City-Wide Traffic Flow Data via Traffic Signal Control

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INTRODUCTION

Enhancing traffic signal efficiency has proven to be an extremely cost-effective way to optimize existing roadway capacity. Among common improvements are the installation of computerized traffic signal systems, upgrading the operation of individual traffic signals and implementing synchronized signal timing. An important factor in achieving traffic signal efficiency is having access to current traffic flow data to generate effective 24 hour signal timing parameters.

The City of Richmond, British Columbia, monitors volume and occupancy traffic flow data on a city-wide lane-by-lane basis from all traffic signals. This data is retrieved in five minute intervals, 24 hours per day from the same vehicle detector loops that each traffic signal controller uses to determine phase selection and green light duration. There are currently 160 fully-actuated traffic and pedestrian signals in Richmond using over 1,800 approach side vehicle detectors - 1,100 of these processing traffic flow information.

An extensive volume and occupancy database provides five minute traffic flow "snapshots" of the entire city (or any part thereof), 24 hours a day. Traffic signal timing, time of day schedules and traffic responsive parameters are optimized using current and historical volume data. The occupancy data is used to measure the effectiveness of signal timing by comparing changes in average occupancy per vehicle data with the implementation of different signal timing parameters.

SYSTEM FUNCTIONAL DESIGN

In 1986, the City of Richmond initiated the implementation of a computerized traffic signal control and monitoring system incorporating features typical to modern systems. Two distinct features of Richmond's system are:

1) The development of a software based Route Preemption System to provide green lights through a series of traffic signals for Fire/Rescue emergencies.

2) A philosophical change in the use of vehicle detector loops to allow for multiple detection functions. Design objectives focused on the ability to:

- Maintain typical vehicle presence detection that the controller requires to determine signal phase selection and green light duration
- Count vehicle volume and occupancy from the same detectors with reasonable accuracy
- Provide more sensitive detection characteristics for trucks, motorcycles and bicycles
- Individually program operational characteristics of each loop detector in the controller to improve signal efficiency, including response to detector failures
- Achieve design objectives in a cost-effective manner

The most significant change in the use of the vehicle loop detector was retrieving volume and occupancy data from at least one detector from each intersection approach lane. This function alone significantly affected traffic signal design, data communications and central site components.

Figure 1 illustrates the process of monitoring traffic flow from intersection vehicle loops through to data retrieval, manipulation and traffic signal optimization analysis.
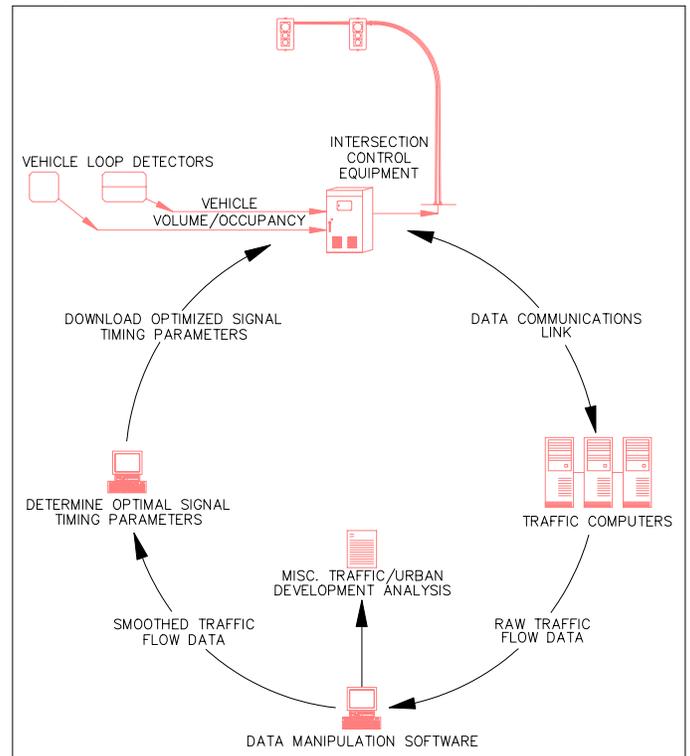

Figure 1. Intersection traffic flow data from vehicle detector loops

Traffic Signal Design

To achieve volume and occupancy data collection, traffic signal design specifications were modified in the following key areas:

- The size, shape and location of vehicle detector loops
- Controller and cabinet components
- Design drawings and documentation

Vehicle Detector Loops - The loop design used for several years was a 7.0 m (length) x 2.0 m (width) quadrupole™ loop placed at the front of the stop bar. This design, while generally effective, did not provide a good height of detection for some trucks and was too long for accurate volume counting.

