Highway 402 Queue Warning System
(Wireless Long Haul Application)

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ABSTRACT

Ever since 9/11, heightened degrees of security at Ontario's Sarnia/Port Huron border crossing have lead to typical truck queues on the order of 5 to 10 km. The overall process to clear vehicles at the border has lead to an unusual mix of fast moving passenger traffic and slow moving truck queues on the Hwy 402 approach to the border. Line-of-sight problems on Hwy 402 due to horizontal or vertical highway curves compound this problem such that motorists travelling at high speeds under free flow conditions unexpectedly meet slow or stopped border crossing traffic. This issue had led to a number of fatalities from queue end collisions. The Ministry of Transportation Advanced Traffic Management Section lead an initiative to implement a Queue Warning System on Hwy 402 to automatically detect queues and then warn motorists in advance of the queue via Variable Message Signs.

One of the biggest challenges with the implementation of this system was the fact that the monitoring and supervision of the system was to undertaken by the London COMPASS Traffic Operations Centre which is physically located over 100 km away from the field plant. A high bandwidth, long-haul communications system needed to be designed to carry 10 high-quality camera images as well as data from the field controllers to monitor traffic conditions. This paper also presents the technology solution provided as well as the lessons learned to ensure a robust operation of the communications network.

BACKGROUND

Introduction

Since the tragedy of 9/11, heightened degrees of security at Canada's U.S./Ontario's border crossings have lead to significant vehicle queues occurring in a relatively unpredictable manner. In particular, the Sarnia/Port Huron border crossing has experienced typical truck queues on the order of 5 to 10 km. The overall process to clear vehicles at the border has lead to an unusual mix of fast moving passenger traffic and slow moving truck queues on the Hwy 402 approach to the border. Line-of-sight problems on Hwy 402 due to horizontal or vertical highway curves compound this problem such that motorists travelling at high speeds under free flow conditions unexpectedly meet slow or stopped border crossing traffic.

This issue had led to a number of fatalities from queue end collisions. The Ministry of Transportation Ontario (MTO) had previously deployed static signs with flashing beacons to warn motorists of slow and/or stopped traffic as motorists approach the border. However, this system could not warn motorists as to where the queues were. Further, if there were an incident occurring on Hwy 402, the local COMPASS Traffic Operations staff would not have the ability to detect, provide detailed information to emergency services, and monitor the situations as they arise.

The Ministry's Advanced Traffic Management Section (ATMS) lead an initiative to implement a true intelligent Queue Warning System (QWS) on Hwy 402 to automatically detect queues and then warn motorists in advance of the queue via Variable Message Signs. The system would leverage the experience gained from the QWS system previously implemented by ATMS on the Hwy 405 and QEW Niagara U.S. border crossings.

Previous Experience on Hwy 405 and QEW

In early 2000, the MTO ATMS retained Delcan Corporation to develop and oversee the construction of a QWS in the Niagara Region of Ontario. The main objective for this pilot deployment was to alert motorists to the presence of trucks queuing for the border crossing by automatically detecting the position of a queue, and displaying a warning on a QWS sign. Providing advance warnings to motorists of any such potential slow moving or stopped vehicles proved to enhance the traffic safety and mitigate the associated problems related to the truck queues.

Given the success of this initial deployment, ATMS recommended that a similar system be implemented on Hwy 402 to address the problems occurring in this respective area.

SYSTEM REQUIREMENTS

Since the QWS is a stand-alone system without manual intervention from operators, the operation of the system must be highly reliable and credible. The design and implementation of the system were thus challenging tasks. The system was required to be designed, integrated and tested to meet the strict requirements that the system shall operate with a high detection rate, a low false alarm rate, fast response time and high system availability. Therefore, the system was built with fail-safe features to ensure that the system is able to self-managed and that it operates in a credible manner.

In addition, there was a requirement for the Southwestern Region COMPASS Traffic Operations Centre (SWR TOC) monitor the area via CCTV cameras for incident management purposes. This presented a significant design challenge as the SWR TOC is physically located over 100km away from the subject area on Hwy. 402 and the communication system would need to provide high-quality camera images over this distance at a reasonable cost.

