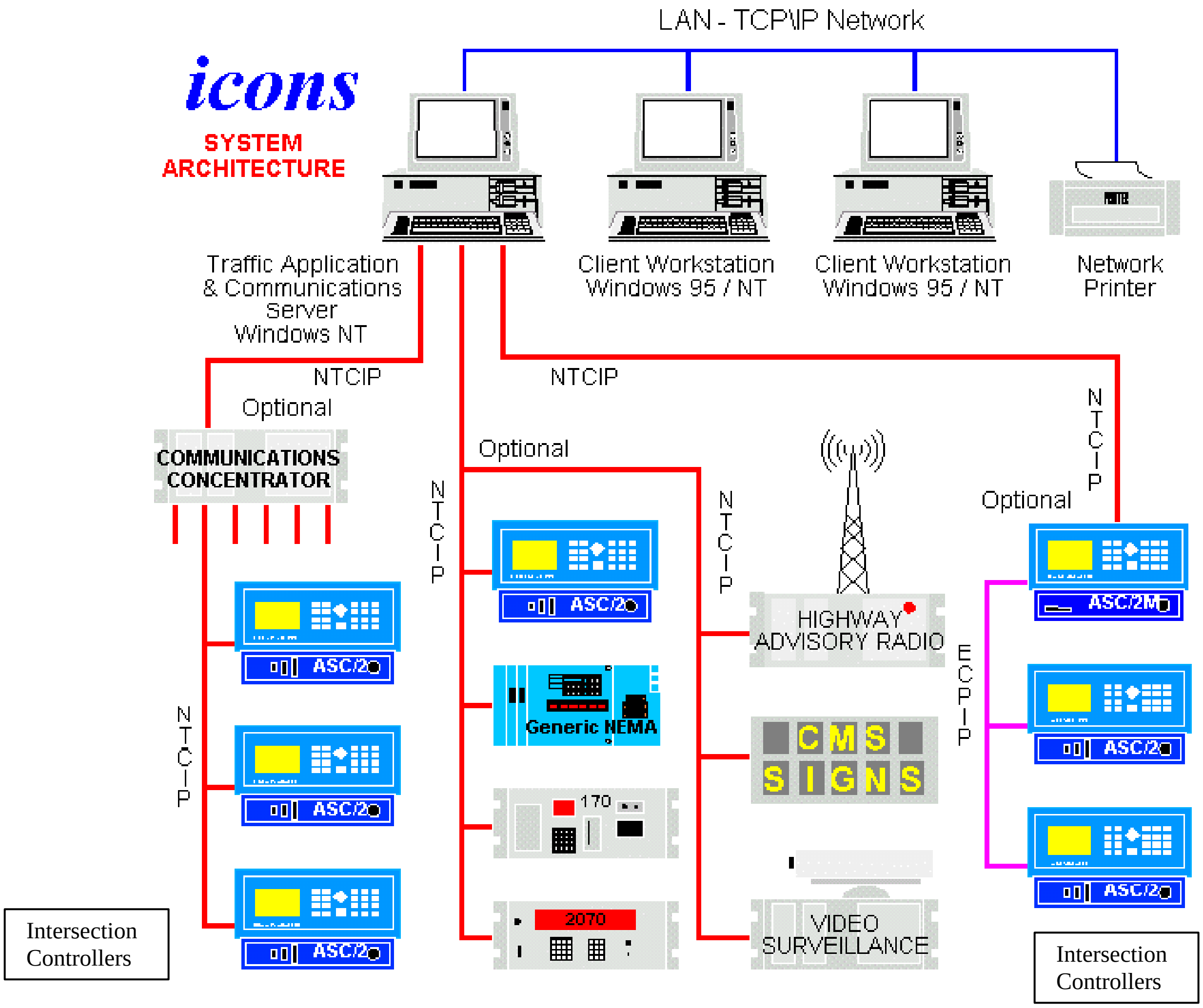


Figure 2.3: ICONS System Architecture

Figure 2.3 shows how the system is configured. The intersection controllers, changeable message signs, video cameras, and the highway advisory radio all are connected to the server. ICONS allows the operators to use individual workstations to gain complete access to the system functions (i.e. changeable message signs, video cameras, and the intersection signal timing). The system is supervised by a dedicated Traffic Applications Server, while Communication Servers are used to process communications with field equipment (8).

The TOC currently uses ICONS to monitor the signal system. Controller information is transmitted to the TOC through ICONS. The ICONS database stores all of the information and is linked with the ATMS database, where the freeway detector data is stored. The systems integrator, contracted by the TOC, will need to incorporate the intersection information with the UTL algorithm and interface information with Aries, which currently displays the highway map.

CHAPTER 3: OTHER TECHNOLOGIES

Other technologies also might be used to calculate vehicle speeds or LOS. The following technologies have not been thoroughly investigated because they require additional equipment while the scope of the project limits research to technologies compatible with the current UDOT infrastructure. Econolite has Autoscope video image processing technology. Autoscope measures speed and capacity. However, it requires a camera, communications, and other special equipment to be installed at each intersection of the arterial. If Autoscope is installed for intersection control and measures speeds near the intersection, then the data can be modified to compare to Arterial LOS.

In addition to video detection, elements of Red Light Runner (RLR) technology could be configured to measure Arterial LOS in real-time. RLR is a combination of sensors, computers, and cameras that sense red light runners and photograph them. Sensors in the road detect vehicle speed near the intersection. The computer calculates the vehicle's ability to pass through the intersection before the light turns red. RLR could return vehicle speeds if the sensors, dormant during most of the green light, begin to record vehicle speeds before RLR needs them.

Japan also is developing technology that has the ability to track individual vehicles. This requires cameras at each intersection along the route, video imaging software, and a computer system dedicated to this program (9). This system could be developed to display an Arterial LOS by tracking a vehicle along an arterial and time the length of its commute.

While the system from Japan could be used to collect Arterial LOS, UDOT is unable to install cameras at each intersection in the Salt Lake Valley. If the other technologies were implemented, the speeds given do not have a direct correlation with the speeds in Figure 1.1. Since these are not viable solutions, another way to determine commuter congestion must be found.

CHAPTER 4: MODELING AND DATA COLLECTION

CORSIM Modeling

KLD associates originally developed CORSIM for the FHWA. This simulator is a composite of two older simulators, NETwork SIMulation (NETSIM) and FREeway SIMulation (FRESIM). NETSIM is an urban street network simulator and FRESIM is a simulator for freeways. They were combined to form CORSIM. Although they can be run in the same network and simulation, they still require a special interface between the FRESIM and NETSIM models and the models still are run separately. All this required functionality is available in CORSIM. (10)

A CORSIM simulation was made that would record the status of the signal, the time of occupancy in 1/10 sec intervals, and give a cumulative count of the vehicles as they pass over the detector. The first model was intended to simulate a normal commute. Volumes for the peak period increased from a v/c of 0.5 to 1.7 by 0.2 increments every 10 minutes, then decreased by the same increments and intervals until the end of the simulation. The maximum volume/capacity (v/c) value (the peak of the commute) was sustained for 20 minutes. The purpose of this simulation configuration is to determine if occupancy changes as the intersection experiences congested and uncongested conditions. A five-minute average is used because it is the minimum time limit that the Econolite controllers allow. Figure 4.1 shows the five-minute floating-average percent of occupancy (FAPO) for stop bar detector as shown by Equation 1. Figure 4.2 shows the five-minute, FAPO for the system detector.

$$5 - minute\ FAPO_i = \frac{\sum_{k=i-300}^{i} Percent\ Occupancy_i}{300} \qquad \text{(Equation 1)}$$

