Design Considerations for Updating Toronto's Transportation Operation Centre (TOC)

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Abstract:

The City of Toronto's Transportation Operation Centre (TOC) has been in place since January 1994. There were no major upgrades to the facilities over the past 20 years. The utilities and equipment were aging and required replacement and upgrade in order to improve work efficiency, capacity and productivity, and bring cost savings through reduction of power consumption and reduction of maintenance costs. The renovation program was initiated in October 2012 and completed in July 2014. In order to suit both the current and projected functional needs of TOC operations, the project management team applied various technical approaches to ensure the operational expectations were met – these included ergonomic analysis, HVAC capacity evaluation, equipment layout, visibility assessment, lighting and furniture requirement validation, etc.

This paper addresses the key architectural and engineering design aspects for the TOC renovation. It provides details on analysing the TOC operational needs to determine the optimum layout, size of display wall, the most effective use of the display wall and display wall technology to fit into a confined space. It also discusses the use of 3D modelling techniques to assess the view distance and angle for video wall placement, and lighting design. A comprehensive capacity analysis for heating, ventilating and air conditioning system was conducted to ensure a high quality of air circulation and employee comfort. A holistic solution of network architecture topology as part of this program to satisfy the needs of both Corporate IT and Traffic Management Centre is also discussed.

Key Words: TOC Renovation, Ergonomic Analysis, 3D Modelling, Video Wall, HVAC

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BACKGROUND

The City of Toronto’s Traffic Operation Centre (TOC), with an area of approximately 350m^2 (3800 ft^2) inside an office building, is the control centre within the City’s Traffic Management Centre (TMC) of the City of Toronto. It serves a critical role in managing corridor traffic, responding to inquires, monitoring traffic incidents, acting upon incident occurrences, providing centralized command/control and active traffic management through Road Emergency Situation Communication Unit (RESCU) operations and Transportation Dispatch services. The TOC is operated on a 24/7 basis by a third party contractor.

Adjacent to the TOC is Transportation Services Divisional Operations Centre (TSDOC), also called the Viewing Room (VR) which is roughly sized 11m × 6.7m and serves as the Transportation Services command centre during special events (e.g. Caribbean Carnival, Canadian National Exhibition and Grey Cup Festivities) and emergency events (e.g. recent widespread flooding). The VR also serves as a TMC meeting room when not being used as a TSDOC.

The TOC and VR, located on the 5th floor of 703 Don Mills Road, City of Toronto, have been in place at the Traffic Management Centre since 1992 when a state-of-the-art facility was built. Most of the equipment in the TOC, e.g., video display wall, lighting system, electrical system, heat ventilation/air conditioning and operation console, etc, had reached the end of its useful life and needed replacement.

A renovation initiative was started in early 2011. The City hired a consultant to provide an assessment and recommendations for upgrades to the video wall system, furniture, layout and utilities, and to identify work function efficiencies within the TOC and VR. Adopting the recommendations from the consultant's report, the City launched a complete renovation program which consisted of two projects: the architectural project (Reno Project) and the video display and control system project (Video Wall Project). The former was handled by the City's Facilities Management Division while the latter (TMC Video Display and Control System Project) was led by TMC staff in the Transportation Services Division.

The actual implementation of the two projects started in September 2013 (Video Wall Project) and February 2014 (Reno Project) respectively. The newly renovated TOC and VR were completed in July 2014, at a total cost of $3.1 million.

OPERATIONAL NEEDS ANALYSIS

1. Display Wall

The Display Wall was a main focus of the renovation due to the need for 24 by 7 operations and its importance to Toronto corridor traffic monitoring and management responsibilities. Four principles[1] were taken into account during the project planning stage - operational effectiveness improvements, achieving routine goals, achieving strategic goals and system sustainability development.