The sections below summarize the following key features implemented to achieve the high reliability of the system:

- Field equipment technologies;
- QWS software;
- Stage-by-stage testing; and
- Fine-tuning.

FIELD EQUIPMENT TECHNOLOGIES

Off-the-shelf, temperature hardened field equipment was carefully chosen to ensure the reliability of the system. LED Variable Message Signs (VMS) and inductive loop detectors are proven and accepted technologies worldwide. The spacing of the signs and loop detectors was strategically determined to optimize the coverage of the highways. The geometry of the highways, the existing road structures and the sign visibility were also taken into consideration in designing the overall layout of the system infrastructure. The system comprised of other off-the-shelf products including redundant fibre optic Ethernet local communications, power, central system network, computers and other field equipment.

Overall System Overview

The basic building block design for the QWS consists of the QWS signs with flashing beacons to notify the public of the queues ahead, 4 sets of vehicle detector stations (VDS) upstream and downstream of the sign to detect queues and CCTV cameras to supplement the operation. Each QWS site, as shown in Figure 1 below, is locally networked together via Ethernet over fibre optic communications. In this manner messages on the QWS signs can be triggered either by its own VDS, or VDS from QWS sites downstream. From a monitoring perspective, COMPASS Operators can log and retrieve historical queue length information from the system.

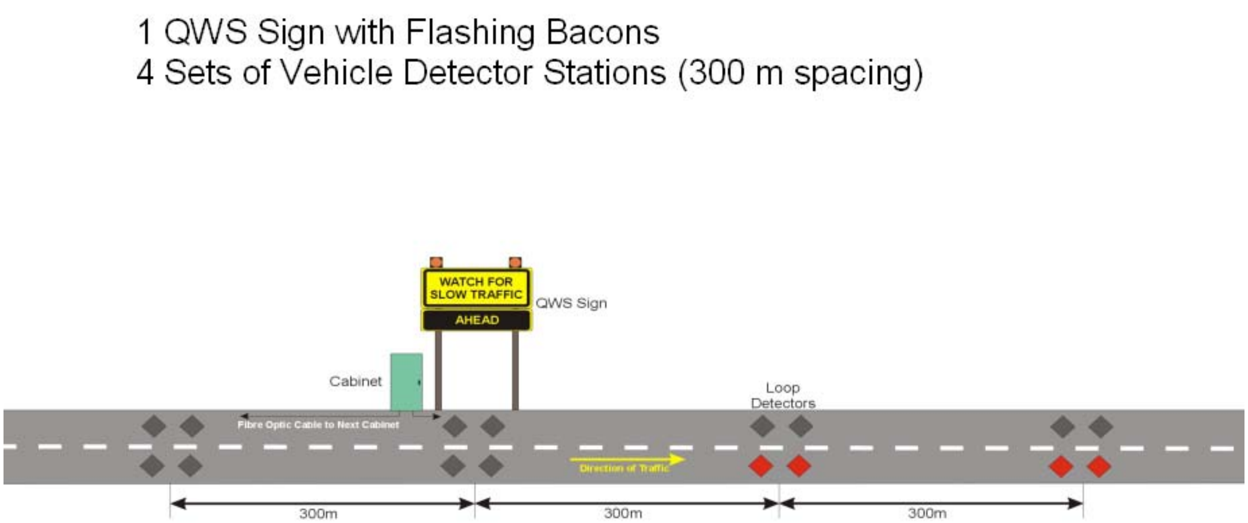

Figure 1 - Overall System Overview of Components

The overall system deployed consists of the following components:

- Six (6) QWS Signs (Static Sign + VMS) with flashing beacons
- Eight (8) Advanced Traffic Controllers (ATC) Controllers (i.e. field hardened computers for local processing of traffic data)
- Thirty (30) border-bound/westbound Loop Detector Stations for queue detection and two (2) London-bound/eastbound stations for basic data collection
- Ten (10) Dome CCTV Cameras
- 15km of local Fibre Optic Ethernet Network
- Permanent power active 24/7 with UPS backup for the communication nodes

