

The City of Calgary's Reversible Lane Control Systems

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ABSTRACT

Begun in 2006 as manual trial projects, the City of Calgary's lane reversals for Memorial Drive and the 5 Avenue Connector on Bow Trail have proven effective in reducing peak hour congestion and community shortcutting on key routes around the downtown core. Following the successful trial, the City moved forward with the Reversible Lane Control Systems (RLCS) project for planning, design, construction and commissioning of automated control systems for both reversals, making them a permanent feature of the weekday commute.

The first such systems implemented in Calgary since the 1970s, the RLCS introduced a number of new control devices to the City's operations, including traffic gates and prism-type changeable message signs. Through an integrated fiber optic network and traffic cameras, the system is centrally controlled from the City's Traffic Management Centre (TMC,) providing a safe, effective and flexible system with which to transition the reversals on a daily basis.

Commissioned in March 2010, the system makes effective use of under-utilized peak hour capacity to improve traffic flows in and out of downtown Calgary. Having maintained the footprints of the existing roadways, the project has integrated well with nearby, established neighbourhoods and is recognized as a success for sustainable transportation. The paper thus highlights a potential model for municipalities looking to find innovative ways to enhance transportation capacity on existing road facilities without undertaking costly or controversial road widening projects.

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1.0 PROJECT BACKGROUND

In 2006, the City of Calgary established a "Transportation Optimization" division within its Transportation Planning Business Unit. Transportation Optimization was tasked with identifying, evaluating and planning improvements that would optimize the operation of the transportation system for all Calgarians. Inherent in this mission is the need to maximize the efficiency and capacity of existing road infrastructure, and to improve system operations without costly road construction projects that would impact established communities and neighbourhoods. ISL Engineering and Land Services was subsequently retained by the City to work with Transportation Optimization in the detailed planning, design and implementation of numerous low-cost / high-value improvements throughout Calgary. In a short time, these improvements have helped achieve the program's objective to improve mobility for all modes of transportation.

An early success of the optimization initiative was a pair of lane reversal projects in Calgary's downtown core - the "5 Avenue Connector" morning reversal on Bow Trail, and the "3M10" afternoon reversal on Memorial Drive. The projects were both implemented by 2006 on a manual, trial basis, using construction detour set-ups with pylons, barricades and temporary signing to direct traffic on a daily basis. This is illustrated by Figure 1.

In 2008, based on the demonstrated effectiveness and wide public acceptance of the trial projects, the City worked with ISL Engineering and its partner firm PBA Consulting Engineers to complete functional planning, detailed design, procurement, construction and commissioning of automated control systems for both reversals. The implementation project was known as the Reversible Lane Control Systems (RLCS.)

The project began in late 2008 with development of a Functional Plan to describe the form, function and layout of the automated control system. The traffic operations of the reversals had been well established through the trial periods, so the challenge was to safely and effectively replicate the manual operation of pylons, barricades, signs and human crews with automated devices that would be readily understood by all drivers. Both systems had traffic operational elements that made them unique among existing lane reversal systems in Canada, and which increased the engineering complexity of the automation.

As the first reversible lane systems to be implemented in Calgary since the late 1970s, the project was the first to be designed to modern intelligent transportation system (ITS) standards, with full control and integration into the City's central Traffic Management Centre (TMC). Through a combination of traffic signals, traffic control gates, dual-state sign boards and traffic-monitoring cameras, tied to the TMC through a fibre-optic network, central server and software platform, the City now has a flexible system that can be safely adjusted to a wide variety of traffic-flow needs.

The automated systems were commissioned in March 2010.

2.0 5 AVENUE CONNECTOR

The 5 Avenue Connector system provides an extra inbound lane to downtown Calgary by connecting the Bow Trail expressway to 5 Avenue S during the morning peak period. The facility takes advantage of the highly-directional nature of traffic flows into and out of Calgary's downtown core by allowing a portion of the morning rush hour's inbound traffic to divert and

“reverse flow” via an under-utilized outbound roadway. The project context is illustrated by Figure 2.

Downtown Calgary is served by a network of one-way avenues. A four block separation between eastbound corridors (9 Avenue S and 5 Avenue S) results from the provision of pedestrian and transit malls along segments of 7 Avenue S and 8 Avenue S. Prior to implementation of the 5 Avenue Connector, all eastbound traffic from Bow Trail was directed exclusively to the 9 Avenue S corridor, where it “bottlenecked” through a single signalized intersection at 11 Street SW. Queues from the intersection often backed up well beyond Crowchild Trail (i.e. more than two kilometres to the west). The situation was further exacerbated by the need for vehicles to make multiple lane changes over a short distance in order to turn left and head for 5 Avenue S.

Functionally, the Connector now diverts traffic via the Pumphouse Road service road to the opposite side of Bow Trail, allowing vehicles to then continue travelling eastbound via westbound Bow Trail and connect directly to the 5 Avenue corridor without weaving, turning or traffic signals to impede flow. This arrangement is illustrated by Figure 3.

The 5 Avenue Connector system is unique in Canada in that it represents a true contra-flow configuration, with the reversal not occurring in a lane adjacent to others with the same direction of travel, but rather on the far side of an opposing roadway for several kilometres (i.e. left-side driving.) It is a gated flow system, with most of the length of the contra-flow lane being physically separated from other roadways, and with points of access controlled through a number of ramps and gateways that re-configure depending on the flow state. Coupled with light emitting diode (LED) signals that advise of lane closures and prismatic dual-state message signs that provide clear traffic directions depending on time of day, the system ensures that access to and egress from the contra-flow, through the traffic control gates, is safe and well understood by drivers.