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In keeping with design objectives, it was decided to implement smaller loops for counting accuracy and multiple loops as needed to create required detection zone lengths. Two different loops having the following characteristics were implemented:

- 3.0 m x 2.0 m Quadrupole™ Loop - Good accuracy for volume and occupancy monitoring. Excellent for detecting low level vehicles including motorcycles and bicycles, (accurate bicycle detection is directly over the run of the loop wire within 0.2 m either side). Detects axles on high trucks, but limited in height of detection for truck bed. Usually placed as the first loop behind the stop bar in multiple detector configurations to enhance motorcycle detection.
- 1.8 m x 1.8 m Loop - Good accuracy for volume and occupancy monitoring. Reasonable height of detection for truck beds. Good motorcycle detection although small motorcycles directly in the loop center could be missed. Good for bicycle detection (directly over the run of the loop wire within 0.2 m either side). This loop is used to extend the detection zone when multiple loops are installed in a single lane. Also used when only one loop is installed in a single lane with its corresponding phase programmed to "recall" to a green light.

The 7.0 m quadrupole™ loop was replaced by a two loop configuration consisting of one 3.0 m x 2.0 m quadrupole™ placed 0.3 m behind the back of the stop bar, followed by a 3.0 m gap and one 1.8 m x 1.8 m loop. This two loop design increased the detection zone by almost one metre while reducing the total (linear) loop cut area from 25.0 m to 20.2 m. To create longer detection zones, the 3.0 m gap and 1.8 m loop is repeated where necessary to create the desired zone length. To ensure that a small vehicle would be detected if stopped between two loops, a design vehicle of 4.0 m in length was used to determine the maximum 3.0 m gap between loops.

Traffic signals with a distinct "main street" are programmed to recall and rest in green. As the green light automatically reverts to the main street, a long detection zone to confirm vehicle presence is not needed. In this case, the City uses a 1.8 m x 1.8 m loop placed 1.3 m behind the back of the stop bar. Field studies indicated this location for the small loop provided the highest consistency of some part of the first vehicle at the stop bar being over the loop - an important factor when collecting occupancy data. From a cost standpoint, this loop was a 7.2 m (linear) cut compared to the original 25.0 m cut.

To detect bicycles using regular vehicle loops, the loop's most sensitive spot must be identified to the cyclist. The City is testing the placement of three 0.1 m diameter circles (made of white pavement marking tape) spaced evenly over one of the loop's wire run, parallel to the curb. This cyclist information method was originally developed and tested in Metropolitan Toronto. Richmond was attracted to this idea by the simple installation, minimal cost and longevity of the markings.

Controller and Cabinet Components - The City uses National Electrical Manufacturers Association (NEMA) standard eight phase controllers and cabinets at all traffic signals. Richmond's controller and cabinet specifications were modified to permit data collection from individual intersection loops. Significant changes were:

- Cabinet capacity increase - In most cases, each loop at an intersection is individually wired back to the cabinet and assigned to an exclusive detector amplifier channel. This design separates each loop's detection activity for programming it's distinct operational parameters in the controller. Detection capacity was expanded by installing racks capable of processing twenty or forty channels of detection, depending on the capacity required at each intersection. Standard two channel rack mount detector amplifiers are used and set in the "presence" detection mode.
- Controller programming capabilities - a traffic controller was procured to process the incoming traffic flow data and to implement improved signal operation. Initially, microprocessor based NEMA controllers were limited in their ability to effectively apply detector data but programming features have improved significantly in recent years.
- Central monitoring and control - each traffic signal is monitored with a Communications, Control and Monitoring Unit (CCMU). This unit, (separate from the controller) controls and monitors specific cabinet inputs and outputs and overrides the controller for synchronization, route preemption and traffic responsive functions. Detector loop volume and occupancy is monitored by and stored in the CCMU for up to 16 detector channels. Complex intersections which require monitoring of more than 16 detector channels have secondary CCMU's installed for this purpose.

Design Drawings - An increasingly complex and flexible detection system required tracking each intersection loop for field wiring, controller programming, database referencing and maintenance tasks. A simple one page diagram was developed to graphically and numerically display this information. Detailed design drawings and specifications were also standardized for traffic signal cabinet connections and field wiring.