- QNX based fully customized software

QWS Signs

The QWS sign is a hybrid sign that contains both static and variable messages, as illustrated in Figure 1. The static sign with a message "WATCH FOR SLOW TRAFFIC" located above the variable sign constantly warns drivers the slow moving traffic and queue ahead. The variable sign located below the static sign provides dynamic information with respect to the end position of the queue from the sign location (e.g., AHEAD, NEXT 1KM, NEXT 2KM, etc.). This queue-end position information gives the drivers a warning if a queue has formed downstream. The two flashing beacons installed above the static sign also help attracting motorists' attention when a queue is detected. To maximize the sign credibility and efficiency, human factors were taken into consideration in determining both the static and dynamic messages. In the event that the VMS has failed off, the static sign remains effective because it continuously reminds the drivers approaching the border crossing to stay alert at all times and watch for any potential unexpected traffic queue ahead.

Figure 2 - Queue Warning System (QWS) Sites

Inductive Loop Detectors

For real-time data collection, a pair of diamond-shaped loops is installed in each lane of a detection zone as shown in Figure 2. The QWS algorithm identifies traffic queues based on measurements of spot speed, volume and occupancy in a lane by lane basis. The algorithm evaluates all the traffic data collected by the vehicle detectors in the system, and determines whether a specific queue warning is required for each sign.

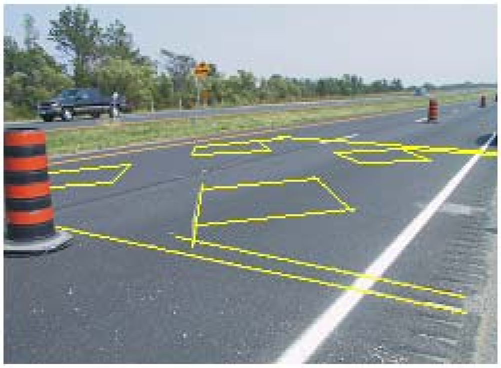

Figure 3 - Inductive Loop Detectors Layout

The double loop configuration is another fail-safe facility. Speed data is collected by use of loop pairs. For queue detection and clearance by the system, detected vehicle speed is an important parameter. However, if one of the loops pair fails, the detector system loses the capability to measure vehicle speed. To improve reliability under loop failure, the system uses the operating loop's occupancy value which allows the system to provide queue detection and clearance.

Dome CCTV Cameras

In order to provide general system monitoring and incident management capabilities to the COMPASS Operators, 10 dome CCTV cameras were installed at 1 km intervals on Hwy 402 from Front Street to Mandaumin Road. The camera poles are approximately 18m above ground providing for a field of view in excess of 750 m upstream and downstream from the camera.

Figure 4 - Dome CCTV Cameras with Lowering Device Installed on Hwy 402

Typically, maintenance sites are required in order for bucket trucks to safely park away from the travelled portion of roadway to maintain the cameras. Rather than developing CCTV maintenance sites, camera-lowering systems were implemented which eliminates the need for bucket trucks altogether. Maintenance staff can simply use the lowering mechanism at the base of the pole and lower the camera to ground level. Not only did this save money in the cost of the maintenance sites, but it also provides for a much safer maintenance program for the cameras.

Subsequent to the installation of the cameras for incident management and QWS monitoring, the Ministry provided these 10 cameras to the public via the Ministry's COMPASS website: http://www.mto.gov.on.ca/english/traveller/compass/camera/sarnia/camhome.htm.