Before-and-after traffic data for connector operations was collected by the City of Calgary. Following implementation, approximately 2000 vehicles began using the 5 Avenue Connector between 6:00 a.m. and 9:00 a.m. on a typical weekday morning, and the eastbound queue length on 9 Avenue S was reduced by more than 1.5 kilometres on average. The effect on queuing near the Crowchild Trail interchange is illustrated by Figure 4.

City measurements also showed that average travel-time delay into downtown Calgary was reduced by an average of 4 minutes per vehicle over the entire morning-commute period, with a maximum delay reduction of up to 11 minutes during the peak hour. This improvement cumulatively saves more than 30,000 hours of idling time per year for Calgary commuters, improving quality of life along with the benefits of reduced greenhouse-gas emissions.

Functionally, the 5 Avenue Connector has added the equivalent of a new lane of roadway capacity into downtown Calgary, while retaining existing road widths. The only significant road construction required was the installation of a standard concrete median barrier to separate the left-side contraflow lane from the adjacent lanes on westbound Bow Trail.

3.0 3M10

The “3M10” lane-reversal system provides for a third westbound lane (“3”) on Memorial Drive (“M”) through 10 Street NW (“10”) during the afternoon peak period. Memorial Drive is an historic roadway located just north of and parallel to the Bow River. The 10 Street NW

intersection (Calgary's famed Kensington Corner) acts as a key commuter junction, facilitating access from the downtown core via the Louise Bridge to several routes in north Calgary; the project context is illustrated by Figure 2.

Prior to implementation of 3M10, the 10 Street NW intersection was a critical bottleneck in the afternoon peak period. The traffic signal was strained to accommodate high westbound traffic volumes on Memorial Drive and high northbound volumes on the Louise Bridge - the latter of which had already made use of reversible lanes since the mid-1970s. The queue length on Memorial Drive was often in excess of two kilometres, leading many commuters to seek short-cut routes on parallel roadways through the adjacent Hillhurst and Sunnyside communities. This often resulted in complete gridlock of the local street network.

Residents of the inner-city Hillhurst and Sunnyside neighbourhoods highly value their proximity to the Bow River with its amenities, including green spaces and regional pathways. Recent initiatives by the City have also recognized the "Memorial" heritage of the roadway, paying tribute to Canadian war veterans through the "Landscape of Memory" project to enhance streetscaping, landscaping and plaza elements on the corridor. Thus, a physical expansion of Memorial Drive to accommodate higher traffic flows wasn't a welcome solution.

The 3M10 system is novel because the contra-flow lane on Memorial Drive is separated from other lanes in the same travel direction by a raised concrete median over a distance of more than 400 metres. Thus, westbound traffic must travel on both sides of the median before completing a number of complex lane merge / cross-over maneuvers to safely bring traffic back onto the same carriageway. The operation is illustrated schematically by Figure 5.

The cross-over manoeuvre, initiated west of the 10 Street NW intersection and completed at a downstream intersection, was safely managed during the manual trial by the placement of dozens of traffic cones on the road to completely direct traffic on a daily basis - an option that, by definition, wasn't available for an automated system. While pop-up bollards were briefly considered to replace the pylons, they were ruled out due to unknown safety performance and reliability in Calgary's winter climate. The cross-over now makes use of signals, signs and line marking exclusively. Overall, the 3M10 reversal is controlled through traditional LED lane control signals, with two sets of traffic gates to close the opposing eastbound lane and assist the cross-over / merge maneuvers in the westbound direction.

The addition of a third westbound lane via the 3M10 reversal resulted in significant improvement of roadway operations, with the intersection now effectively discharging on every signal cycle with little carry-over of vehicle queues. Offset by minimal increases in eastbound delays, due to restricting flow to a single lane, the overall system saves about 120 hours of net total delay every weekday, or more than 25,000 hours over the course of a year. Importantly, short-cutting through the nearby residential neighbourhoods virtually disappeared, significantly improving the safety and environment of the adjacent communities. Incorporation of the "Landscape of Memory" theme within the design ensured that the automated system was non-intrusive and complimentary to the established corridor aesthetic.

4.0 TRAFFIC CONTROL DEVICES

Central to the functionality of the RLCS projects was the need to design and deploy a range of traffic control devices to guide drivers in the safe and effective use of the reversal routes. The challenge was to provide clear and unambiguous directions in a simple, easily-understood and flexible fashion. A variety of traffic control devices were employed, ranging from traditional

static lane marking and signing to dynamic systems that change depending on the state of flow. The dynamic systems include the following devices, which are each discussed below:

- Traffic Control Gates
- Prismatic Message Signs
- LED Traffic Signs
- Lane Control Signals
- Pan-Tilt-Zoom (PTZ) Cameras

4.1 Traffic Control Gates

Traffic control gates serve two functions for the reversible lane systems:

- 1) Single gates that open and close to provide access at individual ramps or access points.
- 2) Groups of three gates with variable and sequential arm lengths that provide a “merge taper” to close a lane of traffic.

A typical gate group is illustrated by Figure 6, and an internal mechanical detail is illustrated by Figure 7. The gates were designed for the project to comply with robust specifications developed for the particular operational and maintenance practices of the City of Calgary. A particular concern was the need to operate consistently in a wide variety of climatic conditions, with a design temperature range of -32 to +40 degrees centigrade, and a requirement to accommodate significant snow loading and continuous use during blizzard, sleet or freezing rain events.