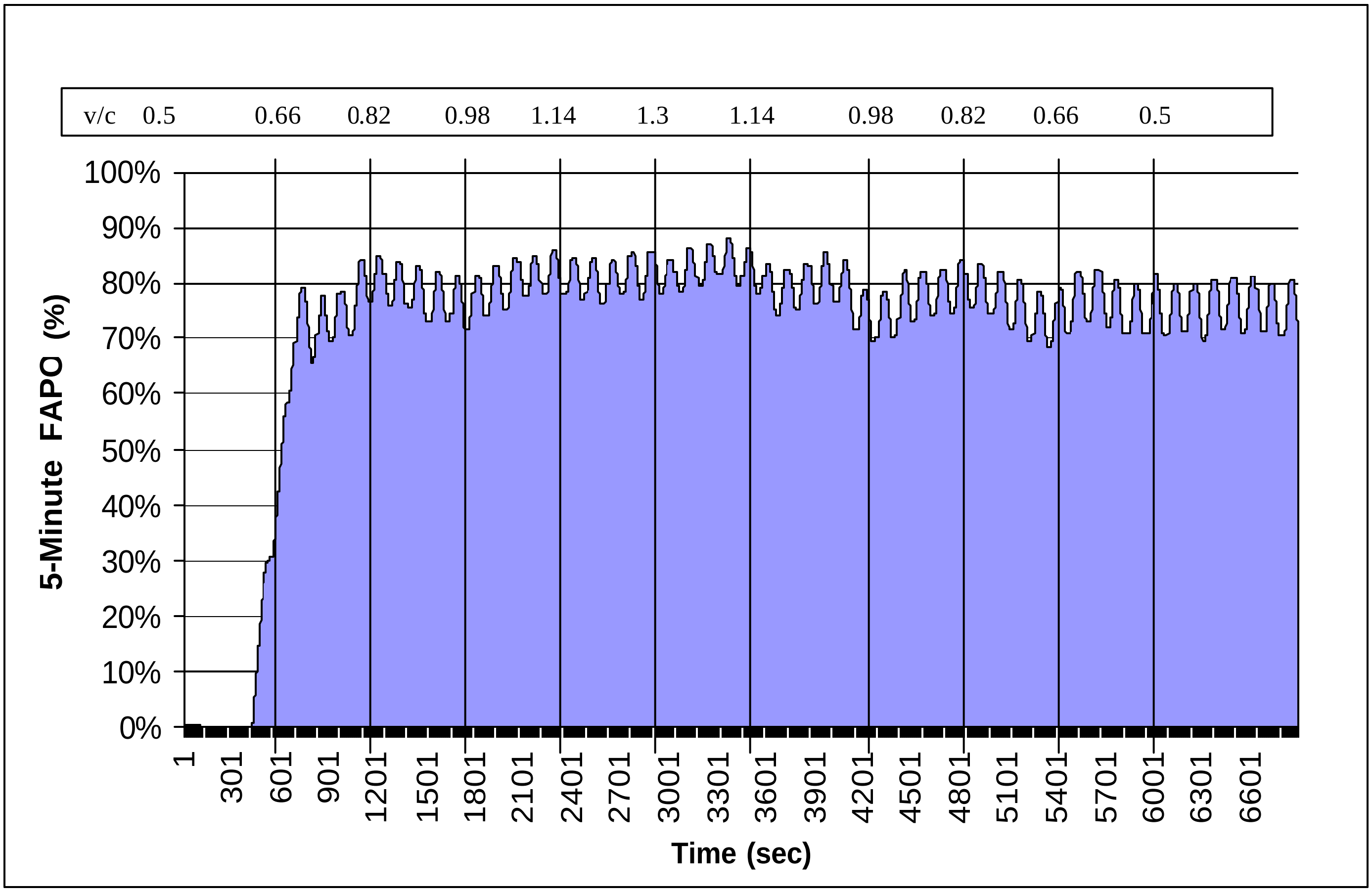


Figure 4.1: Stop Bar Occupancy

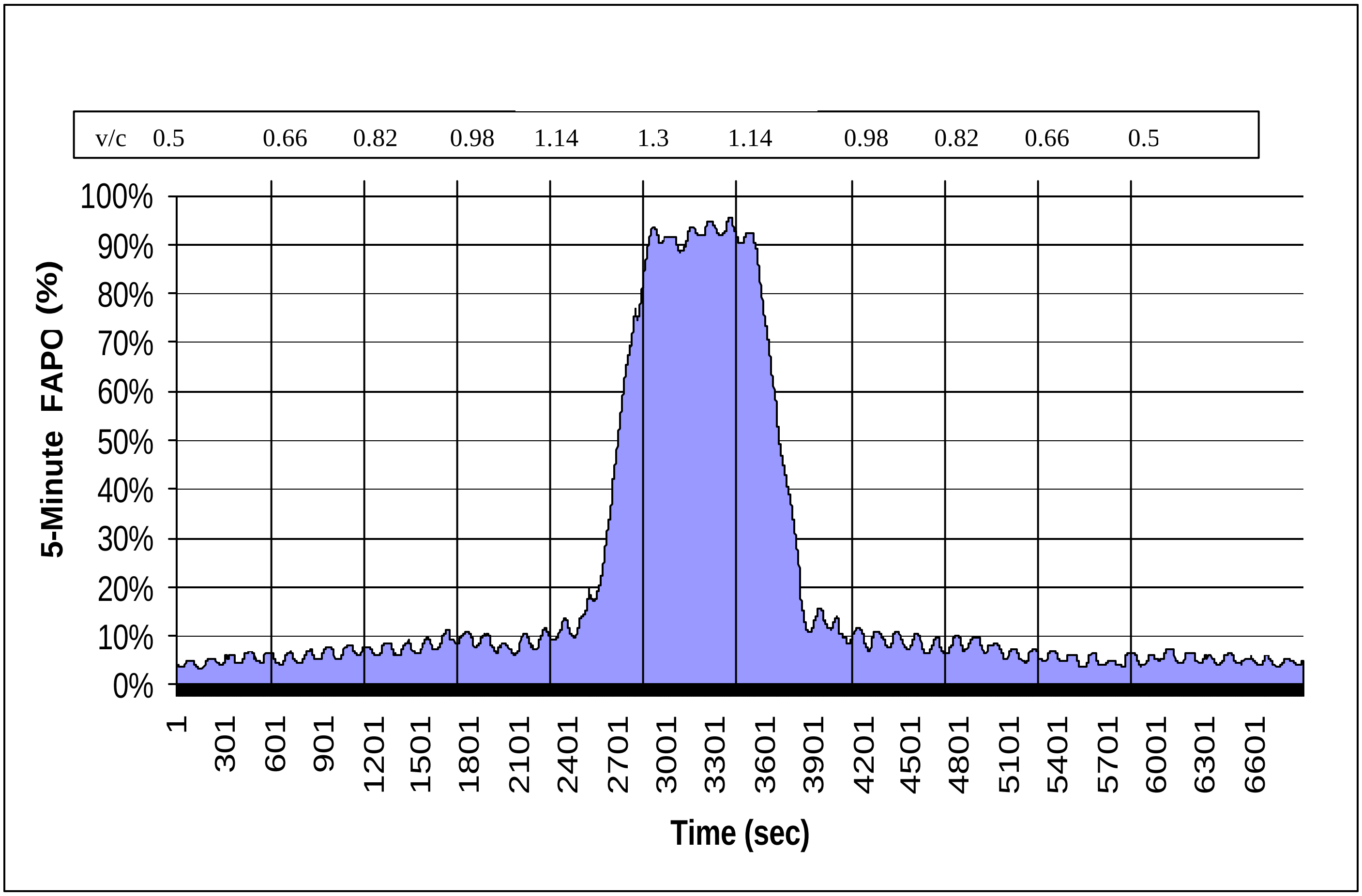


Figure 4.2: System Detector Occupancy

During the simulation, the stop bar was occupied 70 percent to 85 percent of the time regardless of the volume. This occupancy profile did not show a distinct change as the v/c ratio increased throughout the simulation. Thus, it is impossible to identify free flow or congested traffic by stop bar occupancy.

However, the system detector showed a distinct spike in occupancy during the maximum v/c value (the peak of the commute). Throughout the simulation, the detector was occupied less than 20 percent of the time until the v/c ratio exceeded one, then the occupancy drastically increased to 90 percent. This means that system detectors can identify “Red” conditions. Nevertheless, they did not show the “Green/Amber” transition. Notice how the system detector occupancy during the congested period was approximately equal to occupancy of the stop bar detectors. This means that during congested periods, occupancy at the system detector showed the same profile as occupancy at the stop bar. During this time the queue never cleared the system detector, which indicated that it required more than one cycle for a vehicle to pass over the system detector and through the intersection. For this project, if a vehicle has to stop twice for the same signal before passing through the intersection, the intersection is considered congested, or the approach volume is above capacity.

An intersection's capacity is dependent on factors like geometry, approach lanes, green-time, and cycle length. Capacity for a single lane intersection was found. Following that, the HCM definitions for under capacity, near capacity, and at or above capacity were used as congestion thresholds. The HCM defines a v/c ratio of less than 0.85 as under capacity, a v/c ratio from 0.85 to 0.95 as near capacity, and a v/c ratio above 0.95 as at or above capacity (11). In this manner, the accepted thresholds for congestion will be used for real-time detection.

The CORSIM simulation was modified to model an intersection with an approach volume exceeding the capacity. The output data recorded the same information as the first simulation, i.e. signal status, occupancy, and volume in five-minute intervals. UTL simulated one, two, and three lane roads once (with the same green time and cycle length under congested conditions) and compared the hourly volumes. The model showed that the volumes of the 2 and 3 lane roads are multiples (± 5%) of the volume on the one lane road. Five-minute volumes for different cycle lengths and different green times were collected and organized in a table called the Simulation Table (Table 4.1). The Simulation Table gives the five-minute capacity of a one-lane intersection relative to cycle length and Green-time.

Table 4.1: Simulation Table

Cycle Length (sec)	50	60	70	80	90	100	110	120	130	140	150
Green Time (sec)	5-Minute Capacity (vehicles)										
20	65	54	47	40	36	32	30	27	25	23	x
30	95	98	68	59	52	48	43	39	37	34	32
40	x	104	90	78	70	62	57	53	49	45	42
50	x	x	110	96	85	78	70	65	61	57	53
60	x	x	x	116	104	93	86	78	71	66	62
70	x	x	x	x	121	108	99	91	83	77	72
80	x	x	x	x	x	123	112	102	95	88	82
90	x	x	x	x	x	x	125	115	107	100	92
100	x	x	x	x	x	x	x	128	118	111	102

CHAPTER 5: RESULTS

Volume Data

Table 4.1 was plotted by cycle length and capacity in Figure 5.1. The data is grouped by the number of seconds of green-time per cycle. Figure 5.1 shows how the five-minute capacity decreases as the cycle length increases. In addition, it also shows how capacity decreases as the green-time decreases. The exponential trend lines plotted and the equations of the trend lines given. Each trend line had a R^2 value of 0.997 or higher. Each trend line equation can be approximated by:

$$5 - minute\,Cap = \frac{A}{C} \quad \text{(Equation 2)}$$

Where A, the capacity variable, is a function of green-time (g) and C is the cycle length.