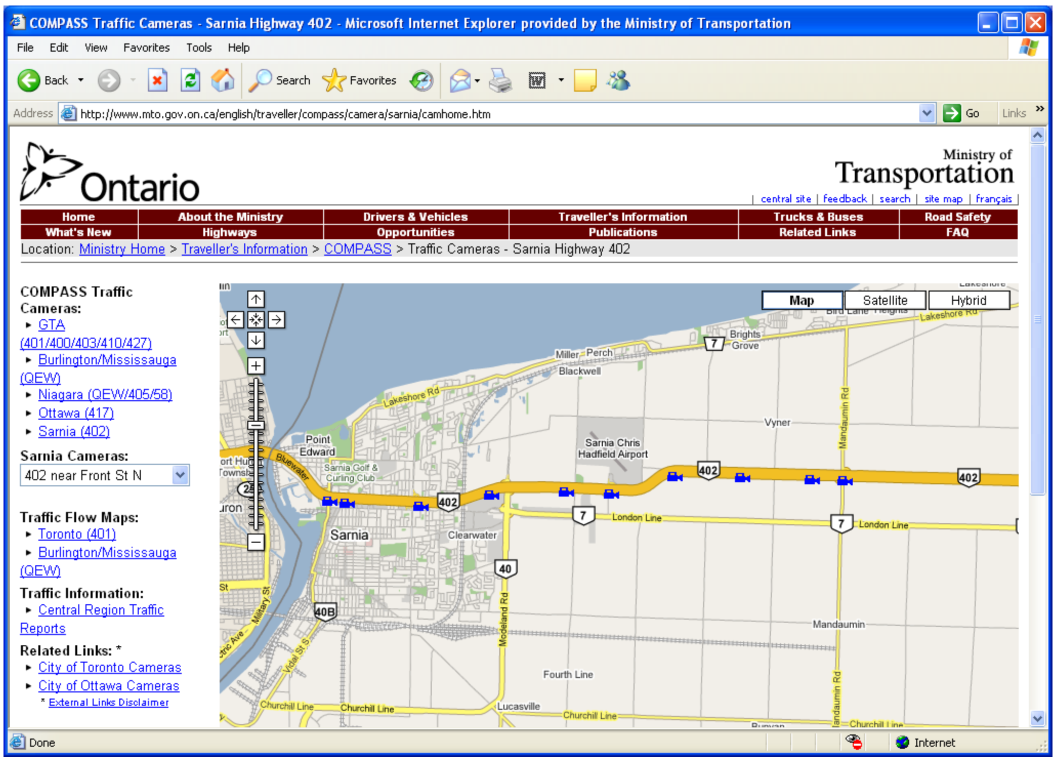

Figure 5 - COMPASS Website Displaying QWS Cameras on Hwy 402

LONG HAUL WIRELESS COMMUNICATIONS SYSTEM

The project challenge was to provide both video and data signals between the Sarnia site and the traffic operations centre location in London (SWT TOC) to allow for remote monitoring. The data requirements are low but the ability to transmit 10 real time video images over the 85 km link was a challenge due to the high recurring costs of leased facilities. It was agreed during the design stage with operational staff to accept MPEG4 compressed images of 350 kb/s in order to minimize the system costs.

Communications Systems Analysis

A trade off analysis was conducted which compared the feasibility and costs for leased communications circuits from the Ministry's GONet service provider versus using a long haul wireless Ethernet bridge between the field equipment on Hwy 402 and the SWR TOC.

The GONet link would have been fairly easy to implement, however, it was anticipated that there would have been costs as high as $10,000/month for the bandwidth required to carry the 10 video feeds. Since the lease costs are bandwidth dependent any additional cameras or improved video quality required by COMPASS Operators would result in higher operating costs. Further, there were concerns regarding the existing network bandwidth restrictions at the London CommCentre as to whether or not these 10 continuously running video feeds would impact the local use of Internet for general business purposes within the building.

The long-haul wireless Ethernet solution was a far less expensive option at ~$1,500/month however, there is risk associated with the reliability of the link. The quality of the wireless communications link can be affected by external factors such as inclement weather and other users in the same band. This trade-off was considered acceptable given that the QWS is fully automated and as such, there wasn't a definitive need for the CCTV monitoring to be operational 100% of the time. Further, by specifying the wireless equipment with higher link margins and greater bandwidth capabilities, it would improve the ability of the equipment to meet the required bandwidth. The design of the system allows the equipment to adjust the data throughput if the signal quality degrades but not to the extent that it affects daily operation of the network.

