ADAPTIVE TRAFFIC SIGNAL CONTROL PILOT PROJECT FOR THE CITY OF SURREY

Joseph K. Lam, P.Eng., Managing Director
Delcan Corporation
625 Cochrane Drive, Suite 500, Markham, Ontario, Canada, L3R 9R9
Tel: +1-905-943-0521, Fax: +1-905-943-0226

Sinisa Petrovic, P.Eng., Traffic Operations Manager, City of Surrey
City of Surrey
14245 - 56 Avenue, Surrey, BC, V3X 3A2
Tel: +1-604-598-7954, Fax: +1-604-598-8693

Perry Craig, P.Eng., Senior Principal
Delcan Corporation
625 Cochrane Drive, Suite 500, Markham, Ontario, Canada, L3R 9R9
Tel: +1-905-943-0508, Fax: +1-905-943-0226

Paper prepared for Presentation at the
Road Safety Strategies and Intelligent Transportation System (ITS) Session
of the 2013 Conference of the
Transportation Association of Canada
Winnipeg, Manitoba

April 2013

ABSTRACT

The City of Surrey, which is currently the 12th largest city in Canada by population, has been the fastest-growing municipality in British Columbia over the past decade, and is on pace to surpass Vancouver as BC's largest city sometime over the next twenty years. With this continued rapid growth, there is a growing need for a better, more cost-effective method to more efficiently manage the traffic demand. To address this need, the City applied for, and successfully secured funding from Transport Canada under the Strategic Highway Infrastructure Program to deploy an Adaptive Traffic Signal Control (ATSC) Pilot Project. The City and Delcan Corporation agreed to implement and evaluate the ATSC Pilot Project using Delcan's "Multi-criteria Adaptive Control" system.

The corridor selected for the ATSC Pilot Project was 72nd Avenue, between 120th Street and King George Boulevard. The seven closely spaced signalized intersections along 72nd Avenue are controlled by the City's BiTrans Type 170 traffic signal controllers, and monitored by the City's McCain "QuicNet" traffic signal management system. The corridor currently operates under coordinated time-based coordination (TBC) operations during the weekdays, and as fully actuated during the weeknights and weekends, with no significant traffic operational problems.

The scope of the ATSC Pilot Project was to demonstrate the integration of traffic adaptive control with the City's existing traffic signal control infrastructure, and to evaluate the benefits of adaptive control. Delcan's ATSC system has been designed to take advantage of modern technologies and to address the limitations of existing commercially available adaptive control systems. The ATSC system's open system architecture is flexible to work with the City's existing Type 170 controllers, vehicle detector loops, and communications network.

This paper describes the real world application of an ITS system designed to improve traffic operations, including lessons learned. The pilot project demonstrated the seamless integration of the ATSC system with the City's existing traffic signal control infrastructure. The field surveys demonstrated that adaptive traffic signal control performed equal to the best optimized TBC signal timing plans during the peak traffic periods, and was able to effectively adjust to unexpected traffic patterns during off-peak periods.

1 INTRODUCTION

1.1 Project Background

The City of Surrey has been the fastest-growing municipality in British Columbia over the past decade by absorbing nearly one-third of the total population growth in Metro Vancouver. Surrey is currently the 12th largest city in Canada by population and is on pace to surpass Vancouver as BC's largest city sometime over the next twenty years. This rapid population growth in Surrey will quickly strain the existing transportation system. Traffic congestion in many areas of the region will degrade to unacceptable levels unless appropriate strategies and plans are put in place.

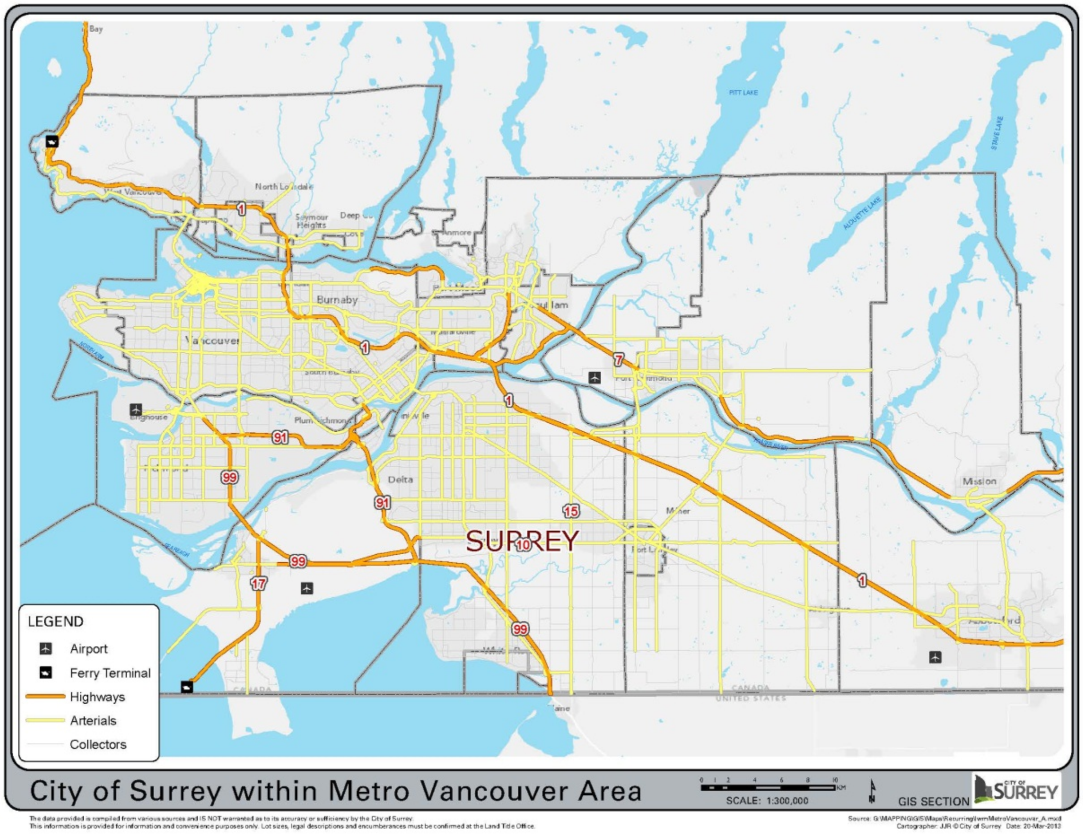
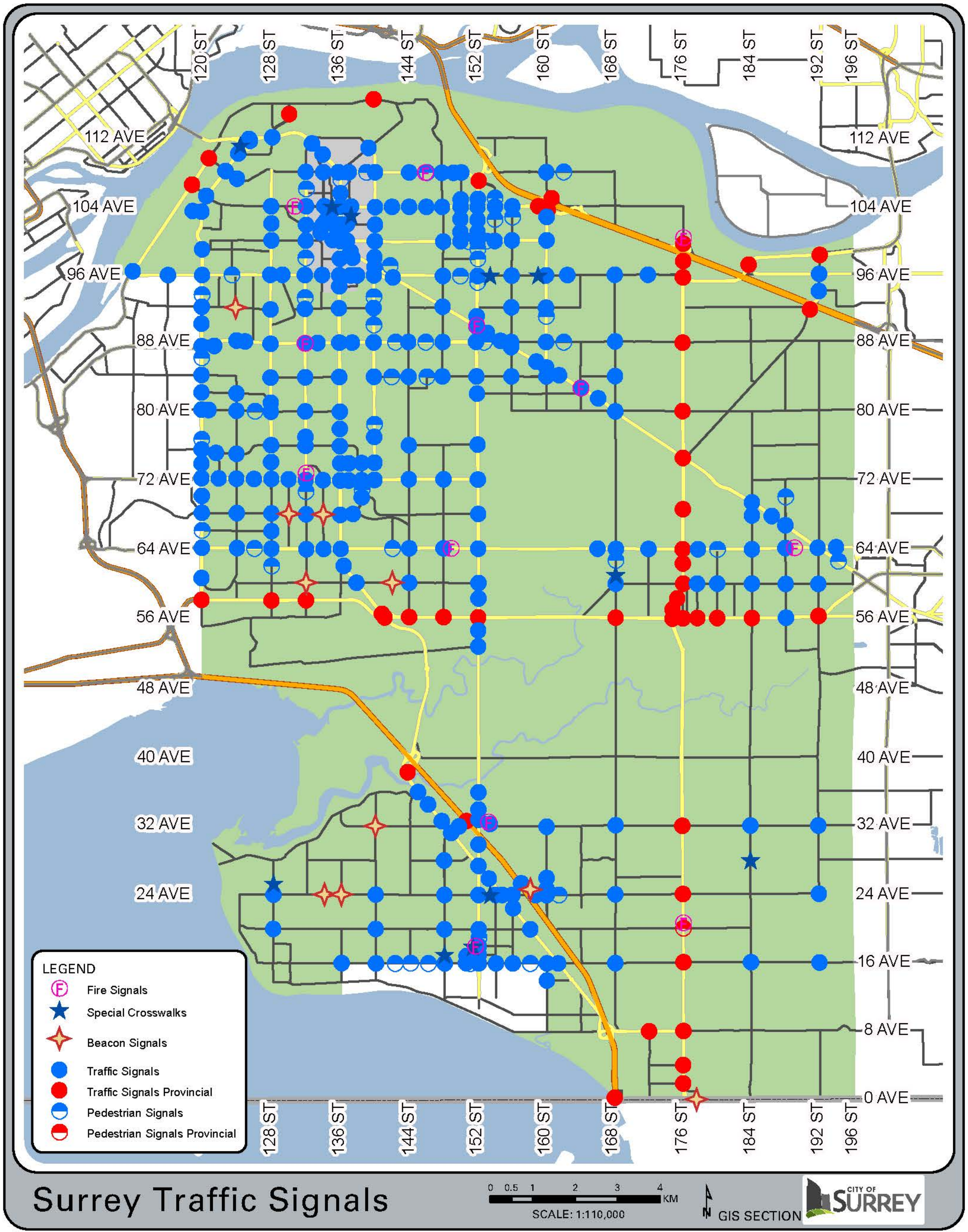