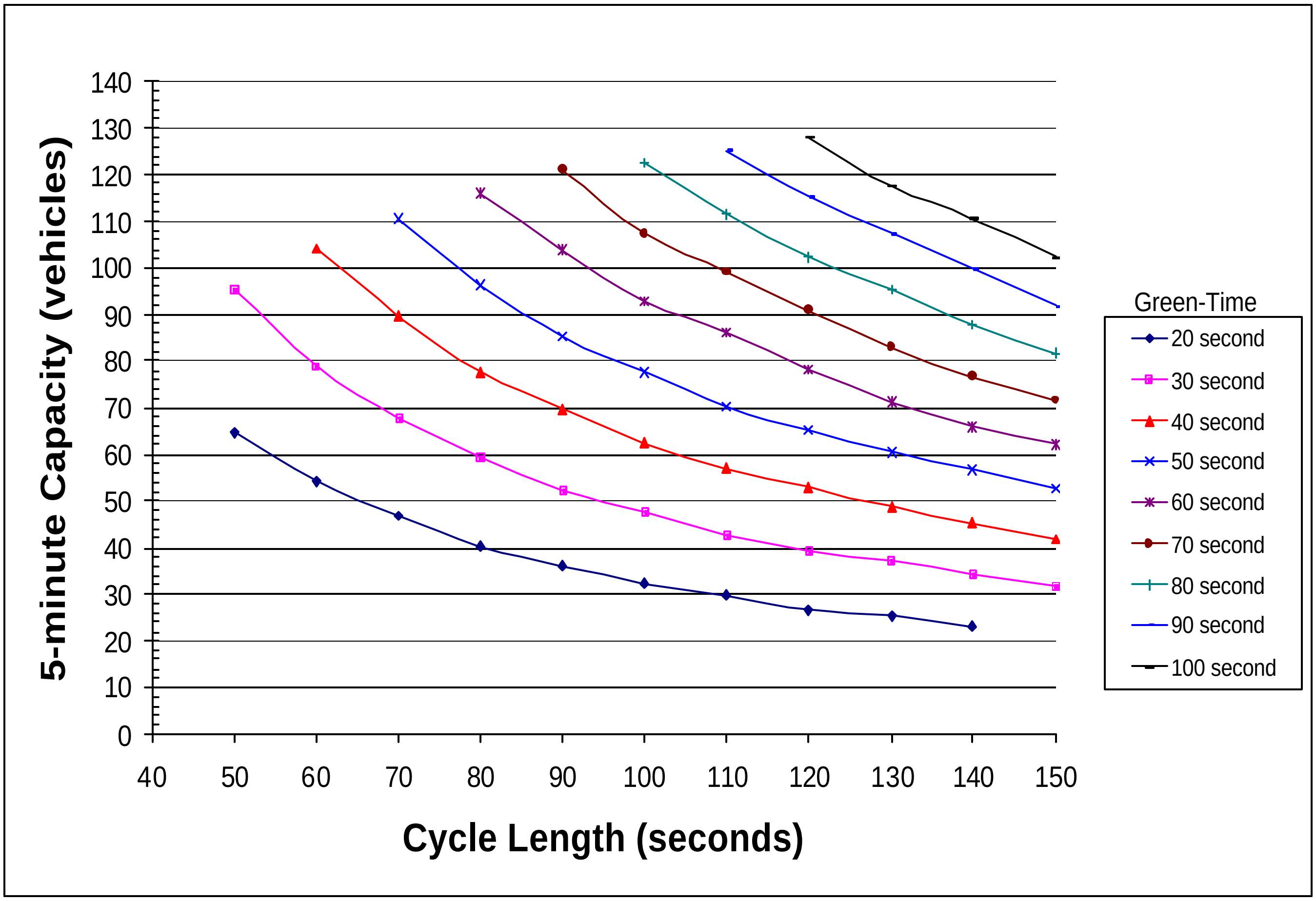


Figure 5.1: Fixed-time Capacity Chart

A increases as the green-time increases. For example, the value of *A* is 3137 for the 20-second green-time line, 9578 for the 60-second green-time line, and 13871 for the 100-second green-time line. *A* vs. *g* was plotted to find how *A* increases as g increases, and a linear trend line was plotted with an R^2 value of 0.96. Figure 5.2 shows the plot and the trend line. The equation of the trend line is:

$A = 151.7 * g + 204$ (Equation 3)

Where *A* is the capacity variable and *g* is the green-time per cycle.

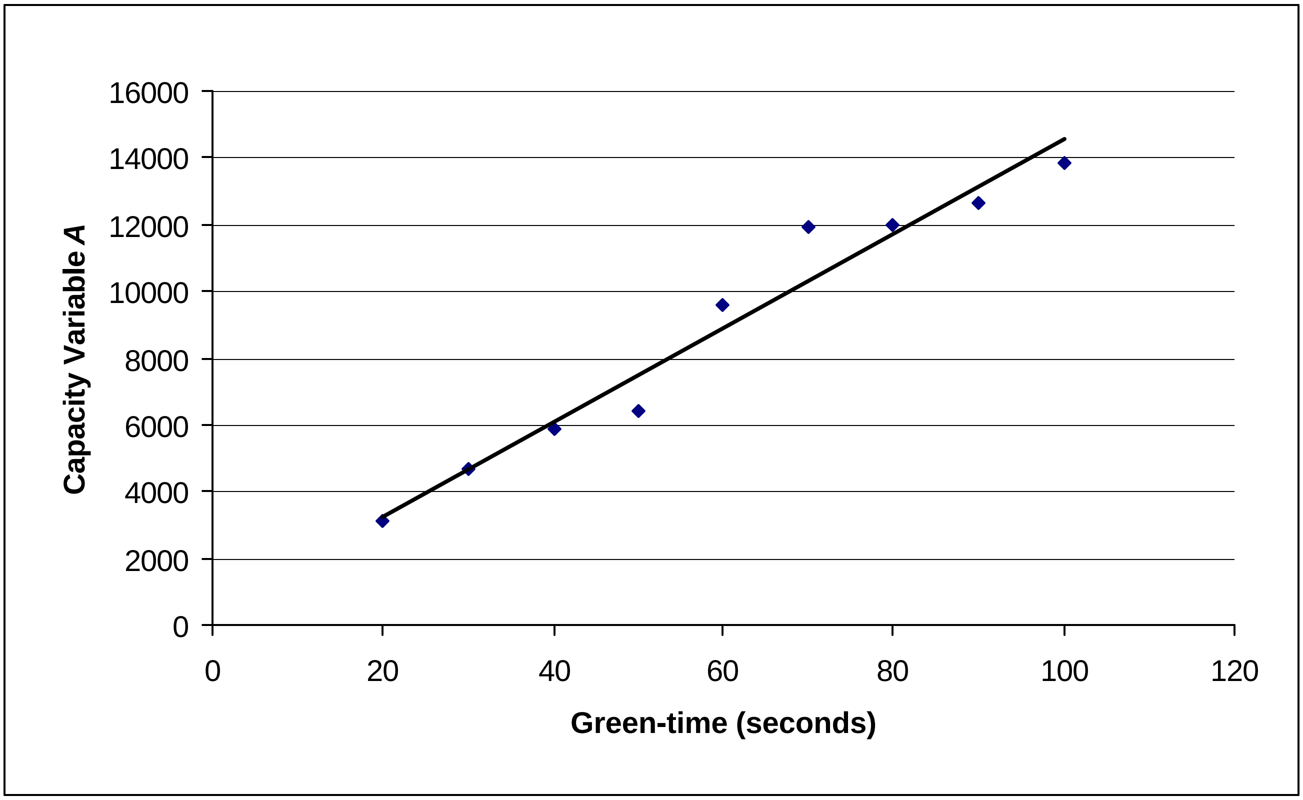


Figure 5.2: Green-Time vs. Capacity Variable (*A*)

Equations 2 and 3 were combined to form Equation 4:

$$5 - minute\,Cap = \frac{151.7 * g + 204}{C} \qquad \text{(Equation 4)}$$

Where *g* is the green-time per cycle length and *C* is the cycle length.

This equation is standardized for five-minute volumes. It will estimate the five-minute capacity for one lane given green-time per cycle length and the cycle length. Table 5.1 shows the percent of error between the Simulation Table (from CORSIM modeling) and the Simulation Equation (Equation 4) using the green-times and cycle lengths to calculate capacity.

Table 5.1: Percentage Error Between Equation 4 Estimates and Simulation Estimates

Cycle Length (sec)	50	60	70	80	90	100	110	120	130	140	150
Green Time (sec)	5-Minute Capacity Percent Error										
20	0%	0%	1%	-1%	0%	0%	1%	-1%	2%	0%	x
30	0%	-1%	0%	0%	-1%	0%	-1%	-1%	1%	1%	0%
40	x	0%	0%	-1%	0%	0%	0%	1%	1%	1%	0%
50	x	x	-1%	-1%	-2%	0%	-1%	0%	1%	2%	1%
60	x	x	x	0%	1%	0%	2%	1%	0%	-1%	0%
70	x	x	x	X	1%	-1%	1%	1%	-1%	-1%	-1%
80	x	x	x	X	x	-1%	-1%	-1%	0%	0%	-1%
90	x	x	x	X	x	x	-1%	0%	1%	1%	-1%
100	x	x	x	X	x	x	x	0%	-1%	1%	0%

Average Square Error	1%
Standard Deviation of Error	0.008

Table 5.1 demonstrates the accuracy of Equation 4 in reproducing the CORSIM capacity volume estimates. The equation accurately estimates capacity of the intersection.

Equation 4 is similar to the capacity equation from the HCM, page 16-14, because it uses the cycle length and green-time to calculate capacity. The HCM Capacity equation, however, estimates the capacity of an intersection in vehicles per hour instead of vehicles per five-minute interval. The HCM Capacity Equation was modified to a five-minute interval by dividing the equation by 12:

$$5 - minute\, Cap = \frac{g * 1800}{C * 12} \qquad \text{(Equation 5)}$$

This equation was used to estimate the capacity of an intersection and then compared results to the Simulation Table. Equation 5 predicted volumes 2 percent to 9 percent lower than those of the Simulation Table and 1 percent to 8 percent lower than those of Equation 4. Table 5.2 shows the percent error between the Simulation Table and Equation 5.

Table 5.2: Percentage Error Between Equation 5 Estimates and Simulation Estimates

Cycle Length (sec)	50	60	70	80	90	100	110	120	130	140	150
Green Time (sec)	5-Minute Capacity Percent Error										
20	7%	7%	8%	6%	8%	7%	8%	6%	9%	8%	x
30	6%	5%	5%	5%	4%	5%	4%	4%	7%	6%	5%
40	x	4%	4%	3%	4%	4%	4%	5%	6%	5%	4%
50	x	x	3%	3%	2%	4%	3%	4%	5%	6%	3%
60	x	x	x	3%	4%	3%	5%	4%	3%	2%	2%
70	x	x	x	x	4%	2%	4%	4%	2%	2%	2%
80	x	x	x	x	x	2%	2%	2%	3%	2%	2%
90	x	x	x	x	x	x	2%	2%	3%	3%	2%
100	x	x	x	x	x	x	x	2%	2%	3%	2%

Average Square Error	4%
Standard Deviation of Error	0.018

Note the error difference between the Table 5.1 (from Equation 4) and Table 5.2 (Equation 5). When the green-time is small, Equation 5 has a higher error than when the green-time is large. This is because the HCM Capacity Equation does not include start-up losses as the signal changes from red to green. This discrepancy makes Equation 5 estimate fewer vehicles per five-minute period than the simulation. When the green-time is longer, there are fewer start-ups per five-minute interval and the HCM Capacity equation becomes more accurate.