Given the above considerations, it was decided to implement a 5.8 GHz, spread spectrum radio, long-haul wireless Ethernet system utilizing existing communications towers as repeater sites. A path profile analysis was conducted and existing towers were identified to be used as the repeater sites.

Communications Path

The final design configuration was based on utilizing three links due to the path length and topology:

- 5.8 GHz radio point to point system with repeaters
- London TOC to a TVO tower covering a distance of 11 km
- TVO tower to a CHTV tower in Alvinston covering a distance of 43 km
- CHTV tower to a 21 m camera pole in Sarnia covering a distance of 35 km

Figure 6 - Installation of Wireless Equipment at Camera Site in Sarnia

Lease for Co-Location of Antennas on Existing Communications Towers

Lease space for the equipment was negotiated with the two tower owners that included equipment shelter space and power. A combination of square patch antenna (short link) and 910 mm parabolic antennas were used to provide the required gain.

The commissioned system is able to provide 36 Mb/s of throughput which allowed the video image quality to be improved by increasing the bandwidth to 512 kb/s for each image. The system has been in operation for over a year and has provided reliable communications since its commissioning.

This solution has provided an effective alternative to leased facilities for long haul communications. The ability to implement this wireless solution is based on the link topology and the ability to cost effectively procure tower space for the equipment. As the technology advances the throughput supported by these wireless systems has improved with systems providing both point-to- point and point-to-multipoint solutions.

QUEUE WARNING SYSTEM SOFTWARE

The software was designed to be intelligent, reliable and flexible. Enhanced features and functions were integrated in the system to provide accurate and confirmed identification of the end-of queue location. These features are:

- Rationale Matching Scheme;
- Queue Tracking System;

- Different Levels of Operational Modes; and
- System Monitoring and Data Logging.

Rationale Matching Scheme

The QWS employs a Rationale Matching Scheme for automatic queue detection and clearance by using the three major traffic parameters (e.g., volume, speed and occupancy). All admissible rationales of traffic pattern are defined in a library. The set of traffic data collected from the field will then be matched with the rationales in the library. The matched rationale will subsequently determine the status of the detection zone (i.e., whether a queue exists in the zone). Whenever a queue has been identified, and using the Worst Lane and Lane by Lane Rules, the system identifies the farthest queue-end location from the border crossing among travelled lanes, and activates the corresponding QWS signs with flashing beacons in a co-ordinated manner. Based on a pre-determined distance "x" to queue-end location resolution, the system automatically chooses the appropriate messages to be displayed on the VMS. The QWS algorithm is designed to detect all types of queue conditions, especially the slow moving traffic and standing truck queues formed near the borders.

Data enhancement and filtering are included in the system. The data collected from the field may be smoothed to minimize normal fluctuations observed in of traffic data. The data may also be required to be persistence checked for a specific period of time. This feature is applied on the real-time traffic data to verify the occurrence or clearance of a queue. The check filters out any misleading data and re-confirms the queue status in each zone before each decision making point in the process.

Queue Tracking System

The Queue Tracking System is used to track and handle the contraction and expansion of a queue. In reality, a traffic queue may shrink or grow significantly over time. In system testing, it was found that during queue dissipation the queue can become unstable and break into multiple queues. Moreover, it was observed on-site that unreasonable gap size between stopped trucks can occur within a long solid truck queue situated on the right hand lane of the highway (some truck drivers tended to find something to do such as eating, napping, leaving the trucks to have a chat with other drivers, etc. while they were waiting for the queue to move). Large queue gaps were observed regularly in the system log. In addition, faulty detectors can impact on the performance of the system. Therefore, in order to resolve the above issues, an implied queue (i.e., an imaginary queue) is used to fill the gap between the detected queues so that a consistent queue formation and clearance can be determined.

Different Levels of Operational Modes

"Co-ordination" mode – is the normal mode for the daily operation of the system. This mode links all loop detectors, controllers and warning signs of a defined area to work as one system. The detectors periodically feed traffic data into the controllers. The controllers constantly communicate with each other and monitor the occurrence and clearance of queues. The controllers process the traffic data and send commands to the signs based on the detected traffic conditions. The system activates one or more signs for a queue-end location. The signs display an appropriate warning message with respect to the end location of the queue.