Gate arm lengths ranged from 2.1 to 6.1 metres, and each included sequential LED flashers and static traffic control signs - either Chevron Alignment (WA-9) or Checkerboard (WA-8) signs depending on the location.

4.2 Prismatic Message Signs

On the 5 Avenue Connector, prismatic message signs were used to provide relevant guide sign routing information for the connector route and Pumphouse Road business access. The rotatable prisms allow the guide sign message to change state, depending on the current access and flow conditions. The triangular prisms allow for three different messages, although only two were used for the project, consistent with the two possible states of the lane reversal.

The signs were designed to meet similar climate-related specifications as the traffic control gates. Design features include periodic wobbling sequences to clear accumulated snow during severe weather events. The sign messages were designed and printed to be fully compliant with the standards of the Manual of Uniform Traffic Control Devices for Canada, giving the full appearance of standard guide signs with diamond-grade retro-reflectivity. Assembly of the signs is illustrated by Figure 8, while the finished appearance and operations are illustrated by Figure 9.

The variable message prism signs were used in both side-mount and overhead configurations, consistent with the needs of the particular roadway facility and message. Due to their high cost and sensitive mechanical systems, the side-mount signs adjacent to high speed roadways were designed with full barrier protection on non-breakaway bases.

4.3 LED Traffic Signs

Customized variable message LED traffic signs were used for two specific applications, as follows.

On the 5 Avenue Connector, LED “Open / Closed” boards were used on general guide signs to indicate to drivers when the connector route is open and accessible each morning. These are illustrated by Figure 10.

On Memorial Drive, an LED sign was used on the raised concrete median west of 10 Street, to signify either a “Keep Right” (RB-25) or a “Double Arrow” (WA-17) condition – the latter being necessary when reverse-flow traffic is directed to travel on both sides of the median. This sign is illustrated by Figure 11.

4.4 Lane Control Signals

Traditional lane control signals including green arrows and red X’s were used on both reversals, but primarily for lane designation on Memorial Drive, as illustrated by Figure 12. Lane designation was largely unnecessary on the 5 Avenue Connector system, as most of the reversal is isolated from adjacent lanes, with only one possible direction of travel once drivers have crossed the access gate thresholds.

4.5 Pan-Tilt-Zoom (PTZ) Cameras

During the functional design process, it was determined that operator intervention from the City’s Traffic Management Centre (TMC) would be an essential part of the reversal transition process, primarily due to the unique physical characteristics of the reversals systems (for example, the isolated left-side driving on Bow Trail.) . The ability of remote human operators to visually assess and confirm “all clear” conditions prior to opening an opposing lane to traffic is an additional safety check during the daily transitions.

In order to effectively complete this process, the project incorporated nine PTZ Cameras into the control system, including two previously-existing camera sites and seven new installations. These camera towers collectively provide full-system coverage of the critical reversal areas over a distance of two kilometres on Bow Trail, and one kilometre on Memorial Drive. A typical PTZ camera is illustrated by Figure 13.

While all traffic control device states are changed automatically from the TMC, the software system also orients the PTZ cameras and prompts for operator confirmation of required traffic conditions at several key times during the ingoing and outgoing transitions of each reversal.

To further enhance the City of Calgary’s growing complement of traffic control cameras, the new sites were incorporated into the City’s main camera control server and strategically located to provide additional system coverage for their day-to-day operations, enhancing such functions as incident response and traveler information systems.

5.0 CONTROL SYSTEM OVERVIEW

Three previously-existing lane reversal systems in Calgary were implemented in the 1970s and continue to operate on a stand-alone basis with analog clocks. Since that time, the City’s Traffic Management Centre (TMC) has brought new sophistication to managing traffic movements near

the downtown core. The TMC uses traffic-monitoring cameras, automatic incident-detection systems and the latest traffic signal control software to gather real-time traffic information. These tools allow TMC personnel to respond to abnormal traffic conditions by notifying trouble trucks or emergency services, revising signal timings or posting limited information for motorists on Dynamic Message Signs or over the City's Traffic Advisory Radio. It was a key project objective that the new reversible systems be integrated with these existing sophisticated traffic-management systems to become part of the TMC operation.

To meet the unique safety requirements of the 5 Avenue Connector and 3M10, the automated systems provide video monitoring and remote-control capability to the TMC operators. The nine PTZ cameras were incorporated with the project and, among other uses, allow operators to visually verify that lanes are clear prior to operating gates or opening a lane to opposing traffic. TMC operations are illustrated by Figure 14.

All field devices are monitored and operated from the TMC through five distributed controllers and two remote cabinets that provide direct interface to devices on Memorial Drive and Bow Trail. A fibre-optic-based Ethernet network provides fault-tolerant communications between the TMC and the distributed control cabinets, while the remote cabinets were connected via 802.11g wireless communications due to the prohibitive cost of direct fibre connections over long distances.

Each distributed control cabinet houses a programmable logic controller (PLC) that monitors and operates the traffic-control devices under supervisory control from the head-end control system. Each cabinet is equipped with a touch screen graphical user interface that allows for local operation in the event of communications loss with the TMC, as illustrated by Figure 15.

6.0 SOFTWARE SYSTEM

Two redundant PC-based servers, located at the TMC, run the Cameleon ITS™ (Intelligent Transportation System) software. This software platform is a customizable, off-the-shelf product, which has seen widespread use for reversible-lane systems in the United States. The City of Calgary had recently adopted Cameleon as the platform for its city-wide video and sign-control system at the TMC, so expanding its use for the RLCS was a natural choice. The software provides a graphical user interface with fully-integrated video to a number of operator workstations, and runs the control sequences that automate the lane reversals through the field cabinets and devices.