Figure 5.3 shows the difference between the simulation, the Equation 4 estimate, and the Equation 5 estimate for a green-time of 20 seconds. Figure 5.4 shows the difference between the simulation, the Equation 4 estimate, and the Equation 5 estimate for a green-time of 80 seconds. These graphs show that Equation 4 estimates are more accurate than those provided by the HCM Capacity equation. The simulation table and Equation 4 are considered more accurate than the HCM Capacity equation because CORSIM integrates start-up losses, arrival patterns, and other factors that the HCM Capacity equation does not.

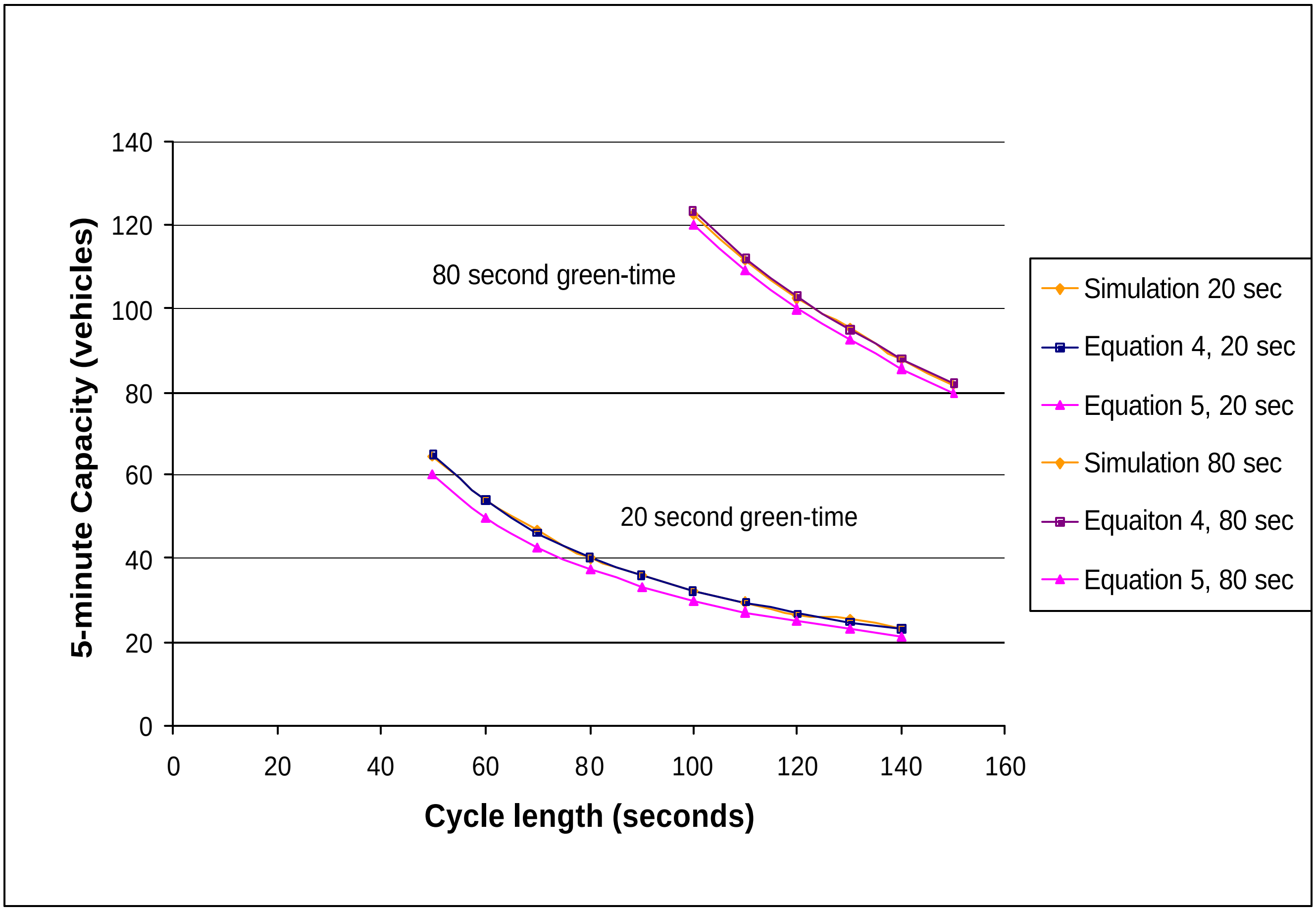


Figure 5.3: Capacity Comparison Between the Simulation, Equation 4, and Equation 5

In Figure 5.3, the increased accuracy shows that a 50-second cycle with a 20-second green-time has a capacity of 65 vehicles instead of 60 vehicles in five minutes and a 100-second cycle with an 80-second green-time has a capacity of 124 vehicles instead of 120 vehicles in five minutes.

Unfortunately, Equation 4 only can be used effectively with a fixed green-time because green-time is assumed to be constant for each cycle length. However, many intersections in the Salt Lake Valley are either coordinated actuated, semi-actuated, or fully actuated. Therefore, green-time varies from cycle to cycle. For example, at some coordinated actuated intersections, minimum green time for the major road can be allowed to extend by 25 percent when the demand for the minor road is small. This high fluctuation prevents assuming a set green-time and requires an equation that estimates the five-minute volumes when a variable green-time and cycle length are possible.

The simulation also counted the cumulative green-time for each cycle length and green-time to form a table similar to the Simulation Table. Table 5.3, called the Cumulative Green-Time Table, shows average amount of green-time during a five-minute period.

Table 5.3: Cumulative Green-Time Table

Cycle Length (sec)	50	60	70	80	90	100	110	120	130	140	150
Green Time Per Cycle (sec)	Cumulative Green-Time during a 5-Minute Period (sec)										
20	120	100	86	75	67	60	54	50	46	43	x
30	180	150	129	113	100	90	82	75	69	64	60
40	x	200	171	150	133	120	109	100	93	86	80
50	x	x	214	187	167	150	136	125	116	107	100
60	x	x	X	225	200	180	164	150	138	129	120
70	x	x	X	x	233	210	191	175	161	150	140
80	x	x	X	x	x	240	218	200	184	172	160
90	x	x	X	x	x	x	245	225	208	193	180
100	x	x	X	x	x	x	x	250	231	214	200

The times (in seconds) of Table 5.3 directly correlate with volumes in the Simulation Table. The capacity values, from Table 4.1, were combined with the cumulative green-time, from Table 6, by their corresponding cycle length and green-time. This information was graphed and a linear trend line was plotted. Figure 5.4 shows the graph of Green-Time and five-minute Capacity.

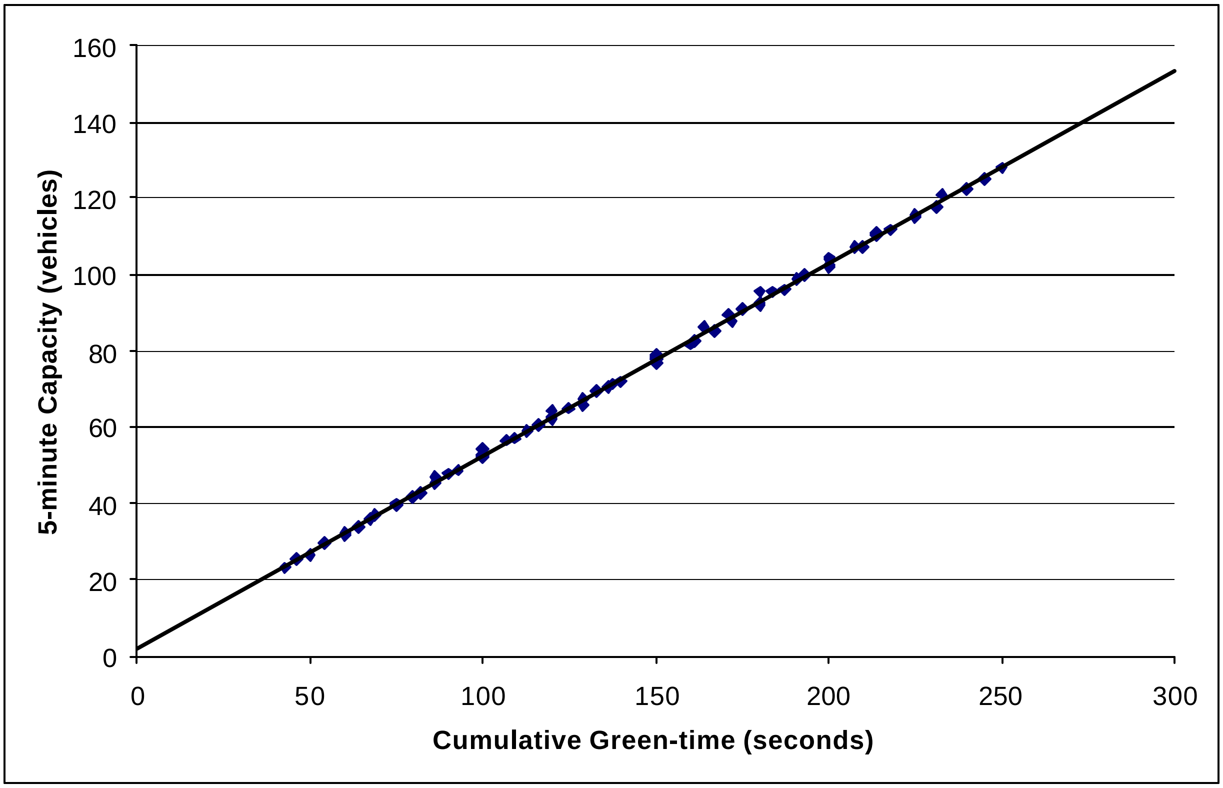


Figure 5.4: Intersection Capacity for Cumulative Green-time

The linear trend line has an R^2 value of 0.9993, which shows a strong correlation. The equation for the trend line is shown as Equation 6.

$$5 - minute\ Cap = 0.5049 * \text{cg} + 2.0391 \qquad \text{(Equation 6)}$$

In summary, Equation 6 provides an estimate of the five-minute capacity (five-minute Cap) of one lane for a five-minute period given the cumulative green-time (cg) for the approach during the five-minute period.

Figure 5.4 shows how the capacity is closely associated with the green-time. This close association allows for a more accurate estimation of capacity when given the five-minute cumulative green-time.