Figure 1 – City of Surrey within Metro Vancouver Area

On major traffic corridors within the City of Surrey, the signalized intersections are currently coordinated during the day by pre-determined signal timing plans that are developed from historic traffic flow patterns and scheduled for implementation on a time-of-day basis. (During the night, the intersections are operated as fully actuated, uncoordinated control.) This approach generally handles the traffic demand quite adequately, particularly when the traffic flow pattern is relatively constant for a period of time. This mode of control, however, is less efficient in terms of handing both short term, microscopic variations of demand at individual intersections, and longer term changes in traffic patterns. As a result, it can result in unnecessary travel time delays, stops / starts and vehicle emissions, as well as having a negative impact on traffic safety due to unnecessary congestion.



Source: G:\MAPPING\GIS\Maps\Recurring\PostedMaps\trnTrafficSignals_2013_A.mxd
Cartographer: JJR Date: 20-Mar-2013

Figure 2 – Signalized Intersection within the City of Surrey

As part of their annual traffic signal improvement program, the City reviews and updates the pre-determined signal timings along four out of the twenty major traffic corridors within the City. The signal timings at any given signalized intersection are therefore typically updated only once every five years. Consequently, with the continued rapid growth of the City of Surrey, as well as the installation of an increasing number of signalized intersections, the pre-determined signal timing plans are expected to age very quickly. The City is therefore looking for new cost-effective approaches, such as automated methods, that will enable them to keep up with the rapid traffic growth and more efficiently manage the traffic demand.

The proposed initiative is the deployment and evaluation of Adaptive Signal Control Technology (ASCT) as an enhancement to the City's existing traffic signal control system. Through the adaptive signal control technology, signal timings will be automatically adjusted and adapted to variable traffic demands measured by on-street vehicle detectors in real time. This mode of control typically reduces delays compared to traditional coordinated signal timing plans, and keeps pace with traffic growth.

1.2 Project Objectives

Traffic signal control systems were introduced to better manage traffic in a signalized and coordinated network. Within a coordinated network, adaptive signal control technology (ASCT) systems provide several advantages over time-based coordination (TBC) systems because of their ability to monitor traffic conditions and implement appropriate timing plans that best serve the current traffic needs.

TBC systems utilize either simple manual strategies or off-line computer optimization packages to pre-determine the cycle lengths, green splits and offsets, based on available historical traffic data. Because of the reliance on historical data, the preparation of the pre-determined timing plans are resource and time consuming to prepare. Moreover, in areas of rapid growth where the traffic flow patterns can quickly change, pre-determined timing plans can age and become out-of-date very quickly. TBC systems are also unable to accommodate highly congested flow or non-recurring traffic conditions caused by collisions, weather conditions or special events.

Because of the inflexibility of TBC systems, and the potential for their timing plans to age quickly, the City of Surrey is looking for new cost-effective approaches, such as an automated method, that will enable them to keep up with the rapid traffic growth and more efficiently manage the traffic demand.

The proposed initiative is the deployment and evaluation of Adaptive Signal Control Technology (ASCT) as an enhancement to Surrey's existing TBC system. ASCT warrants consideration in that such systems can not only adjust signal timing for traffic congestion (e.g., caused by random fluctuations in traffic, incidents, special events, etc.), but can also accommodate longer term changes in the traffic patterns.

The objectives for this ASCT Pilot Project therefore are to implement adaptive signal control technology on a pilot corridor in Surrey and demonstrate that ASCT:

- Can be integrated with the City's existing traffic signal management infrastructure including:
    - McCain "QuicNet" (TBC) system;
    - Type 170 traffic signal controllers (with McCain (formally BiTrans) 233 firmware); and
    - Wireless communications network (with limited bandwidth);
- Ease and cost-effectiveness to deploy;
- Performs as well as the best optimized TBC signal timing plans; and
- Appropriately responds to random fluctuations in traffic patterns as well as to unplanned incidents and events.

1.3 Proposed Adaptive Signal Control Technology

Delcan proposed to implement their Multi-criteria Adaptive Control (MAC) system that has been designed to take advantage of modern technologies and address the limitations of existing commercially available adaptive signal control systems. System and operational benefits that Delcan's MAC system could bring to City of Surrey include the following:

- Multi-criteria adaptive signal control algorithms that cater for a wide range of traffic conditions, including over-saturated and congested situations;
- Distinctive adaptive signal control criteria (i.e., maximum green bandwidth, minimum delays and stops, queue balancing and gating) that are applied to optimize signal timings for the prevailing traffic conditions;
- Flexible detector configuration requirements that enable users to optimize detector coverage, while minimizing capital costs, for better data collection;
- Reduced effort to update and maintain signal timing plans;
- Improved traffic operational efficiency and reduced traffic congestion in key corridors;
- Open system architecture compatible with the ITS Architecture for Canada that can provide for integration and sharing of data with of other ITS initiatives in the Region; and
- Open system architecture and communications protocol, with a technology growth path that can accommodate changing information technologies.

Operational benefits that the MAC system could bring to the general public in City of Surrey include:

- Improved traffic flows;
- Reduced traffic congestion;
- Improved road safety; and
- Reduced vehicle emissions to the environment.