All user screens, prompts and operating sequences were developed for the specific requirements of the RLCS project. Through interaction with City personnel and two Software Validation Workshops, the entire system was reduced to just two operator screens - one for Memorial Drive and one for the 5 Avenue Connector. The stylized operator maps use roughly 100:1 compression, along the direction of traffic flow, and allow the operator to visually monitor system status for the entire reversal area, in real time; this is illustrated by Figure 16.

Four times per day, the system software prompts the TMC operator to initiate or remove the lane reversal - typically operating the 5 Avenue Connector between 6:00 and 9:00 a.m., and the 3M10 reversal between 3:30 and 6:30 p.m. In the event of major traffic incidents or special events, such as the annual Stampede Parade, system administrators can readily extend or revise operation times to suit local conditions.

Each lane reversal consists of a sequence of operations that has been carefully analyzed and timed to ensure the safety of motorists using the lanes. Control from the TMC is fully automated, with the control system executing the various sequence steps in the correct order and with the correct timing. No safety-critical operation, such as moving a gate or opening a lane to traffic, can proceed until the operator has visually confirmed it is safe to proceed using the PTZ cameras, which are automatically oriented by the software to provide the operator with the correct viewpoint (or multiple viewpoints.) Time-space diagrams for the 5 Avenue Connector and 3M10 transition sequences are illustrated by Figures 17 and 18, respectively.

7.0 SYSTEM SAFETY AND TROUBLESHOOTING

The RLCS was designed as a critical Life-Safety System. System redundancies were built in at numerous levels including back-up power, a collapsed-ring fibre communication network, multiple control platforms for each device, and mirrored software systems and servers.

Unsafe operations are explicitly prevented by interlocks, which prevent devices from moving to a new state if any other current device state would render that state unsafe. Interlocks are enforced both locally by the distributed controllers and globally by the two head-end servers at the TMC. Examples of prohibited operations include opening a lane in two directions at once, operating devices out of sequence, or failing to respect a clearance timing interval.

Status signals from the traffic control devices and control system components are constantly monitored and logged by the central software. In the event of any problems with the system, the TMC operators are notified by an on-screen alarm that prompts corrective actions or procedures. In the event of critical problems, additional e-mail alerts are sent to supervisors' smart phones to ensure rapid resource response.

Operator manuals were developed to provide standard operating procedures for typical operations and trouble-shooting. Contingency procedures have been provided for camera obscuration, gate collision, power loss, and a host of other possible device failure scenarios. Procedures were also established for TMC overrides, signals maintenance or re-establishment of manual detours in the event of failure of any part of the system.

8.0 SYSTEM TESTING AND COMMISSIONING

System testing was completed, incrementally, through all phases of project implementation. Testing stages included:

- Unit Tests to assess functionality of each device type, once the first unit had been manufactured.
- Factory Acceptance Tests of every individual device.
- Pre-integration Tests, assessing the coordinated control system with the control cabinets and each device "in the lab."
- Acceptance Tests of each device individually, and of the system as a whole, once installed in the field.

The system integration and commissioning process occurred over a two month period in early 2010, and was designed to ensure that the system was fully operable prior to the "Go Live" date. The process included two full, live field trials, scheduled late at night and with extensive detour traffic control to ensure that public traffic was not misdirected by the testing. Formal training manuals and courses were developed and delivered prior to project "Go Live," addressing all users including system operators, administrators and maintenance personnel.

Hands-on training included development of simulation environments that allowed operators to control and troubleshoot the system using real-time screens, controls, maps and graphics. Scenarios including inclement weather, random equipment failure and traffic accidents were simulated during the training phase, so that these eventualities could be anticipated and addressed by system operators and field-maintenance personnel.

City staff were involved through all stages of implementation, and gained extensive experience with the system over the nearly half a year of development that occurred prior to commissioning. Accommodating changes and input from staff at all levels helped to gain stakeholder buy-in and a sense of ownership of the system from Day One.

The system “Go Live” event occurred on March 22, 2010, with both systems operating successfully under the watchful eye of live television news cameras. A one-month validation period followed, allowing City crews and the design team to work out any remaining issues and to make final adjustments in the day-to-day operating environment.

9.0 PROJECT COSTS

The RLCS project was completed with a total budget of \$3.8 Million (all figures in 2009 dollars) for all components including the traffic control infrastructure, fiber optic network, and central control system.

Typical unit costs for key system elements are roughly summarized as follows:

- Traffic Control Gates - \$20,000 (gate device and arm) plus \$25,000 (foundation and custom protective concrete barrier) each;
- Prismatic Message Signs - \$20,000 (sign, controller and diamond-grade message printing) plus \$3,000 (foundation and installation) each;
- LED Traffic Signs - \$3,000 to \$5,000 each;
- Lane Control Signals - \$700 each, including mounting bracket, or about \$18,000 per typical structure (foundation, pole trunk, mast arm, and 8 signal displays);
- PTZ Cameras - \$3,000 (camera) plus \$8,000 (foundation and pole) each;
- Control Cabinets - \$40,000 each.

The manual operation of the reversals, in place since 2006, had had an annual cost of about \$400,000, primarily labour and material costs for multiple detour crews to manage the reversal transitions four times daily. Coupled with public fuel savings from reduction of idling time, estimated to be on the order of 100,000 litres annually, the permanent system has a pay-back period of less than eight years. Discontinuing the manual daily traffic set-ups has also had the general benefit of freeing City crews to work elsewhere, and has improved safety at these locations by not having the crews work in live traffic.