As the single most important component within the TOC, the video wall itself plays a critical role in determining the project scale. Due to its significant cost, the use of the video wall must be carefully assessed to meet operational needs rather for its ancillary value (e.g., as a show case). The previous video wall consisted of 57 cathode ray tube (CRT) display units which could not display all 76 RESCU Camera images at the same time. With an expected 150 arterial traffic road cameras being added in the next three years as part of the Toronto Congestion Management Plan (CMP), the TOC operations will be expanded from Expressway Management to City-Wide traffic monitoring and management. The previous CRT video wall would not support this new mandate from either a capacity or flexibility perspective. Therefore, upgrading this equipment became a priority.

Some factors that limit the benefit of the traditional video wall include:

- The display capacity of a CRT based video wall was constrained by the number of monitors. When the camera number increases, it is likely that camera displays must be placed on "touring" for operators to view, which is not considered "full coverage" of the network.

- The CRT video wall was built to display camera images only and provided no flexibility in either displaying map images or manoeuvring camera images (e.g., resizing).

- The technology used by CRT generated limited visual effects that do not support wide horizontal and vertical viewing angels. This in turn capped the number of cameras that can be monitored by TOC operators from their workstations.

On the other hand, the reasoning of upgrading the Video wall was debated. Due to rapid technological progress, the operator's need to view and switch camera streams can now be easily accommodated by many off-the-shelf software products which can run on workstations with user-friendly interfaces. These products are commonly used in command centres and security centres where either space is limited or where the budget is limited.

However, modern display products allow for more than simple camera image monitoring. Through the operational needs assessment, the key justification for an improved display was that the operations oriented GIS map display requires a large high resolution display area. This could only be supplied by DLP technology-based display units. Thus, the display wall really should be called a "GIS Map Display Wall" rather than "Video Wall".

The City will also be displaying an advanced transportation management systems (ATMS) which is a GIS map based application for managing the road network. This important functionality demanded the use of an improved video wall that would allow for the display of map-based interface, traffic flow data, camera streams, and traffic control device status, etc, on the map.

2. Layout

Figure 1 shows the "before" layout for the TOC and VR. There were 15 workstations within the TOC which accommodated two groups, namely TMC Dispatch and RESCU. The former, handled by City employees, contained four work stations in the second row. The latter, run by a third party contractor, occupied the front row. Since March 1, 2013, the TMC Dispatch job function has been outsourced. TOC operators are required and able to conduct RESCU monitoring and TMC Dispatch duties at the same time on a routine basis. From an operational perspective, when the contracted service combining these two functions started, there was a need to bring these previously separated staff into a close proximity working environment where they would share facilities (such as the display wall).