Data Communications

Data communications between the computerized traffic signal control system and each traffic signal is based on a distributed intelligence architecture. Each traffic signal CCMU has continuous communications to the central traffic computers to upload event and traffic flow data, and to receive downloaded preemption or traffic responsive instructions. The control equipment at each intersection stores it's specific schedule and signal timing database, thus the distributed intelligence. CCMU

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communications is via four wire telephone type copper cable operating at 2400 baud, full duplex. Data communications is also available to each traffic controller to upload/download database enhancements and to synchronize the time clock.

Central Site

The central communications system and traffic computers must process and store all event and traffic flow data uploaded from each traffic signal's CCMU. Twenty central communications modems are used to communicate to defined groups of traffic signals. The central system is comprised of three pentium servers processing database, communications, and control and monitoring functions. The central database is configured to store 24 hour data for up to 1,280 counting detectors. Approximately one gigabyte of computer memory is required to store 365 days of five minute volume and occupancy data from 1,280 detectors.

DATA RETRIEVAL AND MANIPULATION

Detector loop volume and occupancy is monitored by the CCMU which scans the on/off state of the detector amplifier 60 times per second. A vehicle passing over or stopped on the loop will cause the detector amplifier to enter the "on" state. A volume counter is incremented each time the amplifier goes through an on/off state, and the occupancy counter accumulates the duration of all "on" states. At the end of each five minute period, the summed volume and occupancy data are uploaded to the traffic computers and the CCMU counters are reset.

Loop detector failures along with occasional communications outages result in bad or missing data. To account for these failures, the traffic computer performs validity checks every 24 hours on all detector data for each 5 minute interval. This validation routine compares volume, occupancy and communications data to identify differences between zero volume, a broken (or chattering) detector or a communications failure. Detectors which have data outside a defined volume and occupancy threshold are flagged. A "check and fill" routine inserts data into the flagged five minute time slots with "good" historical data from the same detector, previous day type and time of day. This routine also accounts for holidays and zero volume (valid for early morning hours) to ensure a full data set which is needed for wide area analysis.

Each detector loop is assigned a six digit number which identifies its intersection and lane location. These reference numbers are used for storing and retrieving volume and occupancy data which can be manipulated for analysis in several combinations, including:
- Start/end time, and start/end date
- Defined summation period, from 5 to 525,600
- Select all seven days, or only specified days
- Average - "all", "grouped" or "common" days
- Select data category - volume, total occupancy (aggregate) or occupancy per vehicle (seconds)

- Combine specified detectors and sum data
- User defined description fields for specialized output

CONTROLLER PROGRAMMING

Fully actuated traffic signals utilize sophisticated controllers and detection to determine traffic flow. The controller continually monitors vehicle and pedestrian detection inputs and selects phases and their duration based on programmed decision making parameters. There are literally hundreds of controller programming items for one fully actuated intersection - too numerous to effectively outline here. For simplicity, programming parameters can be classified as fixed or variable:
- Fixed parameters are utilized regardless as to time of day or traffic flow. Some basic fixed parameters are; minimum green, pedestrian walk, pedestrian don't walk, amber, all-red, vehicle extension time, detector to phase assignment etc.
- Variable parameters allow the controller to respond efficiently to fluctuating traffic flow by implementing a hierarchy of traffic signal timing conditions. This hierarchy is typically implemented on a time of day schedule or traffic responsive basis. Some variable parameters are: maximum green (1, 2, 3), rest in walk or last phase served, vehicle or pedestrian recall, protected/permissive left turn phase omit, volume/density operation and signal timing synchronization with other traffic signals.

The type, size and placement of vehicle detector loops are important in the functioning of a vehicle actuated traffic signal. Modern controllers have the provision to define several different characteristics on how each detector loop's input is processed by the controller. Some of these detector characteristics are: vehicle call, phase assignment, delay duration (before the controller sees a vehicle call), phase extension, detector lock, cross switching (single detector to call more than one phase), and simultaneous calls required on specific loops to call one phase (e.g. left turn phase or preemption sequence). These programming features allow significant flexibility in the 24 hour operation of a traffic signal. Richmond uses several loop combinations and detection zone lengths to accomplish the desired operation of each lane at each intersection. Some loop functions and corresponding controller programming are:
- Multiple loops in a common lane can each be programmed with distinct call, delay and extend values to reduce required phase minimum and extension time.
- A controller can be reprogrammed to reduce negative effects of a broken loop by temporarily removing it from service and altering the programmed characteristics of other surrounding loops.
- Assigning call, delay and extend conditions to each loop is very effective in reducing or eliminating false

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calls for a green light, which can cause the traffic signal to cycle unnecessarily.