10.0 CONCLUSIONS / RECOMMENDATIONS

From the standpoint of programming and implementation, a number of key approaches from the project can be highlighted for future consideration by other municipalities, including:

- The initial implementation of the reversals as a pilot project, with manual transitioning of the lane states on a daily basis. This had the dual benefit of allowing the City to refine and adjust operations and of gaining widespread public acceptance, prior to investing in the permanent infrastructure.

- Once the decision was made to proceed with permanent installation, the early and direct involvement of project stakeholders including particularly the field operations staff who would ultimately be responsible for maintaining the selected equipment. In addition to the practical input they provided, the involvement of field staff ensured understanding and acceptance of their role in maintaining the new traffic control devices.
- A flexible approach to procurement and implementation of the system. In particular, the project involved multiple competitive bidding processes that allowed the City to evaluate and select the best-value systems for each of the system components. Capital costs were one aspect of the evaluation, with other factors including life-cycle costs, delivery schedule, warranty, past performance, adherence to specifications, training and support considered as well.

Had the City of Calgary pursued traditional road widening projects on the Bow Trail or Memorial Drive corridors, it is estimated that they would each have cost in excess of \$30,000,000 (i.e. an order of magnitude higher) with significant collateral impacts on adjacent neighbourhoods and the environmentally important Bow River shoreline due to limited road right-of-way. Rather than this outcome, the Reversible Lane Control Systems project has demonstrated that highly cost-effective solutions with equivalent traffic benefits can be achieved within existing urban corridors. Considered from a “Triple Bottom Line” perspective, the RLCS project has validated the potential of modern traffic management design and technologies to deliver enhanced mobility with significantly reduced environmental, social and economic costs.