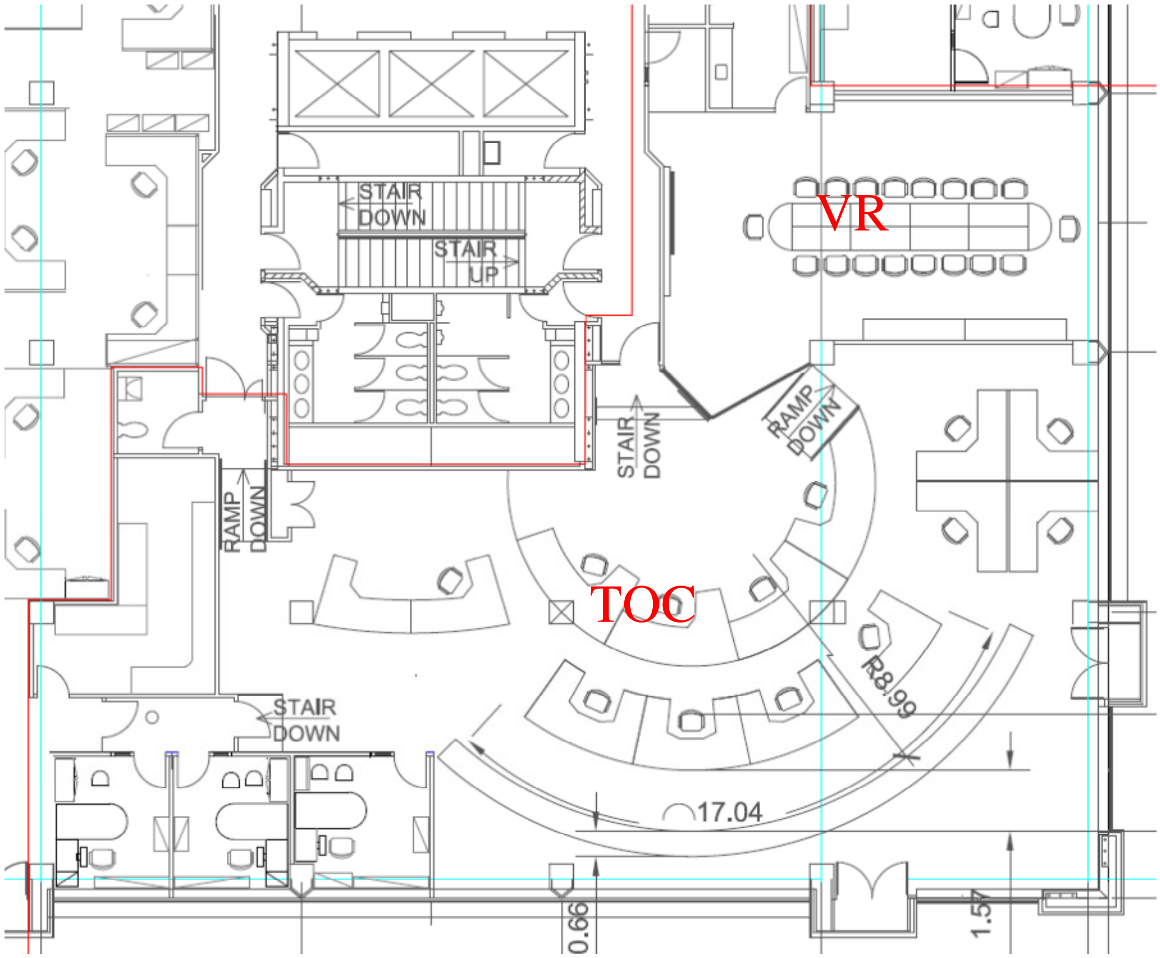

Figure 1. Layout of TOC and VR Before Situation

The following analysis illustrates how the rough size of video wall and number of work stations in the TOC were defined:

First, the ultimate capacity of TOC was determined by:

- a 15-year life cycle
- 24 by 7 operations by a third-party contractor comprised of one supervisor and 15-20 staff
- a total of 300 cameras with 80-90 on the City's Expressways, and 180-200 on 20 major arterial roads, and 10-20 on critical locations, e.g., flooding area.

Second, the display of ATMS applications on the display wall considers:

- When traffic incidents occur, only those involving multiple locations within a large geographic area will be displayed on the wall; other incidents to be handled at the desktop workstations.
- The number of concurrent traffic incidents is estimated to be around 3 - 5 based on previous TOC incident logs.
- Each individual operator would be able to monitor a geographic area sized by 5 - 8 km long and 4 - 6 km wide.

An operator with normal vision (20/20) is estimated to be able to see an 8.86mm tall letter (e.g., "E"), from a distance of 6.1m (20 ft). This is a reference to the operator's "visual acuity". Assuming there is a linear relationship existing between the view distance and the object height, when the distance decreases to 2.74m (9 ft), the object height would be around 1.24 mm. Given that the common pixel pitch distance for normal computer monitors range between 0.25mm to 0.365mm[2], it is estimated that the 1.24 mm object requires 4 pixels to display (1.24/0.3 ≈ 4). Thus the resolution of display area roughly measures four (4) times of the computer resolution.

For instance, a 24" monitor with 1600 × 900 resolution can display a map of approximately 8 km (length) by 6 km (width) geographic area, which is adequate for a person looking from a 0.91 m (3 ft) distance. When the distance increases three (3) times, the resolutions expand three times assuming they are linearly related [3].

Thus, Table 1 shows that a rough pixel dimension estimate of the monitoring area for an individual, which is (4800~6400) × (2700~3600).