Occupancy Data

The draw back with a “volume-only” approach is that it assumes that the intersection, where the controller and detectors are located, is causing congestion and does not consider congestion caused by other circumstances. If spillback from a delay down stream from the intersection prevents travel through the intersection, then the five-minute volume will be much lower than the estimated capacity. In this case, the volume counts would make the intersection appear to be operating under “Green” conditions. Occupancy analysis shows that, unless the intersections were extremely congested, the percent of occupied time for the system detector is less than 20 percent. Figure 5.1 shows that the occupancy increases from 20 percent to 90 percent when the queue does not clear the system detector. Since the change is so drastic, the median occupancy (50 percent) is defined as a default to indicate that the intersection is congested. This occupancy indicates oversaturated conditions at this intersection or spillback congestion from a condition down stream. If the actual volume is less than the capacity, the congestion is due to spillback. Since the distinction is not crucial for this analysis, the algorithm will check occupancy before using the equation.

Results Summary

The system detectors usually are embedded 300 ft before the intersection. Turning vehicles pass over the detectors before they are able to move into the turning lanes. The algorithm should remove these vehicles before it can compare the vehicles passing through the intersection with the Five-Minute Capacity Equation. The most accurate way to remove the turning volumes is to embed sensors in the turning lanes to count the turning vehicles or to uncouple the stop bar sensors. However, using the current hardware, engineers can input turning percentages to estimate the turning volumes.

The final algorithm, called The Commuter Congestion Algorithm (CCA), requires the user to input the number of lanes and turning percentages. During operation, the controller inputs volume, occupancy, and cumulative green time during the five-minute period for each approach. If the occupancy for any approach is higher than 50 percent, the approach is classified as “Red.” If the occupancy is less than 50 percent on an approach, the algorithm calculates the five-minute capacity for that approach using the green time and the number of lanes. Then it reduces the input volume by subtracting the turning volumes and divides the calculated through volume by the five-minute capacity and creates a five-minute v/c ratio. If the five-minute v/c ratio is 0.85 or less, the algorithm returns a “green” traffic condition. If the five-minute v/c ratio is between 0.85 or 0.95, the algorithm returns an “amber” traffic condition. If the five-minute v/c ratio is 0.95 or higher, the algorithm returns a “red” traffic condition. Figure 5.5, on the next page, shows the series of steps for CCA.

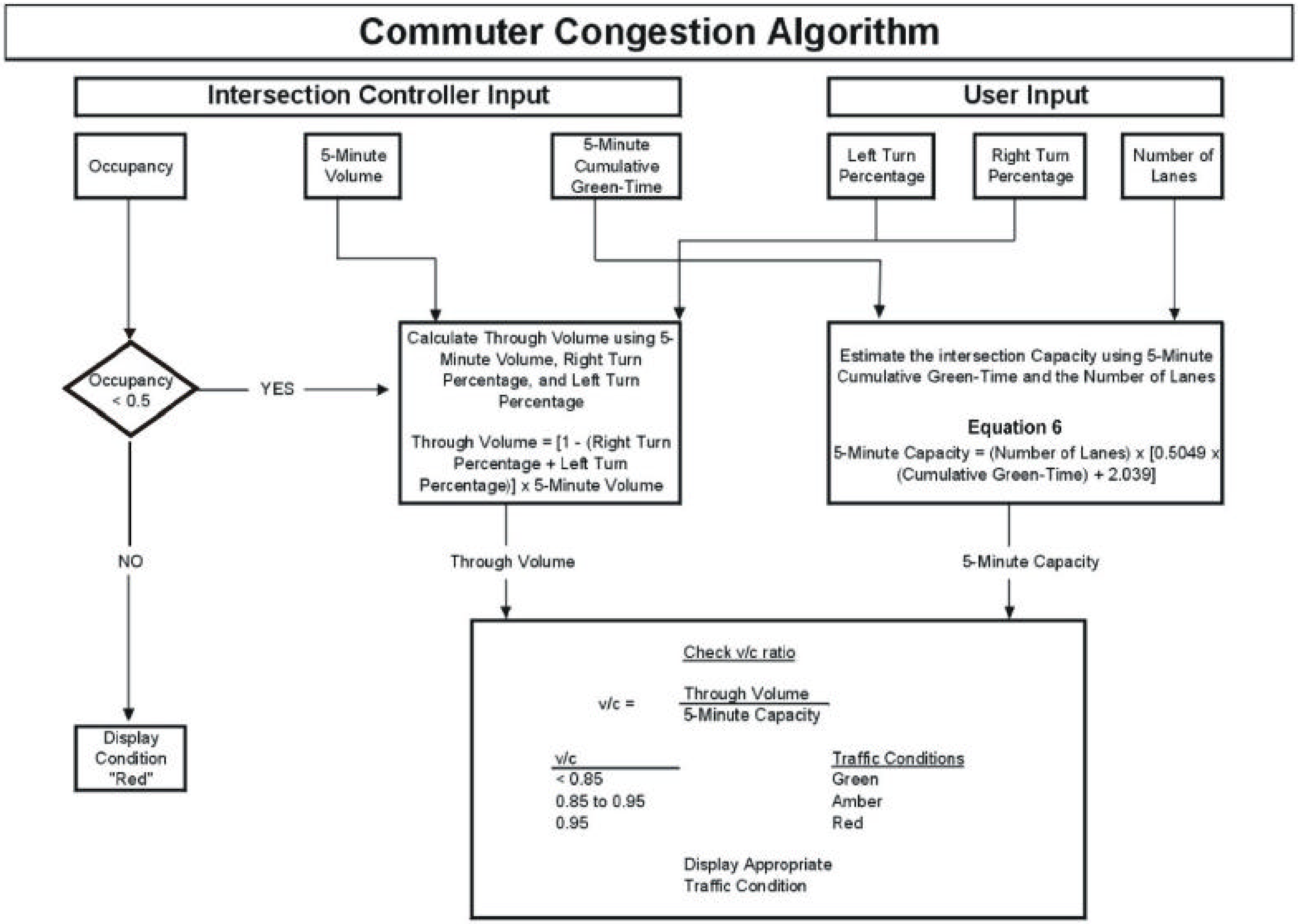


Figure 5.5: Commuter Congestion Algorithm

The congestion threshold values for green, amber, and red are chosen because they correlate with the planning analysis of $v/c < 0.85$ then Under Capacity, $v/c = 0.85$ to 0.95 = Near Capacity, and > 0.95 = At Capacity.

CCA can be modified to monitor protected turns. If the controller counts turning volumes, the five-minute equation should be modified by the appropriate factor from the HCM. The HCM gives protected left turns a factor of 0.95 for one lane, 0.92 for two lanes, and protected right turns a factor of 0.75. There are 29 left-turn lanes and one (1) right-turn lane with detectors in the Salt Lake Valley.

CHAPTER 6: VALIDATION

The purpose of this section is to determine how closely estimates from Equation 4 are to actual congested conditions. Two intersections were used to validate the algorithm, compare actual intersection volume, and determine if the intersection was at capacity. Intersections used for validation are discussed in the following sub-sections.

Field Data Collection

Videotape and detector data at the intersections of 5300 South and State on April 10, 2001, were used to compare simulation results. In addition, volume and green-time were collected at 4500 South and State Street on July 11 and12, 2001. At that time, 5300 South and State was one of the few intersections to have the detectors communicating with a controller recording volume and occupancy and a pan-tilt-zoom camera near the intersection. The camera recorded intersections during the peak periods and the controllers recorded volume and occupancy all day. UTL collected this data to verify the algorithm with the conditions that currently exist on Salt Lake City's major arterials.

The 4500 South and State Street was used because the eastbound approach at the intersection is congested for extended periods throughout the afternoon. The through vehicles were counted and binned in five-minute intervals with the cumulative green-time that occurred during each five-minute interval.

5300 South and State Street

5300 South and State Street was videotaped for data collection. The camera at 5300 South and State Street is directly above the intersection and it did not have a five-minute period that failed in either direction making it difficult to validate the algorithm. This camera position prevented researchers from observing signals and traffic at the same time. The videotape record was compared to the five-minute volumes from the video with the detector data. The two numbers were not the same for any of the five-minute intervals. This error could be a result of time discrepancies between the VCR and the Controller. This could cause the detectors to place a platoon in a different time interval than the person does. There could also be something that is preventing the detectors from accurately communicating with the controllers. Detector performance is outside the scope of this study; however, CCA assumes accurate vehicle counts will be used to determine the five-minute v/c ratio once all detectors are installed.

4500 South and State Street

This intersection is operating with a 120 second cycle length and has green-time extensions for left turn lanes. Volume and cumulative green-time was counted for 37 five-minute periods. There were nine five-minute periods that were not completely congested and did not experience cycle failure. These data were removed. Table 6.1 shows the comparison of the Field volume, the CCA estimate (Equation 4), and the HCM Capacity estimate (Equation 5).

Table 6.1: Equation Verification

Field Green-Time	Field Volume	CCA Estimation	% Difference	HCM Estimation	% Difference
68	67	73	9%	68	1%
82	86	87	1%	82	5%
94	102	99	3%	94	8%
63	65	68	4%	63	3%
87	94	92	2%	87	7%
85	90	90	0%	85	6%
64	74	69	7%	64	14%
92	99	97	2%	92	7%
54	62	59	5%	54	13%
58	57	63	10%	58	2%
71	67	76	13%	71	6%
74	73	79	8%	74	1%

85	94	90	4%	85	10%
82	82	87	6%	82	0%
76	78	81	4%	76	3%
80	88	85	4%	80	9%
77	85	82	4%	77	9%
81	78	86	10%	81	4%
79	84	84	0%	79	6%
78	72	83	15%	78	8%
79	89	84	6%	79	11%
77	76	82	8%	77	1%
78	83	83	0%	78	6%
78	95	83	13%	78	18%
80	80	85	6%	80	0%
77	83	82	1%	77	7%
78	84	83	1%	78	7%
78	87	83	5%	78	10%
MEAN DIFFERENCE			5%		7%

The mean difference between actual capacity and estimated capacity was 5 percent. The CCA equation estimates are 2 percent closer to actual estimates than the HCM capacity equation. This is probably because CORSIM includes start-up losses in the simulation and the saturation equation does not. This data verifies the equation for the CCA as an acceptable estimate for intersection capacity.