1.4 Project Partnerships

This ASCT Pilot System implementation is a public private partnership project between:

- City of Surrey;
- Delcan Corporation;
- Transport Canada; and
- The Insurance Corporation of British Columbia.

2 PROJECT DESCRIPTION

2.1 Pilot Project Location

To select the Pilot Project corridor, potential corridors within the City of Surrey were screened according to the following criteria:

- The corridor must be subjected to variable traffic flows to increase the potential for significant travel time benefits;
- The signalized intersections (7-10) should be relatively closely spaced;
- Communications between the existing/future TMC and the traffic signal controllers on the corridor must either be existing, or easily achieved;
- The existing traffic signal controllers must be Type 170 to demonstrate the functionality of the ASCT system on this controller type; and
- No construction is likely to occur within the next five years which would affect detector placements.

The corridor that best met these criteria and was thus selected for the ASCT Pilot Project was the 72nd Avenue corridor between 120th Street and King George Boulevard. As illustrated in Figure 3, the selected corridor is comprised of the following seven closely spaced signalized intersections: 122nd Street; 124th Street; 126th Street; 128th Street; 130th Street; 132nd Street; and 134th Street.

Figure 3 – Signalized Intersection Locations along 72nd Avenue Corridor

Figure 4 – View of 72nd Avenue

The King George Boulevard and 120th Street intersections were not included in the Pilot Project as they are both part of existing north / south coordination schemes along each of these two respective major corridors.

Along 72nd Avenue, the traffic signal controllers typically operate under coordinated (TBC) control during high volume periods (e.g., weekdays from 6:30 am to 7:00 pm). Outside of these weekday periods, the controllers typically operated as fully actuated (e.g., from 7:00 pm to 6:30 am the following day).

Traffic signal operations along 72nd Avenue are currently well coordinated. The seven signalized intersections are all relatively evenly spaced, traffic volumes are generally manageable, and the TBC signal timing plans employed by the City provide good operational service. While there are some salient traffic generators within this corridor, such as a shopping mall, a polytechnic university, and a secondary school, and special events that impact traffic do occur, there currently are no recurring congestion problems being experienced along the corridor.

The seven signalized intersections along 72nd Avenue are controlled by Type 170 traffic signal controllers (running McCain (formally BiTrans) 233 firmware), and monitored by the City's McCain "QuicNet" traffic signal management system. To communicate with the traffic signal controllers along this corridor, the City employs a tree topology communications network, with a leased line from the control centre to a “master” intersection in the field, and then both point-to-point and multi-point spread spectrum radio links from the “master” intersection to the other local traffic signal controllers.

2.2 ASCT Pilot System Architecture

Delcan’s Multi-criteria Adaptive Control (MAC) system is a network-based, multi-level hierarchy of data processing nodes, acquiring traffic information from the field devices – traffic signal controllers and vehicle detectors – and implementing intersection signal timing parameters modified to respond to and improve the traffic conditions in the supervised traffic area.

2.2.1 Overview of MAC System Architecture

From a functional perspective, the MAC system can be structured at three different levels; namely:
Field level (MAC Adaptor) processing level;
Central MAC processing level; and
Client user interface level.

The MAC system architecture is described by the following five main components:

1. **Central Processor** - The Central Processor uses a recent version of Windows (i.e., XP or greater). This processor is sufficiently powerful to run the following software components:
   - MAC Central;
   - MAC Database; and
   - MAC GUI Server.

2. **Database Processor** – For the Pilot Project, the MAC database was run on the Central Processor; however, for a larger production system, it may be more convenient / advantageous to run the MAC Database on a separate computer. This may be necessary for the following reasons:
To run RDBMS on a non-Windows platform; and
To offload processing overhead from the Central Processor.

3. **Operator Workstation** - To be capable of acting as an Operator Workstation, this is typically a separate computer that has access to the local MAC Network. It is possible to run a browser on the Central Processor in the same manner as an Operator Workstation; though this would normally not be advised for a production system.

4. **MAC Field Adaptors** - The MAC Field Adaptors are installed in roadside cabinets, and the hardware must therefore be capable of handling extremes of temperature and humidity. The computer hardware has at least one Ethernet connection (e.g., for wireless communications). For non NTCIP-compatible field devices, one or more serial (RS-232/485) ports are required.

MAC Field Adaptor units are equipped with independent hardware watchdogs, such that a software failure (e.g., system panic) or hardware lockup (e.g., overheat, CPU glitch) will result in the individual unit rebooting itself. This is not guaranteed to maintain 100% uptime, but is a widely accepted technique in 24/7 field based systems.

A MAC Adaptor, shown in Figure 5, is normally installed in each traffic signal controller cabinet so as to be physically close to the traffic signal controller and the vehicle detector amplifier. Notwithstanding, it is conceivable that, for NTCIP-compliant devices, the MAC Adaptor may be installed in the Traffic Operations Centre or local communications hub (rather than in the traffic signal controller cabinet in the field).

5. **MAC Network** – The network is comprised of a single Ethernet LAN rated at 100 MB.

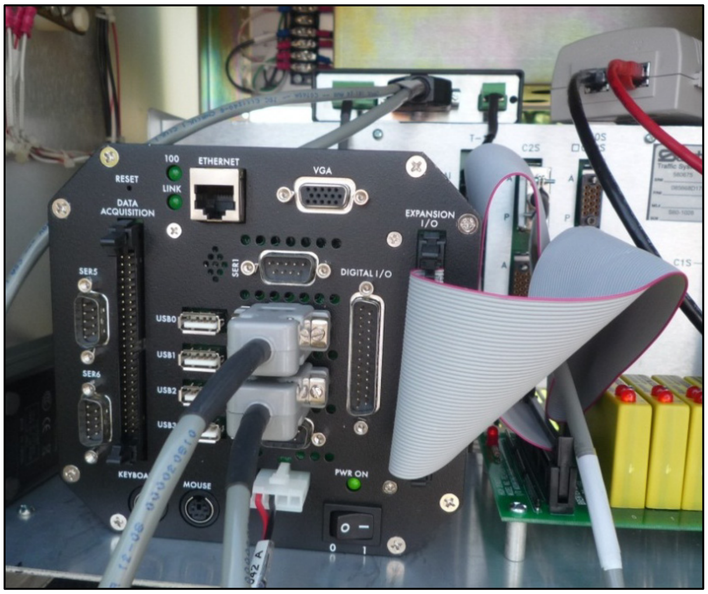


Figure 5 – MAC Field Adaptor in Controller Cabinet

2.2.2 MAC Algorithms

Delcan's ASCT has been designed around multi-criteria adaptive signal control algorithms that cater for a wide range of traffic conditions; from light traffic to over-saturated and congested situations. The MAC algorithms collect and process traffic flow data acquired from the signalized intersections in the given adaptive signal control group, and then calculate the cycle length, splits and offsets for all traffic signal controllers in the group, on a cycle-by-cycle basis. Distinctive traffic signal control criteria (i.e., maximum green bandwidth, minimum delays and stops, queue balancing, and gating) are applied to optimize the signal timings for the prevailing traffic conditions.

Upon initialization, MAC algorithms retrieve road network configuration, intersection phases, and algorithm parameters from the MAC configuration database. This information is used to allocate data structures for intersections, links, phases and vehicle movements.