Display Pixels	Geographic Range (length ×Width)	View Distance
1280×768	5 km × 3.5 km	0.91 m (3 ft)
1600×900	8 km × 6 km	0.91 m (3 ft)
(4800~6400) × (2700~3600)	8 km × 6 km	2.75 m (9 ft)

Table 1. The rough pixel estimate sheet

Multiplying the average display area resolution (5600 × 3150) for each operator by the average number of concurrent incidents (4), we had the total required display pixels estimated blow:

(5600 × 3150) × 4 = 70,560,000 pixels

This formed the selection criteria for the video wall. In other words, the total display pixels must be within the range of 70,560,000 $\pm$ 3% pixels. Based on the analysis, we assigned four (4) operators at the front row whose major duty is to monitor the display wall, one (1) senior operator seat with a supporting role and kept one (1) as spare (Figure 2). The second row also had four (4) work stations with two positions being used for Dispatcher duty, one (1) as traffic signal communication operations and one as spare. The spare two seats were reserved for future expansion.

As a result, the number of seats was changed based on two factors. First was the staff's screen viewing capability, which in turn determines the total display area of video wall based on the maximum staffing number. The second factor was the TOC future expansions potential, i.e., new functions such as signal timing changes or being a backup control centre for other agencies.

Figure 2. 3D Rendering of TOC layout After Renovation

Figure 3 shows the After-Reno layout which consists of 10 operator workstations, one supervisor office and one kitchenette. The contractor thus has a closed space for their own staff which is segregated from City employees.

The rough display size of the wall was determined by its proposed contents and the setup of TOC operations. Due to space constrains (i.e., two load bearing columns sitting in the middle of the room) and the elevation clearance, it was impossible to provide an unobstructed view of a complete video wall. As shown on Figure 2, the video wall contains two separate walls, a large wall on the south side and a smaller wall on north side of the TOC. The wall alignment was adjusted to minimize sight line disruption caused by the north column.