- Vehicles in a right turn lane can turn right on a red light and thus do not require a green light. Right turn lane loops can be programmed not to call a phase, or to call a phase only after the expiration of a defined time-out period of vehicle presence (delay detection). It can also be programmed to only extend a green light etc. This eliminates a vehicle turning right unnecessarily placing a call for a green light.
- Vehicles which turn left from a main street to a side street occasionally place calls for a side street green light by cutting across the edge of the lane and its loop. These side street loops are programmed with a short delay period to eliminate a call being placed by a vehicle cutting across the loop.

TRAFFIC FLOW AND SIGNAL TIMING ANALYSIS

An important factor in optimizing signal timing for a single intersection or on a system-wide basis is access to 24 hour traffic flow data. This data enables the user to program more accurate time clock and traffic responsive parameters to enhance the controllers response to changing traffic conditions.

Analyzing Traffic Flow and Calculating Signal Timing

Traffic volume data is used extensively to define phase duration and time of day schedules for implementing hierarchical traffic signal operation. The signal timing database for each intersection can be categorized as: single intersection operation (non-synchronized), and, linked to multiple intersections (synchronized).

Single Intersection, Non-Synchronized Signal Timing - Depending on the specific purpose of a signal timing analysis, different combinations of traffic volume data are produced. For seasonal analysis, up to three weeks of 24 hour traffic flow data is generated in 60 minute intervals for each intersection. A line graph for each week is created for three day types (weekday, Saturday and Sunday) showing volume versus time for each directional approach to the intersection. Data for each day type is compared to determine consistency of traffic flow and either one week is chosen for further analysis, or the three week data is averaged and re-graphed. Data from each graph is analyzed to:

- Define time periods where more detailed five and fifteen minute traffic flow analysis is required
- Define time periods for generating lane-by lane traffic counts
- Determine the maximum (1,2,3..) green duration for each phase
- Define signal timing hierarchies matching traffic flow patterns and the time of day to implement the corresponding parameters
- Determine time of day for operating signal synchronization

Other traffic flow analysis includes using historical "holiday" traffic counts to calculate signal timing for future holidays of the same type.

Multiple Intersection (synchronized) Timing - When traffic volume justifies operating signal synchronization as identified in the single intersection analysis, a separate process of developing signal timing for groups of signals is conducted. This process involves several manual and computerized steps involving:

- Defining the number of time periods for detailed analysis
- Identifying time of day patterns when protected/permitted left turn arrows can be turned off to reduce the cycle length
- For each time period, determine the optimum cycle length for each intersection
- Identify the direction of primary traffic volume at each intersection, and the next highest (secondary) volume on the perpendicular street
- Identify geographic or special conditions that may hinder synchronization between signals (rivers, saturated intersections etc.)
- Group signals with common cycle length requirements and similar primary/secondary traffic flow patterns
- Finalize synchronized groupings and develop traffic signal timing for each group

For each time slice being analyzed for synchronization, primary and secondary traffic volumes and calculated cycle lengths are manually colour coded onto a map for each intersection. Once the map is completed, logical patterns for grouping traffic signals become more evident. Signals with common cycle length requirements and primary/secondary traffic flow patterns are identified and grouped together. The grouped traffic signals are entered into a computer program and the phases and offsets are optimized for each intersection. The calculated signal timing is then coded into the database for each traffic signal and downloaded to the CCMU.

The most important factor in developing efficient synchronized signal timing is creating groups of traffic signals that operate well together. For some jurisdictions, signal groupings can change several times per day. Unfortunately, there are few guidelines and computer programs to assist in analyzing and developing signal groupings - a time consuming task.

Richmond is working towards interfacing the detector database with a traffic signal timing computer program. The software will incorporate a separate analysis to automatically group signals for synchronization and perform signal timings for each group. The current process has several manual steps which could be computerized to enhance the number of times synchronized signal groupings are evaluated and changed each day. The result will be dynamic and optimized signal groupings for improved system-wide signal timing.