When raw traffic data is received from all intersections in a given adaptive signal control group, with the configured "critical" intersection(s) reporting last, the MAC algorithms perform the following:

- Smooth last predicted values for saturation flow, speed, volume and occupancy;
- Calculate data prediction for each configured link in the control group for traffic volume, occupancy and saturation flow;
- Calculate travel time for all configured links in the control group;
- Determine critical movement for each intersection;
- Calculate degree of saturation for each intersection in the control group;
- Determine optimum cycle length for the next cycle in the control group;
- Determine the splits and offsets for each phase in all intersections in the control group;
- Recalculate the next level of precision by calibrating parameters for occupancy, volume and saturation flow for each configured intersection in the control group; and
- Set cycle length, phase's splits and offsets, and send them to the respective traffic signal controllers.

2.2.3 ASCT Pilot System Architecture

Delcan's Multi-criteria Adaptive Control system was designed to integrate and work with existing traffic signal management systems such as the City's existing "QuicNet" system, Type 170 traffic signal controllers, and communications network. The MAC system is also flexible to work with the City's existing in-ground, circular-shaped, stop line vehicle detector loops as well as with the City's tree topology communications network.

The Figure 6 illustrates the architecture implemented for the City of Surrey ASCT Pilot System.

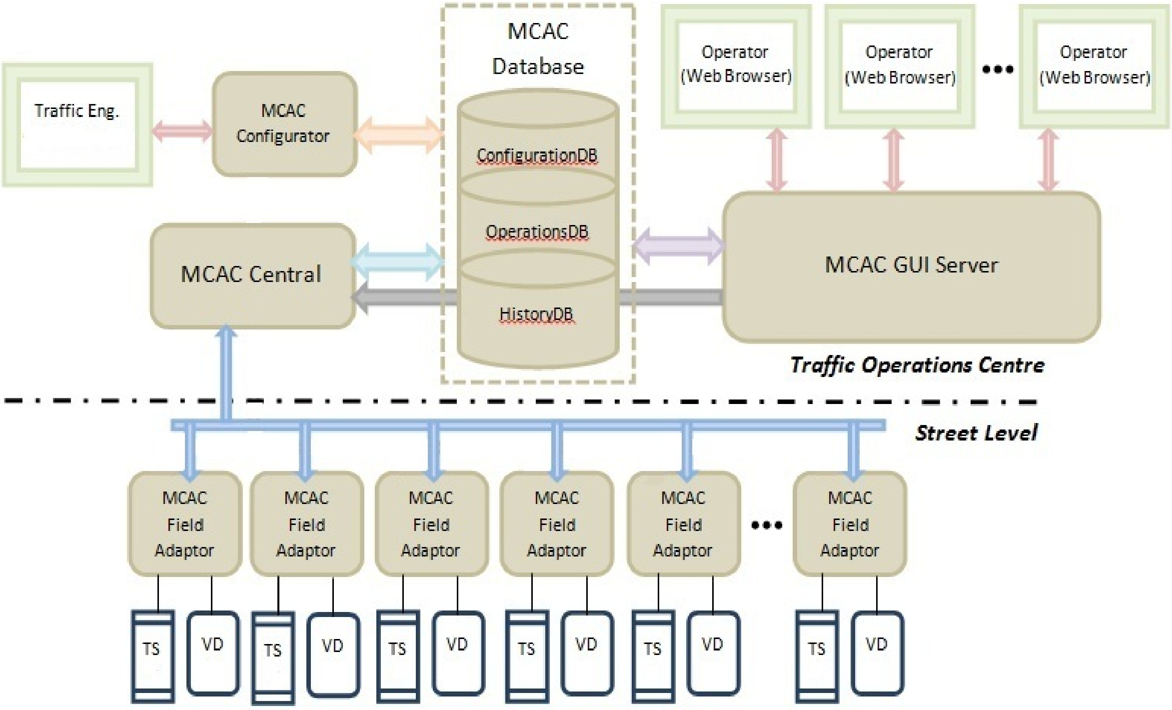


Figure 6 – Pilot Project System Architecture

2.3 Micro-simulation Environment

With recent advancements in micro-simulation technologies, transportation planners and traffic engineers now have improved tools to estimate the potential benefits that may be realized from improvements to traffic signal operations prior to implementing any such improvements on the street. For the ASCT Pilot Project, a custom micro-simulation environment was developed to test and verify the ASCT, and calibrate the parameters used in the ASCT algorithms.

A simulation environment similar to the real-time production system environment was created, which included the following hardware:

- PC computer (running the micro-simulation model);
- Seven controller interface units (i.e., "MAC Adaptors"); and
- Central Traffic Signal Management System (running the MAC adaptive signal control algorithms).

After the micro-simulation environment was developed, the AM Peak period was modeled to create a represent typical test case for testing and configuring the adaptive signal control operations.

2.4 System Integration and Testing

Micro-Simulation

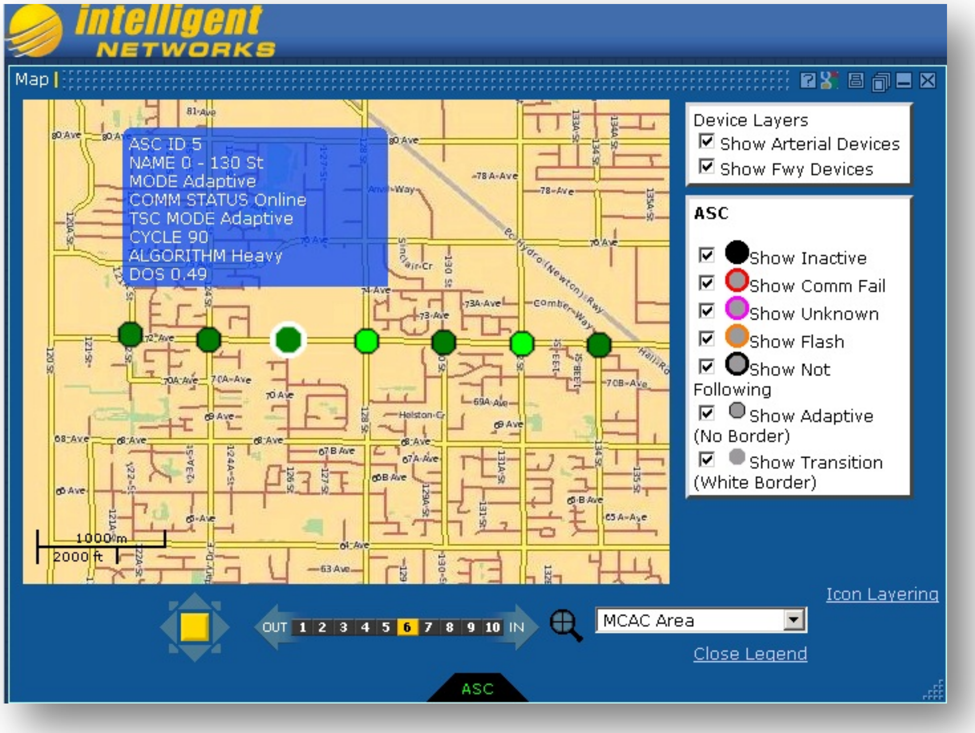
In the testing and fine tuning of the ASCT algorithms prior to implementation of the system on the street, the micro-simulation environment was found to:

- Provide a more efficient and more comprehensive analytical tool for calculating the performance of the central ASCT algorithms (i.e., compared to using spreadsheet formulas, etc.);
- Provide accurate detector pulse data for the testing and evaluating the MAC Adaptor firmware;
- Produce traffic patterns similar to on-street traffic observations (despite the fact that the model does not provide for local semi-actuated operations); and
- Provide a “bird’s eye view” of the whole road network, which was valuable in assessing offsets (i.e., the user can follow vehicle platoons through the network), the impact of vehicle queues, etc.