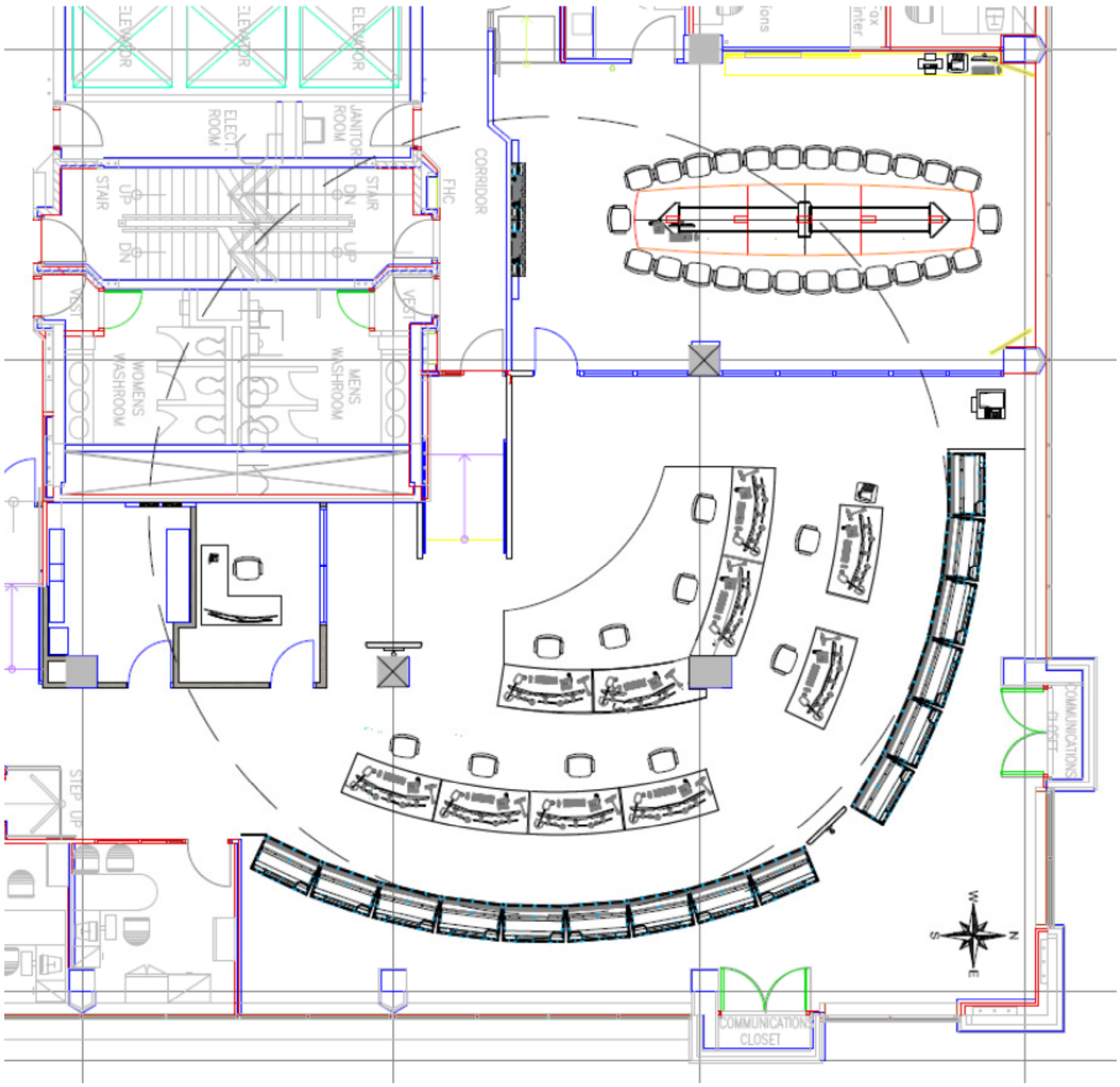

Figure 3. The After-Reno Layout

3. Redundancy Design

This mission-critical environment requiring round-the-clock operation demanded the delivery of system redundancy for power supply, computer networks, and various application systems. The following features were provided:

- Facility Power Supply which is backed up by UPS array and emergency power generators. All TOC workstation computers are connected to the UPS array in order to maintain uninterrupted operations.
- The Video Display and Control Systems have redundant designs built-in to support hot-swap capability between multiple servers.
- The display wall is capable of automatically switching to alternative signal sources within seconds after the "no signal" status is detected to minimize the downtime.

4. Ergonomic Requirements

4.1 View Distance

The critical viewing distance (CVD) from the display wall to the console was fixed given the nature of TOC operations. The CVD design was conducted after the video wall cube module (Mitsubishi 62" DLP Cube) was selected. The optimum distance should balance picture quality and ergonomic requirements. The former was determined by material resolution (i.e., too near causing pixilation; too far causing motion sickness and loss of details), brightness and view ability angle. The latter was dictated by focusing area of individual and human spatial vision perceptions.

Although the specifications for the display cubes indicated their wide range of viewing capability (as outlined below), pragmatic considerations needed to be taken into account.

View ability Angle	Horizontal	1/2 gain: ±35Degree, 1/10 gain: ±57Degree
	Vertical	1/2 gain: ±16Degree, 1/10 gain: ±28Degree
Vertical Dimension		32.81" (833.5mm)
Horizontal Dimension		52.5"(1333.5mm)

Table 2. Mitsubishi 62" WUXGA DLP Cube View Ability Angle[4]

A literature review[5], [6] indicated that there are various calculation methods for CVD (e.g., determined by 3-4 times cube vertical dimension[7], or 1.5-2.5 times cube diagonal dimension [9]). After consulting the manufacturer, we chose a 9.2 ft viewing distance with a horizontal viewing angle ranging from -31˚ to +31˚ for 1/2 gain and a vertical viewing angle of 16.5˚for 1/2 gain.