"Local" mode – In the event of communications problems, power failures or node failures, the system is capable to automatically shift its mode of operation from the "Co-ordination" mode to a "Local" mode where the operation of the local VMS can still be maintained by an individual node.

System Monitoring

Data Logging

Although this system is designed to be unmanned, the system can be monitored by several ways. Comprehensive event and historical traffic data logs are provided for information and analysis purposes. The event log indicates the daily operations and activities of the system including queue status, equipment status and fault, whereas the traffic data log records daily (24-hour) data including a distribution profile of vehicle speed and vehicle lengths. These logs were very useful during the system implementation and fine-tuning. For instance, the logs were used to identify and understand traffic behaviour. The event logs were employed to track the improvements in system performance during the fine-tuning process. The daily traffic data logs were reviewed for confirming sensitivity tuning of the loop detectors. System fine-tuning can be time-consuming because tracking a real queue on-site can be very difficult or even impossible. With the data logs available, most of the tuning process can be performed in-house by reviewing the data and performing data analysis.

Graphical User Interface

A user friendly Graphical User Interface (GUI) was developed for the implementation of QWS. This application provides a monitoring tool for traffic data; sign status including current message displayed; loop status; and queue detection map. The SWR TOC recently adopted the COMPASS Lite central software application for traffic management of their ATMS infrastructure. This software allows the COMPASS Operators to monitor and control their ATMS infrastructure on a GIS based map. It was hence necessary to ensure that the QWS application be integrated with COMPASS Lite for the SWR TOC implementation.

The Ministry's plan for software throughout the provinces COMPASS Operations Centres is to use what is referred to as Next Generation COMPASS System software. This would be a browser-based application that would allow COMPASS Operators across the province to log in, monitor and control their existing ATMS infrastructure within their respective region. The future plan is to have the QWS application integrated within this system.

Paging Services

In order to maintain a high rate of system availability, the operator is notified immediately when any equipment or system fault is detected, so that the faulty equipment can be fixed in an efficient and timely manner. To serve this purpose, the QWS is equipped with a paging service that automatically reports system problems (e.g., power, communications and equipment failures, and other critical events). Operations/maintenance staff is paged when the system detects a problem. In addition, a "Heartbeat" feature installed in the system periodically monitors the health or continued proper operation of the system, and reports the heart beats via the pager.

Stage-by-Stage Testing

Extensive testing procedures were conducted during the system implementation to demonstrate the acceptance test requirements pre-defined for the system. The testing was performed in a stage-by-stage basis. The purpose of the stage-by-stage testing was to minimize the risk of implementing an unsafe system in the field. The approval of each test gradually confirms the reliability of the system. The staging tests also provide the authorities with a chance to build their confidence and understanding on the system before putting the system on-line. The following are the methodologies of three-stage tests used to procure the acceptance of the system.

Stage 1: Lab FAT (tested with the equipment in the lab using simulated queues)

A fully equipped test system was set-up in the lab. Refer to Figure 7. The equipment included a central system, a workstation, ATC controllers, and a VMS with beacons. Different traffic pattern inputs from the detector loops were simulated using a traffic simulator. Failed detectors could also be simulated. The VMS was used to verify the messages activated by the system when a queue was detected. The purpose of the "Lab FAT" was to ensure that the software, algorithm, system network, system features and functionality were completely established before installing the system in the field.