FIGURES



Figure 1 – Manual Trial Operation of the 5 Avenue Connector

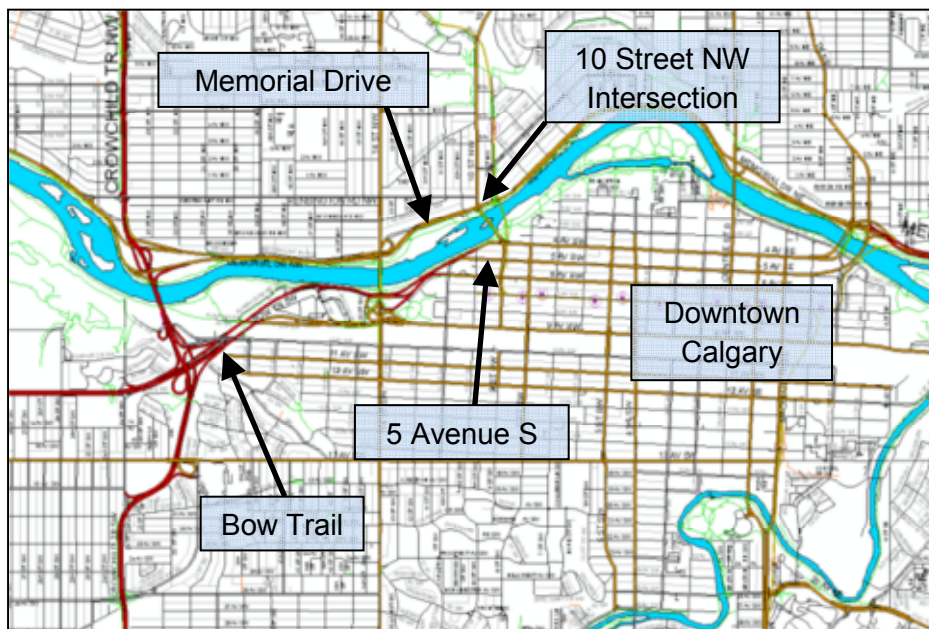


Figure 2 – Project Context

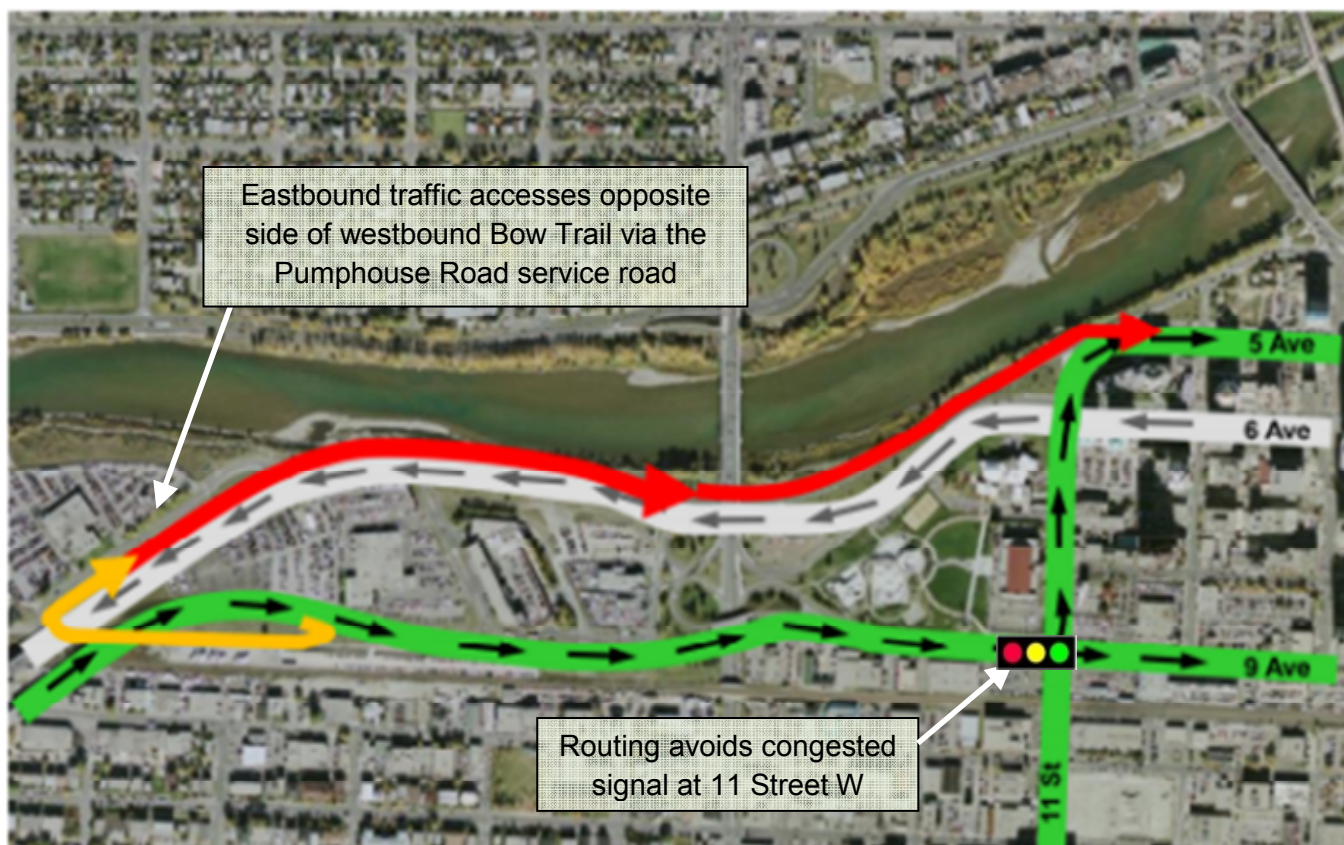


Figure 3 – 5 Avenue Connector Routing

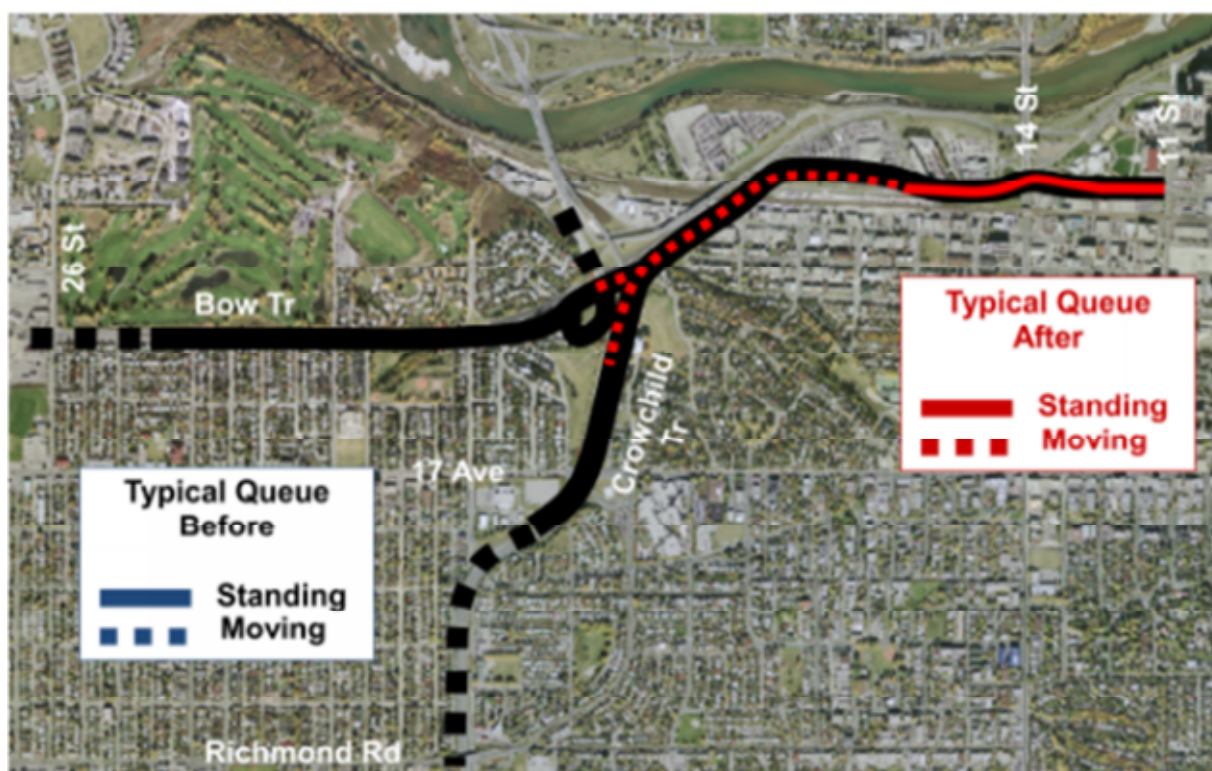


Figure 4 – Bow Trail Queuing



Figure 5 – 3M10 Operations