Figure 4. View Ability Analysis of TOC layout After Renovation

However, 1/2 view gain applies on the extreme conditions[8] that the operator may be capable of viewing 50% of the displayed information on the wall from the angles defined above. With the ATMS software, the focus of operator's view will be on the centre of the display area in front of them (e.g., incident icons on the maps) thus the view gain should be higher than 1/2.

4.2 View Angle

The original video wall layout was a circle with a radius of 30 ft (9.1 metre), which was suitable for 27" CRT display units. The new wall consists of 62" 4:3 aspect ratio display cubes which are 2.3 times larger in size that the CRT units. A rigid adherence to the original circular layout for the new display wall arrays would have negatively affected the view quality for displays across the two walls [10]. To address this issue, the connection angle between two sacked units was adjusted to 6^o compared to the original 9^o. As a result, the two walls follow separate curves in order to create a flat and smooth appearance for each wall. This setup also utilized the space efficiently.

4.3 Lighting

There were five fluorescent lights perpendicular to the video wall right above the first row and three additional lights over the second row, each comprised of two 32 watt lamps. The lights in the first row were located above operator's work stations, at 1.56 meters to the top of workstations. Four lights were located above the second row work stations at 1.44 meters to the top of workstations. All fluorescent lights in the TOC, except for two over the Road Dispatch desk, were controlled by a single dimmer switch located close to the north entrance which often triggered staff conflicts. Due to the uneven ceiling cavity, the reflectivity above the RESCU operator work stations is much lower and hence the overhead lights above the second row should be controlled individually.

Through the architecture design, the TOC room was updated to include a total of five lighting zones with energy efficiency lights being provided.

4.4 HVAC system upgrade

The building central HVAC system provides heating, ventilation and air conditioning for all floors. The air vents are mounted along the entire window sill of each floor, and so extended along the north and east walls of the TOC. The air conditioner system rotates between day-mode and night-mode daily in summer. During the night-mode, from 23:00 to 4:00 of next day, one of two condenser units on the roof level is shut down as an energy-saving measure. Night shift staff previously raised concerns that the temperature in the TOC increased significantly when only one condenser unit was operating during summer time. An ancillary air conditioning system was installed to provide relief for TOC staff but it was rarely used because of a noise issue.

The mechanical assessment identified the needs for an in-door air conditioning unit to provide an additional air cooling capacity of 13,000 BTHR and to maintain the noise level below 30 dB. The unit was mounted on the ceiling at the north-west corner behind the display wall. With all gaps being sealed, TOC operators in the control room can barely hear any operating noise.

4.5 Height Adjustable Console

The old consoles for the TMC dispatchers and RESCU operators were in place since 1994 (Figure 5). The console board was comprised of several units of standard office furniture. Surface load, knee well space, view/reach distance and keyboard height were considered in the original console design. However, further flexibilities were required to accommodate the requests for variable height work surfaces, robust chairs appropriate for long shift operations, task lighting and locations for office devices in accordance with the City's workplace ergonomic requirements (e.g. computer box, printer, copy machine and fax machine, etc).

Figure 5. Operation Consoles Before Situation

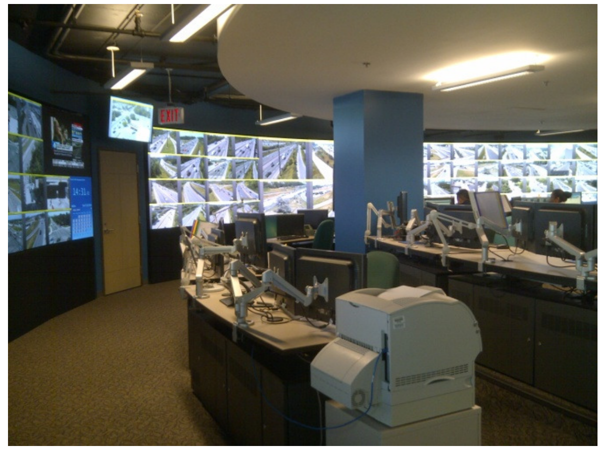

Figure 6. The Current Operation Console

The original console was made on site as one complete piece per row; thus the console height was fixed for all workstations. For the renovation, multiple seats must be separated so that individual can adjust the workstation to his/her own comfortable level. As well, the space must be utilized efficiently to provide a tidy and clean environment and improve productivity (e.g., provide a dedicated cabinet underneath the surface for computers, and provide a dedicated cable management system, etc)

Ten height-adjustable consoles with height being adjustable from 25" to 55" were procured, each equipped with three 24" monitors (Figure 6).