CHAPTER 7: DISCUSSION

The most accurate way to use CCA would be to uncouple the stop bar detector so the intersection controller can get an accurate count from each lane, or UDOT can install detectors in the turning lanes to subtract turning vehicles. Nevertheless, CCA can be used to monitor commuter congestion with the current infrastructure. CCA does this by subtracting turning volume estimates and comparing the five-minute through volumes with a five-minute congested volume.

Flow data was collected during the peak period for eight intersections along State Street and used CCA to display the commuter conditions. Figure 7.1 shows the CCA display for State Street for the PM peak. (Note: The values for amber and red conditions were changed to 0.5 and 0.85 respectively.)

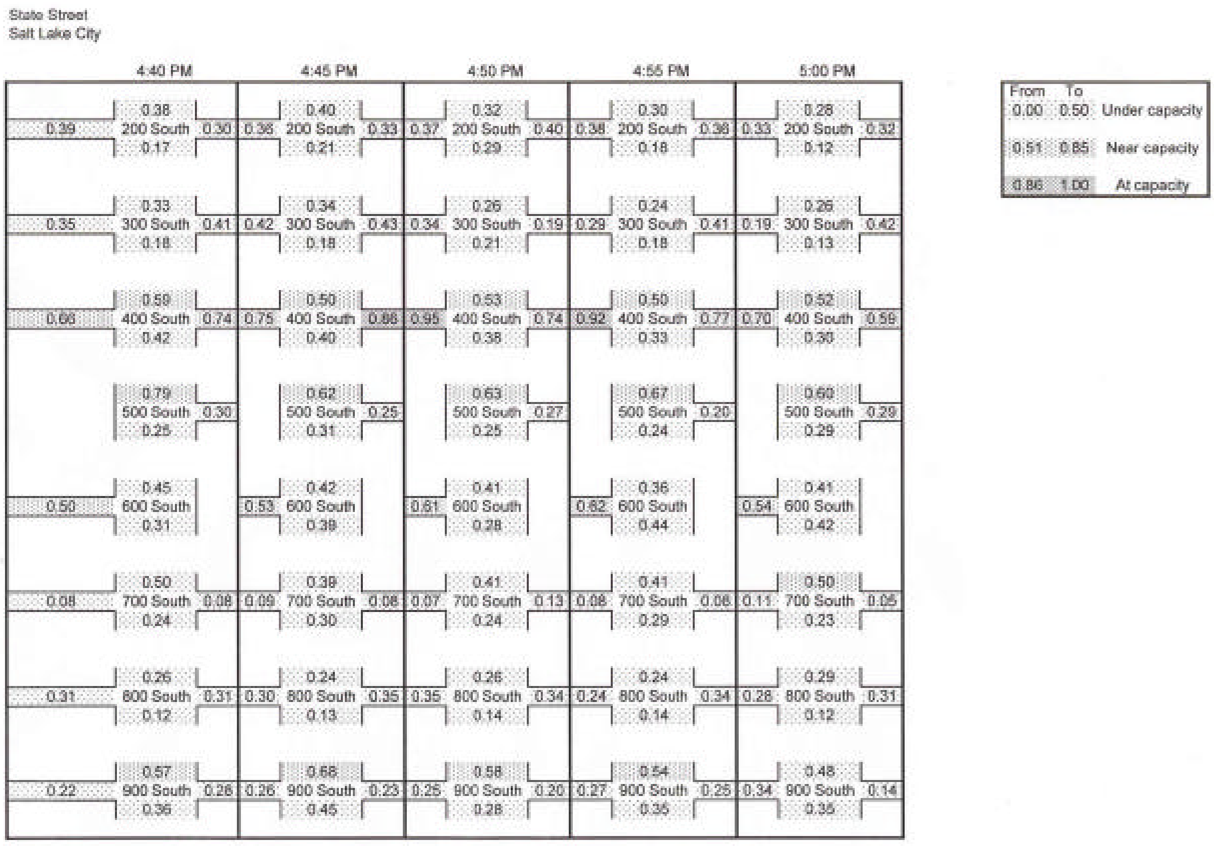


Figure 7.1: State Street Congestion

Figure 7.1 shows the v/c ratio for each approach on all eight intersections in five-minute intervals. A copy of the MS Excel spreadsheet used to calculate and display information is on the CD ROM that accompanies this report.

This new technique for estimating commuter congestion in real-time has many potential applications. Web-based information would be available to warn users of congestive areas and used in conjunction with Internet road maps that graphically display freeway congestion. Transportation operators may use surface arterial congestion information to find surface street incidents. They also may identify locations where either geometric or signal timing improvements are needed. If new timings are implemented, the CCA can help identify the effectiveness of the improved signal timing. Figure 13 shows a potential application for CCA on Utah's graphic web-page interface, Commuter Link.

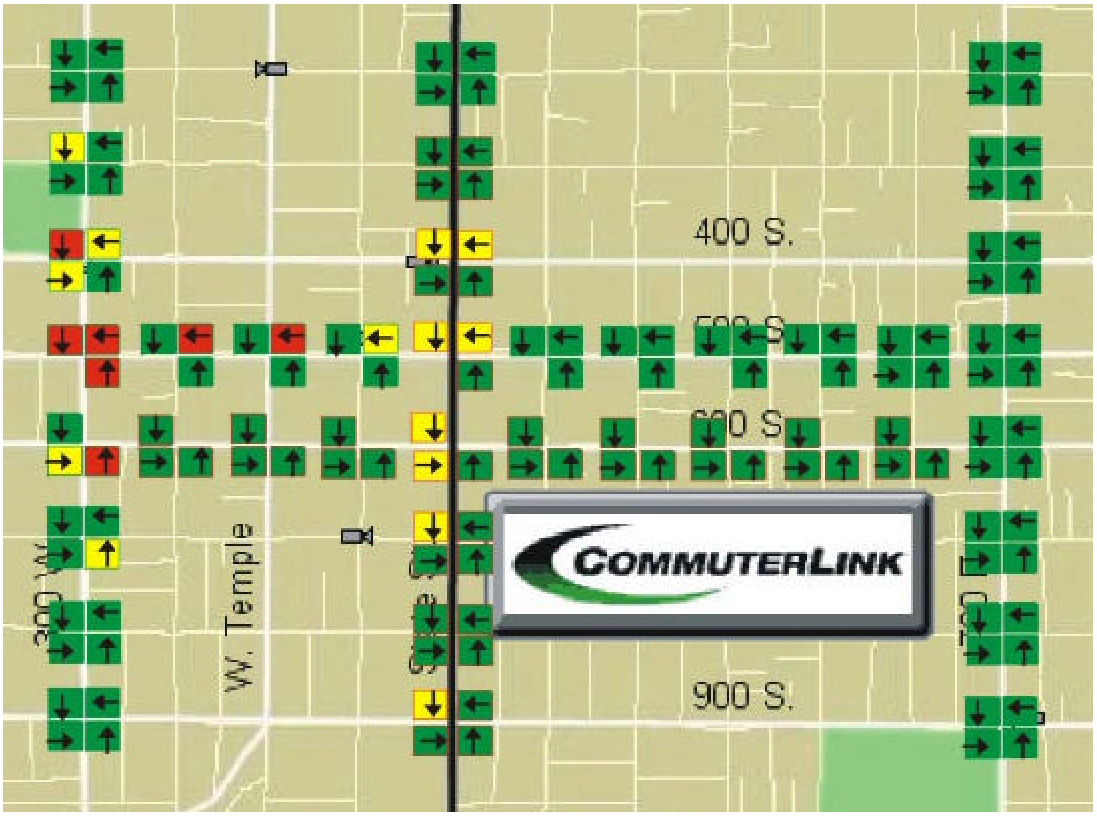


Figure 7.2: Possible Commuter Congestion Algorithm Webpage

CCA also can be used to estimate congestion for any turning lane. It requires that the lane has a detector and the equation is multiplied by the appropriate turning factor, as defined by the HCM. The HCM gives a factor of 0.92 and 0.85 for left turns and right turns, respectively.

CHAPTER 8: CONCLUSION

This research has been able to establish:

- A relationship between detector data (volume and occupancy) and intersection congestion by using the CORSIM simulation system and the Highway Capacity Manual (HCM)
- A CORSIM model was used to determine the five-minute capacity of an intersection as a function of green-time. This information was used to develop an equation that will estimate five-minute capacity as a function of green-time.
- Green-time and volume was recorded at a congested intersection for 39, five-minute intervals. The cumulative green-time for each five-minute interval was used to estimate the capacity of the intersection using the equation developed by this research. The estimates were within 5 percent of the actual field counts.

The equation was developed into an algorithm that uses volume, occupancy, and green-time to calculate the intersection capacity and display congested conditions. The HCM was used to define congested conditions as free-flow (“Green”), near capacity (“Amber”), and at capacity (“Red”). This algorithm is called the Commuter Congestion Algorithm (CCA).

UDOT has a system (Econolite's ICONS) that allows it to monitor commuter progression on freeways. With CCA, UDOT will be able to monitor commuter progression on the surface streets using system detectors, intersection controllers, and ICONS. CCA enables UDOT to monitor intersections regardless of the number of lanes, the cycle length, and the green-time. In addition, CCA allows for the congestion thresholds to be changed to fit the needs of the TOC. CCA requires the following input:

Initial Input from human interface:

- Right turn ratio
- Left turn ratio
- Number of Lanes

Real-Time Input from field controller:

- five-minute volume
- five-minute occupancy
- five-minute cumulative green-time

CCA will check that the occupancy is not above the congested threshold. If the occupancy is above the threshold, the algorithm will display the congested condition as “Red”. If the occupancy is below the threshold, the CCA will estimate intersection capacity using the cumulative green-time and number of lanes. Next CCA will calculate the through volume of the intersection by subtracting the estimated turning vehicles from the five-minute volume. Finally, it will compare the through volume with the estimated capacity and display the appropriate congested value as “Red,” “Amber,” or “Green.”

CHAPTER 9: IMPLEMENTATION PLAN

The following steps are necessary to implement CCA.