In particular, the ability to review the operations of the network as a whole was considered to be a significant advantage of the micro-simulation model. The model provided insights that could not be seen through field observations, and as such, provided a good tool for the fine tuning the ASCT parameters. The simulation model also provided confidence in the proposed operations prior to deployment in the field.

User Interface

The MAC GUI, shown in Figure 7 below, provides the operational monitoring and control of intersections configured for adaptive signal control using a MAC Adaptor unit. The MAC GUI is a web browser based GUI that does not rely on the installation of any locally installed component. The MAC GUI updates dynamically information without refreshing other parts of the display.



ASC ID 5
NAME 0 - 130 St
MODE Adaptive
COMM STATUS Online
TSC MODE Adaptive
CYCLE 90
ALGORITHM Heavy
DOS 0.49

Device Layers
☑ Show Arterial Devices
☑ Show Fwy Devices

ASC
☑ ● Show Inactive
☑ ○ Show Comm Fail
☑ ○ Show Unknown
☑ ● Show Flash
☑ ○ Show Not Following
☑ ● Show Adaptive (No Border)
☑ ● Show Transition (White Border)

Figure 7 – MAC Graphical User Interface

The MAC GUI allows operator access to the MAC operational functions through a navigation panel or menu. The navigation panel/menu supports the selection of MAC functions. The functions available for selection include:

- Administration;
- Operational Mode Control;
- Intersection Monitoring;
- System Performance; and
- Help.

Multi-criteria Algorithm Design

As the traffic conditions change during the day, driver expectations change accordingly and different control criteria are applicable. For example, during light traffic conditions, it is important to maximize the 'green bandwidth' (i.e., the green 'window' for uninterrupted movement along the major street). Under this traffic condition, the link travel times on the major street are the governing criteria. During gridlock conditions, the objective should be to avoid blocking intersections.

Most, if not all, other adaptive signal control technology packages developed to date only deal with traffic conditions in the medium to heavy traffic range. To address the drawbacks evident in other existing commercially available adaptive signal control system and provide enhanced traffic signal management capabilities, Delcan designed a new package of multi-criteria adaptive signal control algorithms that cater for a wide range of traffic conditions, including light traffic to nearly saturated traffic, over-saturated, and gridlock traffic.

Detector Data

To realize its objective of changing the signal timing plans in real-time to match the prevailing traffic demands, the ASCT algorithms require the timely input of accurate traffic count data. Delcan's ASCT package is open to all types of detector sensor technologies, including both in-ground and above-ground detector technologies. The ASCT system design is also flexible to allow for different detector locations including either stop line and/or link entry detectors. For the Pilot Project, the MAC Adaptors were interfaced to the City's existing (circular) stop line loop detectors at each of the seven intersections. For a few of the key intersections, additional link entry loop detectors were installed.

Controller Interface

The central ASCT system algorithms interface with the local controllers via a MAC Adaptor installed in each the respective controller cabinets. The MAC Adaptor monitors the display of the traffic signal phases, and coordinates this phasing information with the detector data that it is collecting. Each cycle, this phasing and detector data is sent to the central system. New signal timing parameters received from the central system are provided to the traffic signal controller before the start of the next controller cycle. This interface between the MAC Adaptor and the City's existing Type 170 traffic signal controllers was tested both in the lab and in field trial tests.

Communications Network

The ASCT system was integrated to work with the City's existing communications network. To communicate with the traffic signal controllers along the 72nd Avenue corridor, the City employs a tree topology network, with a leased line from the control centre to a "master" intersection in the field, and then both point-to-point and multi-drop spread spectrum radio links from the "master" intersection to the other local traffic signal controllers. From the central ASCT system, the network operates like a multi-drop serial network. This interface between the central ASCT system and the MAC Adaptors in the field was successfully shown to work in the field trial tests.

3 OPERATIONAL PERFORMANCE

3.1 Evaluation Methodology

After the ASCT Pilot System was operational under the production environment, field observations and fine-tuning of the system were conducted. Before-and-after travel time and queue length surveys were subsequently undertaken for evaluating the performance of the Pilot System under real traffic conditions. The details of the survey dates and procedures, etc., and results of these surveys are described in Section 4.3.

3.2 Field Operational Observations

General Observations

The following points summarize the salient points that were noted from field observations made during the deployment and testing of ASCT:

- Similar traffic flow characteristics were observed in the field as noted above under the micro-simulation performance.

- Observations for days when ASCT system ran in the "background" mode showed that the degree of saturation for the analyzed intersections was in the range of 0.5 to 0.9, although for 128th Street, the degree of saturation in peak periods reached a value of 1.1;
    - For days when ASCT system was active, the degree of saturation for the analyzed intersections was in the range of 0.4 to 0.8, and it did not go over a value of 0.8, not even for 128th Street during the in peak periods.

- The ASCT system correctly reacted to traffic trends to provide optimized cycle lengths, phase splits, and offsets. In particular, ASCT was observed as appropriately responding to unexpected and unplanned events such as heavier volumes due to a special event or an incident. One such example was observed on the evening of August 2nd, 2012, when as illustrated in Figure 8, the ASCT system response matched the volume trend during the PM Peak period. The traffic volumes on that day remained high until after 8:00 pm (due to a nearby special event), and the ASCT responded by correspondingly keeping the cycle length higher for longer than would normally have been the case under TBC operations.

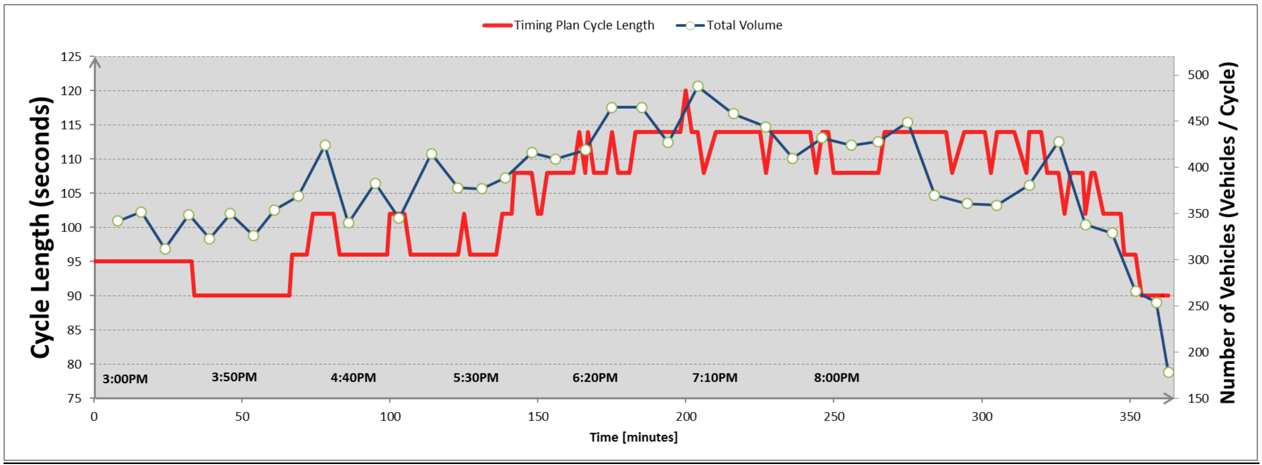


Figure 8 – Total Approach Volumes vs. Adaptive Cycle Lengths for 122nd Street, Thursday, August 2, 2012

- The ASCT system correctly optimized the signal timing plans based on input from the existing vehicle stop line detectors plus input from minimal additional link entry detector loops installed at only the key intersections. In this respect, the system maximized the use of the existing infrastructure (i.e., stop line detectors), while minimizing the cost of ASCT deployment.