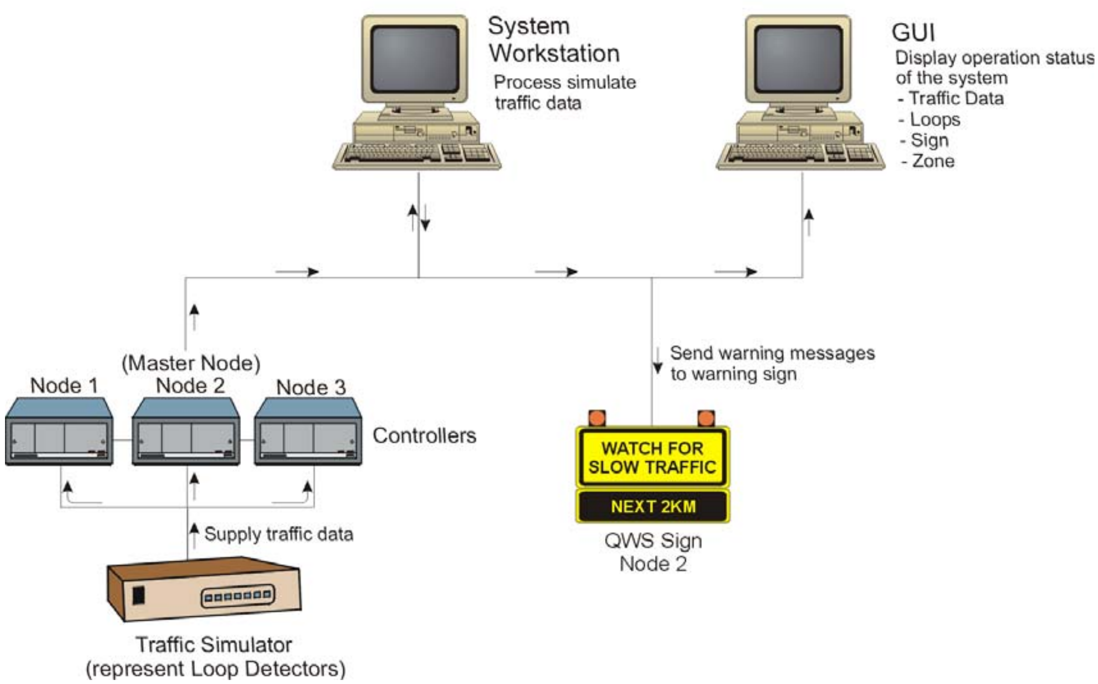

Figure 7 - Testing Equipment Layout

Stage 2: Simulated SAT (tested with the equipment in the field using simulated queues)

After the approval of the Lab FAT, the test proceeded to the second stage "simulated SAT". Similar to the "Lab FAT" stage, different traffic patterns were simulated using a traffic simulator. The equipment and system software were installed and integrated on site, including the signs and the ATC controllers. The simulated data was fed into the field controllers to simulate queues. The controller then processed the data and provided the appropriate messages via the monitoring screens. The purpose of the "simulated SAT" was to ensure that the software, system network, and the controllers were fully integrated and properly configured before placing the system on-line.

Stage 3: Field SAT (tested with the equipment in the field using live queues)

The Field SAT repeats the above procedure with live traffic data. One team was located in the TOC to remotely monitor and the other team was on site to witness the vehicle queues, activation of the signs and to ensure that the field equipment was integrated properly. The purpose of the "Field SAT" was to verify that operation of system was running on-line and working properly.

System Fine-Tuning

The QWS is a highly configurable system. It allows the user to configure the system parameters (e.g., parameter thresholds, persistence cycles, loop configurations, etc), which control operation of the system. These parameters are then fine-tuned based on the traffic patterns, driver behaviours and geometry of the highway to achieve the optimum performance of the system. The flexibility of the system allows the user to tune the performance and adjust the sensitivity of the system for different highway characteristics and geometry. For example, the queue formations and dissipations as recorded by the system were greatly improved and became more stabilized by increasing the number of persistence cycles in the queue clearing module.

SUMMARY

The implementation of the system was a success and there has been a notable reduction in the number of rear end collisions on Hwy 402. The system provided much improved safety at a cost only a fraction of that required to implement highway improvements associated with removing horizontal and vertical geometric challenges. The project provided the opportunity to test long haul wireless Ethernet technology in the context of an ITS application. It is foreseen that this technology would be used again in future in circumstances whereby ATMS equipment is being installed in rural locations with significant distance between the field plant and the traffic operations centre.

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