Evaluating Signal Timing Effectiveness

Computer Simulation and Historical Data - Signal timing is typically evaluated using traffic engineering computer programs to generate various "measures of effectiveness". These programs both calculate and evaluate signal timing using an extensive database which includes operational details for each traffic signal. Some required data includes: phasing, vehicle and pedestrian minimum timing, traffic flow characteristics, intersection geometry, controller settings and much more. Most of these computer programs are not sophisticated enough to adequately model the capabilities of modern controllers and detector layouts, and those that come close involve significant database compilation.

In recognition of this, Richmond searched for a better way to measure the performance of signal timing and, of more importance, changes to signal timing. It was recognized that since vehicle detectors were being monitored at the stop bar in each lane, that the duration (occupancy) of one vehicle waiting on any detector could be measured. Using the five minute volume and occupancy data, "average occupancy per vehicle" (in seconds/vehicle) can be calculated and used as a real indicator of signal timing performance. This occupancy per vehicle data allows for a microscopic analysis and has provided significant data for comparing the effectiveness of different signal settings. Average occupancy per vehicle data is compiled during the same time period from at least two consecutive and similar weeks to smooth fluctuations in traffic volume. An advantage of city-wide traffic flow monitoring is that a single intersection or a series of intersections can be analyzed to determine the effects of signal timing changes.

Industry guidelines for implementing different signal timing strategies on a volume-threshold basis is minimal. Through iterations of comparing volume/occupancy data for different signal settings, the City will be able to match different signal timing hierarchies to traffic volume thresholds.

Real Time Monitoring of Intersection Operation - Each intersection can be monitored in real time from the traffic control centre to observe it's cycling characteristics. As a signal cycles, information such as walk light on, green light on and duration of each completed phase is displayed. Of particular importance is the display of lane-by-lane occupancy duration for each detector. Staff can monitor cycle by cycle performance of signal timings by watching how long the first vehicle in each lane is waiting for a green light, particularly on secondary phases. Other information relating to CCMU programming and control commands are shown to assist in evaluating the signal operation.

GENERAL OBSERVATIONS AND APPLICATIONS

The re-design of intersection vehicle detector loops for monitoring lane-by-lane traffic flow has resulted in many cost-effective applications. Some observations and applications of the design and database are:

- Detectors have a long life span due to stable weather conditions and general lack of frost
- Smaller multiple loops allow optimum detection of different types of vehicles in a cost-effective manner
- Special bicycle loops are not needed as both loop configurations detect bicycles
- Extensive use of vehicle detector loops is a very cost-effective detection system considering Richmond's multiple uses, data accuracy and life cycle costs
- The cycling of a pedestrian signal is monitored to determine the actual usage of each signal
- Lane-by-lane counting has virtually eliminated manual traffic counting at traffic signals, while yielding 24 hour data
- Revenue is generated by supplying traffic count data to outside agencies - in practically any manipulated format.
- The approximate time of a motor vehicle accident can be determined through evaluation of intersection volume and occupancy patterns.
- Traffic flow data can be used to establish parking restrictions
- Road construction projects can be prioritized by analyzing traffic volume
- Potential development locations can be evaluated based on comparing traffic flow levels at competing sites
- Optimum roadside advertising locations can be selected based on traffic flow rates
- Access to current traffic flow data assists in the response to citizen complaints regarding traffic issues
- City specific peak hour and seasonal traffic flow factors can be developed using the extensive database.
- Volume or occupancy analysis can be conducted on a single intersection, series of intersections, or city-wide using simultaneous data.

CONCLUSIONS

Creating multiple detection functions using the same vehicle detector loops that a traffic signal controller uses to determine phase selection and green light duration has been very successful. In essence, this design has resulted in five minute traffic flow "snapshots" of the entire city (or any part thereof), 24 hours a day. While some advanced traffic signal applications of the volume and occupancy data are in their infancy, the use of the basic volume data has been invaluable for typical traffic engineering analysis. Traffic signal staff are encouraged by the use of "average occupancy per vehicle" data in assessing signal timing performance and its application to determining volume-thresholds for implementing signal timing changes. Additional efforts will be made to further computerize existing manual tasks and in applying the traffic flow database for signal timing generation and performance analysis.

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The availability of a 24 hour city-wide traffic flow database has provided cost-effective, extensive and reasonably accurate data for a variety of applications - which many users now take for granted.

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