- For the Pilot Project, the ASCT algorithms always used the posted speed value, configured for each link. This worked well for the 72nd Avenue corridor where traffic congestion was minimal. However, it was envisage that to better optimize controller offsets, a recommended future system enhancement would be for the system to predict the average link travel speeds based on real-time field measurements.

Cycle Lengths

The cycle lengths that the ASCT system was able to select and download to the local controllers were constrained in the configuration parameters by the following minimum and maximum values:

- The minimum cycle length was set to 90 s (i.e., based on the phase minimum green and pedestrian don't walk times); and
- The maximum cycle length was set at 120 s (i.e., the same as the maximum cycle length used in the existing TBC timing plans).

Total intersection traffic volumes at 128th Street and the corresponding ASCT-calculated controller cycle lengths between 7:00 am and 7:00 pm are illustrated in Figure 9 for a typical day, Tuesday, October 23, 2012. (In the chart, the right axis is the cycle length, and the left axis is the volume in vehicles per cycle.)

From this graph, the following salient points are noted:

- The ASCT-calculated cycle lengths follow the general volume trend and change in a timely manner;
- In the middle of the day, the cycle length tendency is to stay at the configured minimum cycle length value of 90 s; reflecting the relatively low traffic volumes; and
- When the current cycle length provides adequate capacity (e.g., in the middle of the day), there is seldom a need to increase the cycle length in response to minor fluctuations in traffic demand.

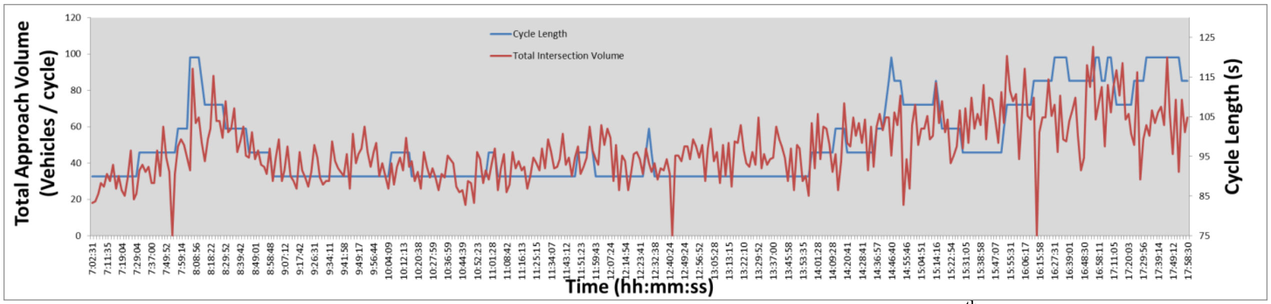


Figure 9 – Total Approach Volume vs. Adaptive Cycle Lengths for 128th Street,
Tuesday, October 23, 2012

An additional observation was that, in configuring the ASCT system, the maximum cycle length was restricted to the same maximum value that had been implemented for the TBC timing plans; so that the timings remained within a "reasonable" range. This configuration choice did limit the adaptive operations. As ASCT has the ability to continuously adjust the cycle length in response to the current traffic demands, a higher maximum cycle length could have been enabled to allow the system to respond to peak traffic demands as required (with the knowledge that the cycle length would also be lower with lower traffic demands).

Controller Offset Transition
In analyzing the data recorded during ASCT operations, it was identified that the local traffic signal controllers had spent an unexpectedly large amount of the time in transition when implementing new timing plan changes. Controller offset transition is accounted for in the ASCT algorithm design; for example, the respective cycle length, split and offset parameter changes are limited to very small incremental changes that should typically be implementable by the controller within the next cycle. In this respect, the local traffic signal controllers were configured to use the "short-way" offset transition method.

Notwithstanding, the duration of the controller offset transition periods were unexpectedly long. Moreover, the Project Team considered that the duration of these transition periods could diminish the efficiency of the ASCT operation.

To minimize the duration of the controller transition periods and improve ASCT operations, techniques to further fine-tune the system configuration data and/or enhance the ASCT algorithms should be investigated.

3.3 Field Operational Performance

3.3.1 Vehicle Travel Time Surveys

Survey Procedure
Travel time data was collected by test-car runs utilizing an "average car" technique that required the surveyor to travel according to the speed that the majority of vehicles were travelling. Both eastbound and westbound travel times, respectively, were measured along 72nd Avenue. The survey checkpoints were the successive signalized intersections.

Each travel time survey was conducted on a typical weekday in the AM Peak, Off Peak and PM Peak periods. For each time period, the survey was continuously carried out for two hours by making round trips back to the original starting point. The 'before' and 'after' surveys were conducted in October 2012.

Comparison of Results
To evaluate the performance of ASCT relative to TBC, the following Measures of Effectiveness (MOEs) were obtained from the evaluation of the 'before' and 'after' travel time survey data:

- Average travel time savings for the corridor;
- Average travel speed for the corridor;
- Average vehicle stops in the corridor; and
- Average vehicle delay for the corridor.

The initial benefits of ASCT that can be immediately measured in a pilot project directly depend on the initial "base" case. For the City of Surrey ASCT Pilot Project, the "base" case was optimized TBC timing plans. From the results from the travel time surveys are summarized in Table 1 below, it can be seen that the differences between TBC and ASCT are very minimal. A statistical analysis of the 'before' and 'after' travel time data was therefore conducted to test whether the 'after' survey data was significantly different from the 'before' survey data.

The travel time data for both the 'before' and the 'after' samples have wide spreads around their respective averages. Statistical tests were carried out for both the eastbound and the westbound travel time data, independently, to test the hypotheses that:

- The variance of the 'after' sample data is the same as the variance of the 'before' sample data; and
- The mean of the 'after' sample data is the same as the mean of the 'before' sample data.

From the results of the statistical tests, it was concluded that, for both the eastbound and westbound directions of travel, it was concluded that:

- Mean of the 'after' travel time sample data is probably the same as the mean of the 'before' travel time sample data; and

- Variance of the 'after' travel time sample data is probably the same as the variance of the 'before' travel time sample data.

Average Travel Time (s)	TBC	ASCT	Difference	Difference (%)
AM Peak	272	276	4	1%
Off Peak	330	333	3	1%
PM Peak	306	320	14	5%
Average Travel Speed (km/h)	TBC	ASCT	Difference	Difference (%)
AM Peak	39	39	0	0%
Off Peak	32	32	0	0%
PM Peak	33	33	0	0%
Average Vehicle Stops (No)	TBC	ASCT	Difference	Difference (%)
AM Peak	2.5	2.6	0.1	4%
Off Peak	4.2	4.0	-0.2	-5%
PM Peak	3.7	4.0	0.3	8%
Average Vehicle Delay (s)	TBC	ASCT	Difference	Difference (%)
AM Peak	51	55	4	8%
Off Peak	90	94	4	4%
PM Peak	79	83	4	5%

Table 1 – Travel Time Survey Results
(Combined for both Eastbound and Westbound)

Consequently, it is concluded that ASCT performed equal to the best optimized TBC signal timing plans, which represents the best case scenario.

The performance result also demonstrated that the ASCT system correctly reacted to current traffic trends to provide optimized cycle lengths, phase splits and offsets.

An additional observation was that, in hindsight, the length of the arterial corridor (at approx. 3.2 km) was probably too short for definitive 'before' and 'after' vehicle travel time comparisons. With a typical total travel time of 4 to 6 minutes, any potential differences in travel times under the different modes of control were hidden within the normal corridor travel time variations.