1. Develop an interface between CCA and ATMS database.
2. Develop a user input (geometries and turning percentages) in the ATMS Database for each approach to be monitored (for the arterials with system detectors).
3. Program intersection controllers to report occupancy and volume from the system detectors in five-minute intervals for each approach for the intersections in the arterials.
4. Record the cumulative green time during the five-minute intervals for the corresponding approaches as provided by ICONS.
5. Have ICONS retrieve occupancy, volume and cumulative green time (controller input) every five-minutes and store the data in appropriate ATMS database files.
6. Run CCA with user and controller input data by linking CCA to the ATMS database.
7. Develop an arterial map similar to the freeway map (possibly combine the two).
8. Define congestion thresholds (congestion colors).
9. Link CCA with the database and display map.

CHAPTER 10: ADDITIONAL RESEARCH

This research may provide many useful tools that can automate LOS and other measures of effectiveness. CCA may be modified to incorporate and estimate actual HCM LOS such as:

- Intersection LOS
- Arterial LOS
- Protected/permitted left turn congestion

The modifications would require more extensive algorithm input and possibly additional field equipment.

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LIST OF APPENDICIES

Appendix I

The information in Appendix I is taken from Econolite's webpage.

http://www.econolite.com/company/overview/overview.htm

Who We Are

Founded in 1933, Econolite is a leading North American manufacturer and distributor of traffic control equipment and systems. Broad traffic industry background and manufacturing capabilities have allowed Econolite to take leading edge technology and apply it to advanced traffic control hardware and traffic management systems. Product lines include actuated and pretimed controllers, arterial masters, distributed/closed loop traffic control systems, advanced traffic management systems, wide area video vehicle detection systems, traffic control cabinets and traffic signal display equipment.

As a traffic control equipment supplier Econolite has been involved in a wide variety of projects over the past 65 plus years. These have been as simple as supplying display equipment for intersections to providing engineering, equipment, integration, installation, and test of multi-intersection systems. Econolite has over 2000 arterial systems in operation controlling in excess of 15,000 intersections. Additionally, Econolite has over 2500 wide area video vehicle detection systems operating in both intersection and freeway applications.

Throughout its history Econolite has strived to provide leading edge technology solutions for traffic control. This is made possible by engineering capabilities that include both hardware and software development, evaluation, integration, productization, and test. This has resulted in a number of Econolite innovations including development of the first digital controller, introduction of the first microprocessor based controller, wide spread application of closed loop arterial control systems, installation of both the first NEMA TS2 Type 1 and Type 2 cabinet assemblies, introduction of the first wide area video vehicle detection system using multiple sensor inputs and support of the NTCIP protocol. In addition to its proprietary product development, Econolite also provides custom hardware and software development to provide solutions to specific customer requirements.

Econolite offers a unique blend of capabilities and experience combined with a dedicated and professional staff. Econolite is committed to the application of new technology for the safe and efficient control of traffic.

Summary of Capabilities

Econolite combines extensive traffic industry experience together with software, hardware, and systems engineering capabilities to provide the following products and services:

Traffic Control Products

- Actuated and Pretimed controllers
- Arterial Masters
- Advance Transportation Management Systems
- Distributed Traffic Management Systems
- Communications Systems
- Traffic Control Cabinet Assemblies
- AutoscopeÒ Wide Area Video Vehicle Detection Systems
- Vehicle and Pedestrian Signals

Services

- Traffic Engineering, Planning and Analysis
- Hardware and Software Development
- Systems Integration and Test
- Needs Analysis
- Functional and Environmental Testing

Summary of Experience

Econolite has been involved in the development of traffic control equipment and systems for over 30 years. During this period Econolite has become recognized as an industry leader in applying new technology to traffic control applications. In particular Econolite is a recognized leader in the development of advanced traffic controllers, distributed arterial control systems, advanced transportation management systems and video vehicle detection systems.

Appendix II

The information in Appendix II is taken from Econolite's webpage.

http://www.econolite.com/product/systems/icons.htm

Description

Let's assume you want to observe system operation for two crossing arterials within your present closed loop system. You'd have to call up each arterial system separately, observing each system display one at a time. But in order to see both arterials simultaneously, you would need a system that allows multiple communications ports to be active at the same time -- something that has not been available in low-cost system software. So, Econolite developed Aries, the industry's first 32-bit Microsoft Windows 95® / 98® /Windows NT® Distributed Traffic Management System.

Overview: Integrated Control of Traffic Networks

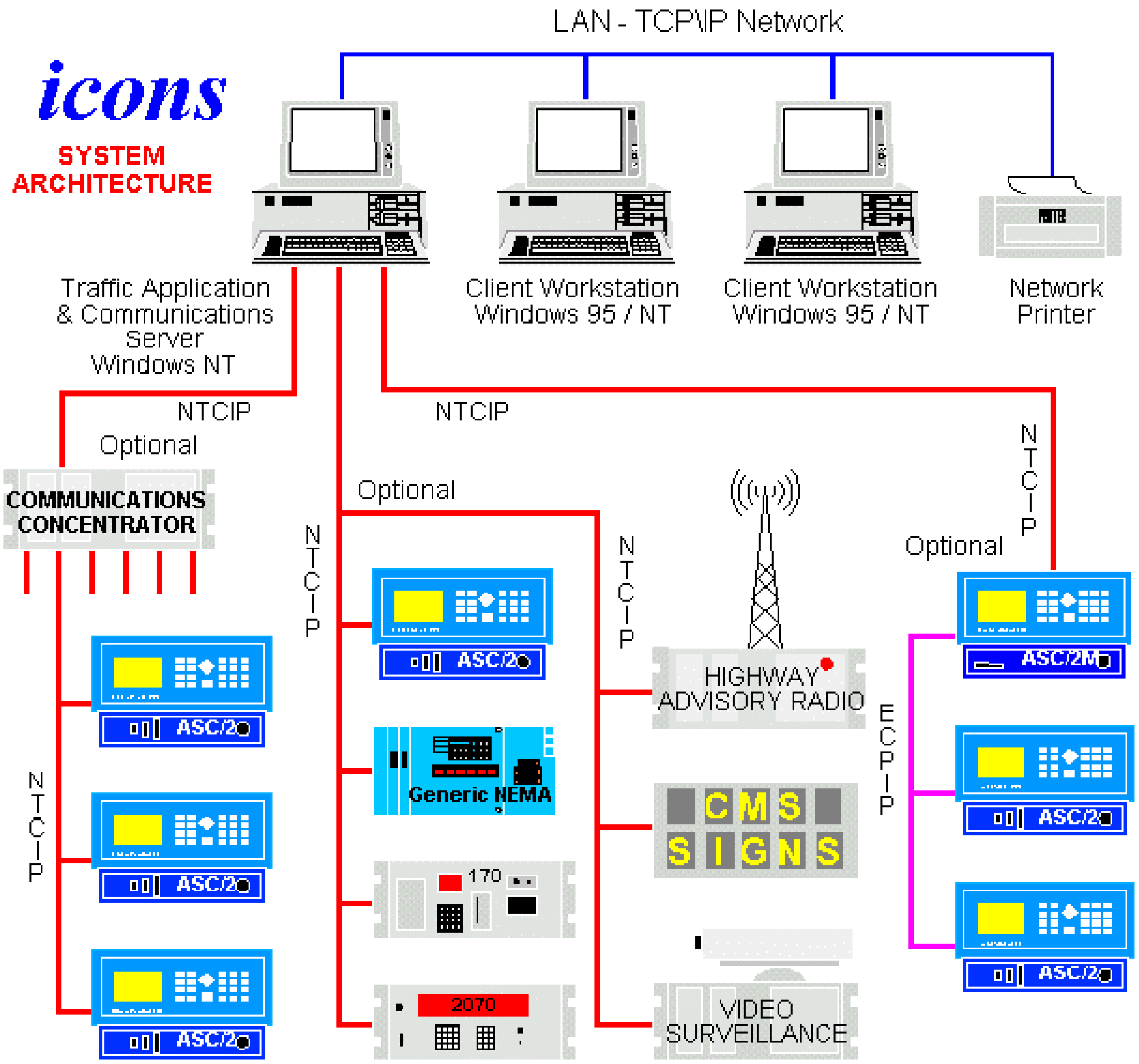
icons is the acronym for integrated control of networks. It is an Advanced Traffic Management System which uses the NTCIP protocol and represents Econolite's next generation of hybrid central systems. It provides a centralized, integrated platform for traffic signal system control, information management, and graphical data display. By using icons, the operator is able to assimilate data more rapidly through a map-based graphics display, thereby improving traffic operation and decision making efficiency.

icons provides a full-featured, easy to use, object oriented graphical user interface (GUI). Intersection specific objects support centralized traffic management and control of signalized intersections. icons extends this graphical user interface to manage other ATMS/ATIS related data.

Open Systems Architecture

icons is supported across a distributed client-server architecture for improved performance and configuration flexibility. The use of standard personal computer hardware, commercial software, and support of the industry standard communications protocols allows the system to adapt to changes in technology.

icons provides functionality over time with minimum impact on system components. Any number of operator workstations can be networked together, each providing complete system access and functionality. By using the NTCIP protocol, icons can easily support NEMA, Type 170 and 2070 controllers in the same traffic system.



The icons architecture is illustrated in the above diagram. Overall system supervision is provided by a dedicated Traffic Applications Server. In addition, Communication Servers are used to process communications with the field equipment. The number of Communication Servers in a system depends on the number of communication channels needed to serve the field equipment. User interface to the system is provided by Client Workstations connected to the Traffic Applications Server over a local or wide area network.

Each Communications Server provides communications for up to 16 channels using the AB3418, AB3418+ or NTCIP protocols. Communications channels can be used as direct or multidrop channels to local field equipment or be used as high-speed channels communicating with multiple local field equipment channels through a communications concentrator.

The local field equipment can include any traffic controller that supports NTCIP, including NEMA, Type 170 and 2070 controllers. In addition, other devices commonly used in a traffic management system can be supported, such as Dynamic Message Signs (DMS), and video surveillance systems. The system also supports communications with Econolite's ASC/2M zone masters using a modified version of the AB3418 protocol. In this architecture, the zone masters can continue to communicate with existing local controllers using Econolite's standard system protocol, also called Econolite Control Products Interface Protocol (ECPIP).