Figure 6 – Traffic Control Gate Group



Figure 7 – Interior of Traffic Control Gate



Figure 8 – Prism Sign Assembly



Figure 9 – Dual-State Prism Sign Changing States



Figure 10 – Variable LED “Open / Closed” Sign



Figure 11 – Variable LED Median Sign



Figure 12 – Lane Control Signals and Marking



Figure 13 – Pan/Tilt/Zoom Camera



Figure 14 – Traffic Management Centre Operator



Figure 15 – Control Cabinet

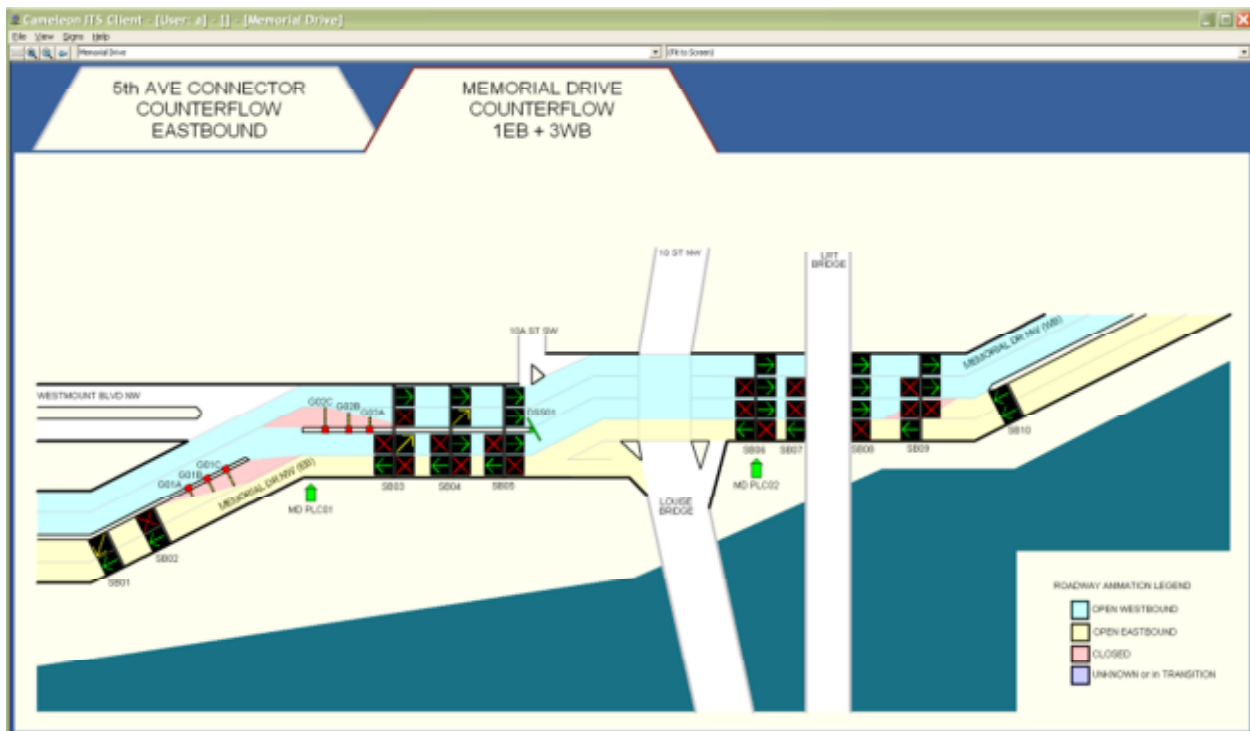


Figure 16 – TMC Operators' Screen

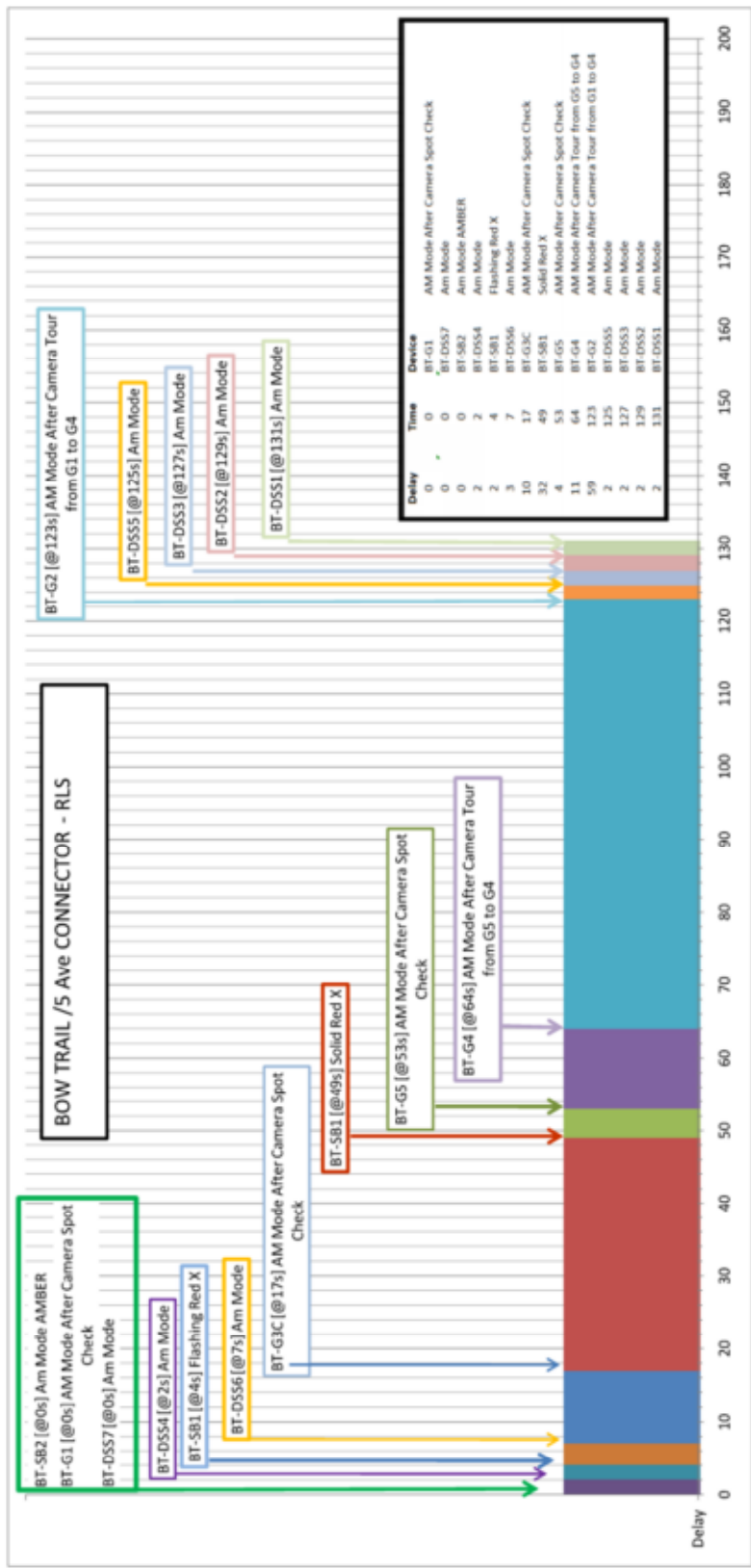


Figure 17 – 5 Avenue Connector Time-Space Diagram

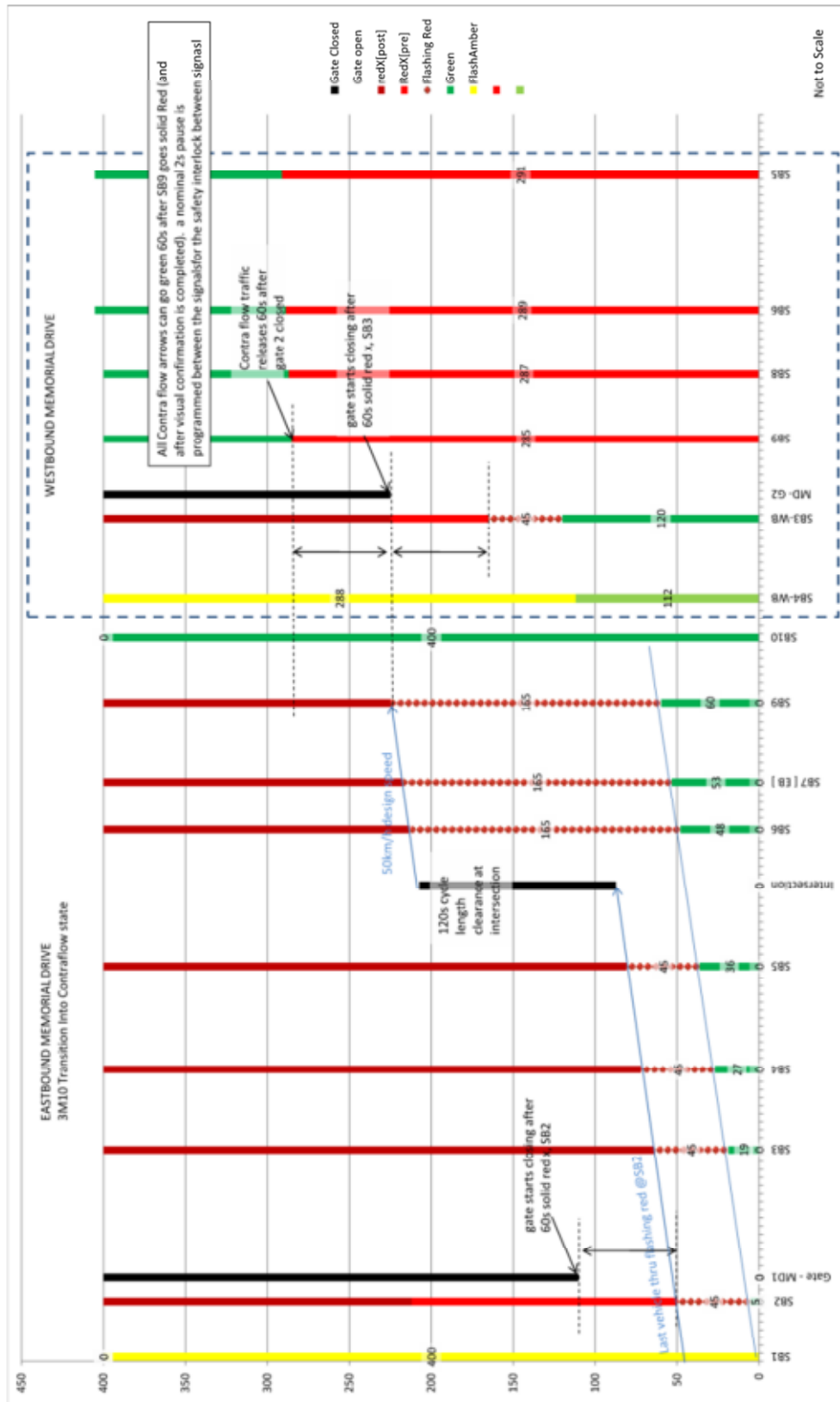


Figure 18 – 3M10 Time-Space Diagram