Over the longer term, ASCT will continuously adjust to changes in traffic volumes and flows; whereas the TBC plans will steadily erode over time. Experience in Surrey indicates that delays due to ageing signal plans range from 1 to 3% a year. (Previous studies have shown that for populated and congested cities, depending on the rate of local development, the performance of TBC plans can be expected to deteriorate at a rate of 8% to 12% per year if the plans are not periodically updated.) Although the City's TBC plans are typically updated every 3 to 5 years depending on the severity of the problems involved and the budget available, there is still a significant gap between the performance of ASCT and TBC between signal plan updates.

For example, if it is assumed that a signal timing plan ages 15% over a five year period (3% per year), then the additional vehicle delay that is accumulated over that five year period is 37.5% more than if the timing plan had been continuously optimized – two and a half times more than the amount that the timing plan has aged.

Assuming an approximate travel time along the 72nd Ave corridor of 300 s per direction, then over the five year period, the average driver would have incurred an additional 225 seconds of delay per day or (assuming 250 working days per year) 15.6 hours of delay per vehicle. If the timing plan was updated every two and a half years, which is about the best that any municipality could typically achieve, then the additional delay caused by the aging timing plan would be 18.75%; equivalent to 7.8 hours of delay per vehicle per round trip over a 5-year period..

Conservatively assuming an average demand along the 72nd Ave corridor of 600 trips per hour over the highest 11 hours of the day, at a cost of $10 per hour, would result in the additional delay costing $514,800 over a 5-year period (or $1,029,600 over a 10-year life cycle of the adaptive system), in addition to the cost of retiming the traffic signals.

The cost to deploy ASCT along 72nd Ave was miniscule compared to the delay cost savings per year; hence, the investment in ASCT was highly cost beneficial.

3.3.2 Weeknight and Saturday Traffic

In addition to the weekday timing plans, the City of Surrey implements weekend timing plans on some key corridors where there is significant commercial activity. Along 72nd Avenue, a weekend plan is deployed from 10:00 am to 6:00 pm on Saturdays. Outside of this period, the controllers are operated as fully actuated.

The ASCT system was observed to appropriately respond to heavier traffic volumes generated by commercial activity (e.g., "shopping trips") on weeknight evenings (e.g., Thursday nights) and on Saturdays. One such example was observed on Saturday, November 3rd, 2012, when as illustrated in Figure 10, the traffic volumes typically increased through the day until about 4:30 pm, and ASCT (which was deployed only from 10:00 am to 6:00 pm) responded to follow the trend by increasing the cycle length during the afternoon. (In the chart, the right axis is the cycle length, and the left axis is the volume in vehicles per cycle.)

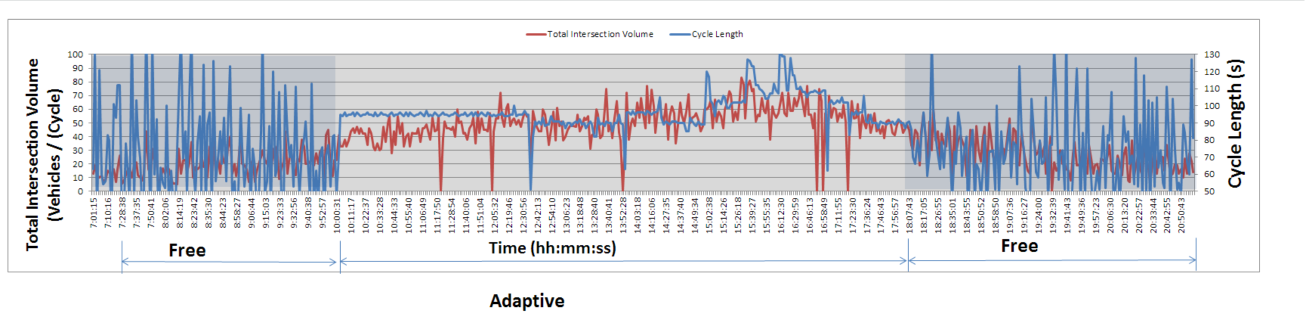


Figure 10 – Total Approach Volume vs. Actual Cycle Length for 128th Street, Saturday, November 3, 2012

Note that the graph plots the actual cycles implemented by the controller on the street. During ASCT operations, the controller is also configured to enable semi-actuated operations for the minor phases, and as a result, the reported cycle lengths can vary higher or lower than the ASCT configured maximum and minimum cycle lengths.

3.3.3 Queue Length Surveys

Survey Procedure

To evaluate the level of service provided by the ASCT system to intersecting side streets, maximum queue length and remaining queue length surveys were conducted on the north and south approaches of four streets within the study area that exhibited high north / south volumes during parts of each weekday.

The 'before' and 'after' queue length data was generally collected in parallel with the respective 'before' and 'after' travel time surveys on the following days:

- 122nd Street; and
- 124th Street:
- Before – Wednesday, October 31, 2012
- After – Wednesday, October 24, 2012
- 128th Street; and
- 132nd Street:
    - Before – Tuesday, October 30, and Thursday, November 1, 2012
    - After – Tuesday, October 23, and Thursday, October 25, 2012

Queues for the left turn movements were recorded independently of the queues for the through and right turn movements. For the through and right turn movements, the total number of vehicles in all lanes were recorded.

Comparison of Results

To evaluate the performance of ASCT relative to TBC, the following MOEs were calculated from the 'before' and 'after' queue length survey data:

- Average maximum queue length (i.e., at the start of the Green phase); and
- Average remaining queue length (i.e., at the end of the Amber Phase).

Examples of the results from the queue length surveys are summarized for the intersections of 124th Street and 128th Street in Table Nos. 2 and 3, respectively. From these results, it can be seen that while the differences between TBC and ASCT are very minimal, ASCT does generally perform slightly better. Consequently, it is again concluded that ASCT performed equal to the best optimized TBC signal timing plans.

Southbound Left Turn Lane	Ave Maximum Queue			Ave Remaining Queue		
	TBC	ASCT	Difference	TBC	ASCT	Difference
AM Peak	2.7	2.5	-0.2	0.9	0.7	-0.2
Off Peak	3.7	2.6	-1.1	1.2	0.4	-0.8
PM Peak	3.1	2.7	-0.4	0.7	0.8	0.1

Southbound Through Lane	Ave Maximum Queue			Ave Remaining Queue		
	TBC	ASCT	Difference	TBC	ASCT	Difference
AM Peak	3.7	3.2	-0.5	0.7	0.2	-0.5
Off Peak	5.4	4.3	-1.1	0.8	0.3	-0.5
PM Peak	5.9	6.2	0.3	1.1	0.9	-0.2

Northbound Left Turn Lane	Ave Maximum Queue			Ave Remaining Queue		
	TBC	ASCT	Difference	TBC	ASCT	Difference
AM Peak	0.8	0.7	-0.1	0.2	0.2	0.0
Off Peak	1.8	0.9	-0.9	0.5	0.2	-0.3
PM Peak	2.0	1.4	-0.6	0.6	0.5	-0.1

Northbound Through Lane	Ave Maximum Queue			Ave Remaining Queue		
	TBC	ASCT	Difference	TBC	ASCT	Difference
AM Peak	4.0	5.3	1.3	0.7	1.0	0.3
Off Peak	6.2	6.8	0.6	4.1	2.6	-1.5
PM Peak	5.2	5.9	0.7	1.3	1.1	-0.2

Table 2 – Queue Length Survey Results for 124th Street

Southbound Left Turn Lane	Ave Maximum Queue			Ave Remaining Queue		
	TBC	ASCT	Difference	TBC	ASCT	Difference
AM Peak	2.4	2.0	-0.4	1.0	0.6	-0.4
Off Peak	3.5	3.4	-0.1	1.7	0.8	-0.9
PM Peak	3.7	4.1	0.4	1.8	1.8	0.0