Technical Highlights

Overview

- PC-based client/server architecture
- Map-base graphical user interface on client PCs
- Windows 98 or Windows NT client
- Windows NT Traffic Applications Server
- Object-oriented design
- Open system communications protocol using AB3418, AB3418+ or NTCIP

Dedicated Traffic Applications Server

- Windows NT server
- Performs all traffic application functions
- Controls system communications
- Optional separate communications server

- Up to 16 communications channels per server
- SQL database interface
- Long-term data storage/archiving

Basic Control Approaches

- Hybrid central control
- Download/plan select
- Continuous central monitoring
- Once/second all intersections
- Automatic update of time via dial-up
- Calls for time updates; no special central clock required.
- Scheduler implementation locally with central override capability

Traffic responsive from central

- Optional TRP control from zone masters
- Traffic Responsive Operation
- Pattern matching to pick "best plan"
- Based on smoothed volume & occupancy
- Up to 60 system detectors per section
- Plan selections based on user-established "minimum betterment" criteria
- Section intersections can be dynamically assigned

Intersection Control Modes

- Manual override
- System
- Section
- Local

- Remote override
- Allows regional incident management
- Central control
- Traffic responsive
- TOD scheduler
- Local control
- Manual plan or free
- TOD scheduler
- Commanded free
- ASC/2M Zone Master (optional)
- Manual
- Traffic responsive
- TOD Scheduler

Map-Based Graphical User Interface

- Graphical display of area-wide, regional, section and intersection data
- Easy-to-use menu system
- Windows® 95 multimedia support
- Fully zoomable, scrollable displays
- Raster and vector image backgrounds
- Import formats supported:
- BMP (Windows® bitmap)
- DFX (AutoCAD through third-party packages)
- Full hypertext type help

Dynamic Graphic Editor

- Used for area-wide, section/group and intersection displays
- Intersections
- Vehicle signals
- Ped signals
- Detectors
- Text messages
- Status
- Placement of dynamic icons
- Assignment of dynamic attributes
- Intersection status
- Phase color
- Detector status
- MOE status

Area-Wide Map

- Object selections from map or menu
- User programmable accelerator buttons
- Status, monitoring & control available by clicking on object icons to select
- Intersection status - on/off, flash, preempt, coordinated, main street green
- Selectable section/group map view
- Multi-level, bi-directional zooming
- Multi-layer visibility options
- Expanded status/MOE information
- Color coded links

- Phase status arrows

Intersection Displays

- Signal color status
- Phase
- Overlap
- Pedestrian
- Individual detector status
- MOE legends
- Raster image backgrounds
- Capability to display many intersections at once

Database Management

- Data stored on network accessible database files
- Managed by SQL server product
- Full upload/download/compare feature for local controller data
- Full cut & paste operations
- Security/access/activity tracking

Report Types

- Standard & custom types
- Standard reports for displaying/printing database entries
- Custom event reporting
- Custom report support - tested object linking & embedded interface to:
- Borland's Delphi
- Microsoft's Excel

Reporting Capabilities

- Operational status reports
- System, section, intersection, detector link, communications channel, special functions
- Event log reports
- Scheduler reports
- Graphical/text-based MOE reports

Real-Time "Window" reports

- Intersection/arterial graphic displays
- Intersection communications tracer
- Interactive time-space diagram
- Real-time split monitor
- MOE trends monitor

Server Hardware Requirements

- Pentium, 500 MHz minimum
- 128 MB of RAM
- 8 GB of free hard disk space
- CD ROM drive
- Super VGA monitor, 1024 x 768
- Digital tape backup
- Ethernet interface

Client Workstation Hardware Requirements

- Pentium, 500 MHz minimum
- 128 MB of RAM

- 4 GB of free hard disk space
- CD ROM drive
- Super VGA monitor, 1024 x 768, 17 minimum"
- 8 MB of video RAM, 24 bit color depth
- Ethernet interface

Other System Hardware

- Remote dial-in connection port
- requires minimum 56K kbps modem
- Multi-port serial communications module
- Separate communications server for more than eight channels

Commercial Software Included

- Window NT Server/Workstation
- Windows 98
- Microsoft Office Pro Suite (optional)
- Microsoft SQL server

Background on NTCIP

The best source of information is the NTCIP Guide, which is published on the web. In summary, the National Transportation Communications for ITS Protocol (NTCIP) is a standard for transmitting data and messages between devices used in Intelligent Transportation Systems (ITS). Development of the standard began in 1992 in response to frequent requests for standardization from the users of traffic signal controllers. Now that the standard is available, it is expected that most vendors will offer NTCIP support in present and future traffic control devices.

The NTCIP protocol allows traffic management systems to communicate with a mixture of devices on the same communications channel. These can be controllers by different manufacturers as well as other devices, such as variable message signs. Econolite's icons system adds the critical software and graphical user interface elements, which are required to make an NTCIP-based traffic management system a reality.

Appendix III

This is a sample of data retrieved from CORSIM - used to build the tables and calculate the equations for CCA, and from the field counts. There are 71 files that were used to build the volume table and each file is 832 pages long. Data is included in the CD ROM that accompanies this report.

The following page is the first page of the 50-second cycle with a 20-second green-time. In the cells of the right hand corner of the page are the statistical information used for the research. To the right of the word average is the average five-minute volume. To the right of the word green-time is the average amount of green-time, or cumulative green-time, per five-minute interval.

The second page shows the table used to build Figure 11. This table is the combination of Table 3 and Table 6. The capacity values (from Table 3) are listed in the right-hand column next to the cumulative green-time (from Table 6) with the corresponding cycle length and green-time.

interval	Count	signal	Occupancy in 0.1 sec										seconds	volume
0	0	G	1	1	1	1	1	1	1	1	1	1	1	
1	0	G	1	1	1	1	1	1	1	1	1	1	2	
2	0	G	1	1	1	1	1	1	1	1	1	1	3	
3	0	G	1	1	1	1	1	1	1	1	1	1	4	
4	0	G	1	1	1	1	1	1	1	1	1	1	5	
5	0	G	1	1	1	1	1	1	1	1	1	1	6	
6	0	G	1	1	1	1	1	1	1	1	1	1	7	
7	0	G	1	1	1	1	1	1	1	1	1	1	8	
8	0	G	1	1	1	1	1	1	1	1	1	1	9	
9	0	G	1	1	1	1	1	1	1	1	1	1	10	
10	0	G	1	1	1	1	1	1	1	1	1	1	11	
11	0	G	1	1	1	1	1	1	1	1	1	1	12	
12	0	G	1	1	1	1	1	1	1	1	1	1	13	
13	0	G	1	1	1	1	1	1	1	1	1	1	14	
14	0	G	1	1	1	1	1	1	1	1	1	1	15	
15	0	G	1	1	1	1	1	1	1	1	1	1	16	
16	0	G	1	1	1	1	1	1	1	1	1	1	17	
17	0	G	1	1	1	1	1	1	1	1	1	1	18	
18	1	G	0	0	0	0	0	0	1	1	1	1	19	1
19	1	G	1	1	1	1	1	1	1	1	1	0	20	2
20	1	G	0	0	0	0	0	0	0	0	0	0	21	3
21	1	G	1	1	1	1	1	1	1	1	1	1	22	4
22	1	G	1	1	1	1	1	1	1	0	0	0	23	5
23	2	G	0	0	1	1	1	1	1	1	1	1	24	6
24	3	G	1	1	1	1	1	0	0	1	1	1	25	7
25	3	G	1	1	1	1	1	1	1	1	1	0	26	8
26	3	G	0	0	0	0	0	0	0	0	0	0	27	9
27	4	G	1	1	1	1	1	1	1	1	1	1	28	10
28	5	G	1	1	1	1	1	1	0	0	0	1	29	11
29	5	G	1	1	1	1	1	1	1	1	1	1	30	12
30	5	G	1	1	1	0	0	0	0	0	0	0	31	13
31	6	G	0	0	1	1	1	1	1	1	1	1	32	14
32	6	G	1	1	1	1	1	1	1	0	0	0	33	15
33	7	G	0	0	0	0	0	0	0	1	1	1	34	16
34	7	G	1	1	1	1	1	1	1	1	1	1	35	17
35	8	G	1	1	0	0	0	0	0	0	1	1	36	18
36	8	G	1	1	1	1	1	1	1	1	1	1	37	19
37	8	G	1	1	1	1	0	0	0	0	0	0	38	20
38	9	G	0	0	0	1	1	1	1	1	1	1	39	21
39	9	G	1	1	1	1	1	1	1	0	0	0	40	22
40	10	G	0	0	0	0	0	0	0	0	1	1	41	23
41	10	G	1	1	1	1	1	1	1	1	1	1	42	24
42	11	G	1	0	1	1	1	1	1	1	1	1	43	25
43	11	G	1	1	1	1	0	0	0	0	0	0	44	26
44	12	G	0	0	1	1	1	1	1	1	1	1	45	27
45	12	G	1	1	1	1	1	1	1	1	1	0	46	28
46	12	G	0	0	0	0	0	0	0	0	0	0	47	29
47	12	G	1	1	1	1	1	1	1	1	1	1	48	30
48	13	G	1	1	1	0	0	0	1	1	1	1	49	
49	13	G	1	1	1	1	1	1	1	1	1	1	50	
50	13	G	1	1	1	1	1	1	1	1	0	0	1	

average	95.3
st dev	4.3
N	71.7
count	72
green-time	180

Cumulative Green Time	5-minute Volumes
43	24
46	26
50	27
54	30
60	32
60	32
64	35
67	36
69	37
75	40
75	39
80	42
82	43
86	47
86	45
90	48
93	49
100	54
100	52
100	53
100	53
107	57
109	57
113	60
116	60
120	64
120	62
120	62
125	65
129	68
129	66
133	70
136	70
138	71
140	72
150	79
150	78
150	78
150	78
150	77
160	82
161	83
164	86
167	85
171	90
172	88

175	91
180	95

240	122
245	125
250	128

Cumulative Green Time	5-minute Volumes
180	93
180	92
184	95
187	96
191	99
193	100
200	104
200	104
200	102
200	102
208	107
210	107
214	110
214	111
218	112
225	116
225	115
231	118
233	121