Southbound Through Lane	Ave Maximum Queue			Ave Remaining Queue		
	TBC	ASCT	Difference	TBC	ASCT	Difference
AM Peak	7.5	7.8	0.3	0.5	0.4	-0.1
Off Peak	12.0	17.7	5.7	3.5	4.9	1.4
PM Peak	18.9	27.5	8.6	6.5	11.0	4.5

Northbound Left Turn Lane	Ave Maximum Queue			Ave Remaining Queue		
	TBC	ASCT	Difference	TBC	ASCT	Difference
AM Peak	3.3	2.8	-0.1	1.2	0.8	0.0
Off Peak	7.7	3.9	-0.9	4.4	1.3	-0.3
PM Peak	5.9	4.6	-0.6	3.0	1.8	-0.1

Northbound Through Lane	Ave Maximum Queue			Ave Remaining Queue		
	TBC	ASCT	Difference	TBC	ASCT	Difference
AM Peak	11.9	9.8	1.3	1.1	1.1	0.3
Off Peak	9.8	10.7	0.6	0.6	0.8	-1.5
PM Peak	10.9	11.1	0.7	0.6	0.7	-0.2

Table 3 – Queue Length Survey Results for 128th Street

4 CONCLUSIONS AND LESSONS LEARNED

4.1 Conclusions

From the successful deployment and performance of the Delcan MAC ASCT system on a pilot corridor in Surrey, it is concluded that the adaptive signal control technology met the objectives for the City's ASCT Pilot Project. The salient conclusions from the ASCT Pilot Project may be summarized as follows:

1. *System Integration* – The open system architecture design provided for the seamless integration of the ASCT system with the City`s existing traffic signal management system.

2. *Integration with Existing Traffic Signal Controllers* – The ASCT system, and in particular the MAC Adaptors, were successfully integrated and proven to work with the City's existing Type 170 traffic signal controllers.

3. *Integration with Existing Wireless Communications Network* – The ASCT system, and in particular the MAC Adaptors, were successfully integrated and proven to work with the City's existing tree topology communications network, which is comprised of a leased line from central to the field and then point-to-point and multi-drop spread spectrum radio links to the local MAC Adaptors and traffic signal controllers.

4. *On-street Operational Performance* – The ASCT system performed equal to the best optimized TBC signal timing plans. Furthermore, because TBC plans are typically updated only once every five years, and ASCT will continuously adjust to changes in traffic demands, this should result in a continuously widening gap between the performance of ASCT and TBC control.

5. *ASCT Operations* – Intersection queue length studies and historical volume data show that the ASCT system correctly reacted to changes in real-time traffic demands to provide optimized cycle lengths and phase splits. Travel time studies along the 72nd Avenue corridor show that the ASCT system correctly optimized the controller offsets.

6. *Evening and Saturday Traffic* – The ASCT system was observed to appropriately respond to heavier traffic volumes generated by "shopping trips" on evenings and Saturdays (e.g., when, under TBC, either fully actuated or a weekend timing plan would typically have been in operation).

7. *Incidents and Special* Events – The ASCT system was observed to appropriately respond to incidents and special events that resulted in unexpectedly heavier traffic volumes (e.g., particularly during the Off Peak period when, under TBC, a lower cycle length would typically have been in operation).

In summary, the key features of Delcan's MAC ASCT system are:

- Smooth integration with existing legacy field equipment;
- Co-exists with legacy traffic signal management system;
- Multi-protocol interface and ability to work with multiple controller manufacturers / types;
- Management of oversaturated and gridlocked traffic (as well as heavy traffic);
- Capability to operate in a "background" monitoring mode;
- Flexible (and minimal) detector requirements;
- Low data transmission requirements (and hence low communications cost) make available by the distributed processing capability;
- Robust and highly efficient communications scheme that supports a variety of wireless communications technologies; and
- Easy and cost-effective to deploy.

Many of these key features may not be available in other commercially available adaptive signal control systems. As such, the MAC ASCT system is a unique technology that provides a low-cost, high quality solution for deploying adaptive signal control technology. The City of Surrey ASCT Pilot Project will be very effective as a demonstration tool for local, national and international agencies looking to enhance their traffic signal operations with adaptive signal control technology.

4.2 City of Surrey's Perspective

The rapid growth of the City has an impact on the transportation system, including signal operations. Some of the City corridors are operating near capacity and, due to right-of-way and financial constraints, additional capacity is not a practical alternative. The City therefore pursued applications that would improve the utilization of the existing roadway. This included improvements to the signal operations via an automated system to allow operational changes with minimal staff involvement. The ASCT program installed on one of the major corridors resulted in performance at par with time base coordinated operations. The City expects that over the years, the system would allow savings in resources by not updating the TBC timing plans every three to five years.

Reason for buy in from Surrey – Open system, with minimal hardware and software upgrade costs. The system's ability to be integrated with the existing infrastructure made it a success story. The system installation cost was shared by both Transport Canada's and Delcan's support; allowing the City to pursue this application.

Advice for other jurisdictions looking into ASCT – While ASCT will allow the 72 Avenue corridor to operate at optimum levels for many years in the future without manual updates, the application is probably more suitable to jurisdictions that own a large network of signals and experience significant seasonal traffic variations. The capability to adjust signal operations in response to changing traffic demands will allow optimum performance throughout the year.

4.3 Lessons Learned

Lessons learned from the ASCT Pilot Project implementation and testing include the following:

1. To maximize the benefits of deploying ASCT, arterial corridors and signalized intersections with more highly variable and/or unpredictable traffic volumes should be selected as preferred locations.

2. The ASCT system successfully optimized the signal timing plans with minimal additional vehicle detectors. The system maximized the use of the existing stop line detectors; with additional link entry detector loops installed at only the key intersections.

3. To best optimize controller offsets, a recommended future system enhancement would be for the system to predict the average link travel speeds based on real-time field measurements. (For the Pilot Project, the ASCT algorithms always used the posted speed value, configured for each link.)

4. In configuring the ASCT system, the maximum cycle length was restricted to the same maximum value that had been implemented for the TBC timing plans. However, as ASCT has the ability to continuously adjust the cycle length in response to the current traffic demands, a higher maximum cycle length should be enabled to allow the system to respond to peak traffic demands as required (with the knowledge that the cycle length will also be lower with lower traffic demands).

5. The length of the arterial corridor (at approx. 3.2 km) was too short for definitive 'before' and 'after' vehicle travel time comparisons. With a typical total travel time of 4 to 6 minutes, any potential differences in travel times under the different modes of control were hidden within the normal corridor travel time variations.

6. The local traffic signal controllers spent an unexpectedly large amount of the time in transition when implementing new timing plan changes, which could diminish the efficiency of the ASCT operation. Techniques to further fine-tune the configuration data and/or enhance the ASCT algorithms to improve the duration of the transition periods should be investigated. As a minimum, the local traffic signal controllers should always be configured to use the "short-way" offset transition method.

7. Robust and reliable communications between the Central Server and all MAC Adaptors in the field is a key consideration in the deployment of the ASCT system (as the ASCT algorithms cannot run until all the MAC Adaptors have reported data for the last completed cycle).

8. The PARAMICS micro-simulation test environment produced traffic patterns similar to on-street traffic observations, and as such, it provided a "bird's eye view" of the whole network; excellent for reviewing network traffic flows, intersection offsets, vehicle queues, etc. Output from the model was therefore effective in the off-line configuration and fine-tuning of the ASCT algorithms. In addition, the micro-simulation process of also confirmed the quality of the ASCT system configuration data prior to commencement of adaptive signal control operations in the field.