5. Viewing Room (VR) Upgrade

There were several changes made to the VR, atheistically and functionally, including:

- Replacement of the whiteboard and drop down screen with a 2×2 ultra-thin Bezel Mitsubishi LCD panel, each sized 55" with LED illumination and Full HD native resolution. The display panel is under control by Activu display control suite.
- Replacement of the existing modular meeting table by a complete-piece conference table.
- Demolishing of the triangular shape access entrance between TOC and VR, and the rebuilding of an entrance in-line with the new glass wall.
- Replacement of the drywall between TOC and VR by a glass wall that provides a better view of the TOC for senior management when the VR is used as the Transportation Service Divisional Operation Centre (TSDOC).
- Readjustment of the ceiling and lighting in VR.

Figure 7. Viewing Room Before Situation

Figure 8. The Current Viewing Room

Figure 7 and 8 illustrate the before and after scenarios.

6. Workstation Design

As a command centre, the TOC requires an instant response when the incidents occur. Therefore ease of use is important. From an operator's perspective, all operational tools and computer software shall be integrated into one complete interface, i.e., single keyboard, mouse and joystick to be equipped at each workstation, and all software interfaces can cross monitors smoothly and seamlessly. In other words, multiple keyboards, mice and joysticks, individual software running on specific monitors in this mission critical environment would not be acceptable.

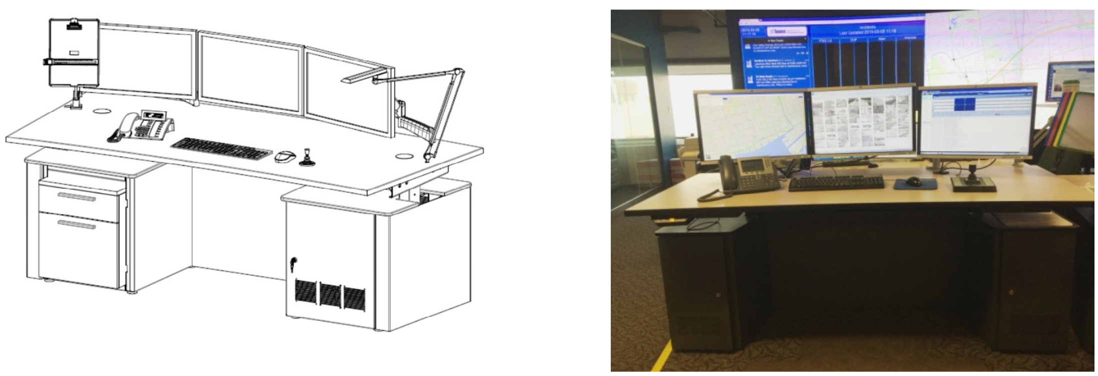

Figure 9. Typical Setup of Workstation (courtesy of Sustema Inc)

Prior to the renovation, all TMC operator workstations were on the City's Corporate IT network with typical applications, such as Windows Login, GroupWise, Microsoft Office Suite, Toronto Transportation Maintenance Systems (TMMS) and Cisco UCCE call centre management system. With all new software and new workstations being added as part of the project, we originally expected that there would be no difference in terms of one complete interface for operators. After multiple rounds of discussions with Corporate IT in this regards, a compromised solution was deployed.

However, due to data transferring capacity constraints, i.e., the high volume of data traffic (mainly video streaming) generated by two new systems, (namely Activu Video Wall Display

Management System and Genetec Video Control System), two computers were installed at each workstation, one on our Corporate IT network with regular applications and another on a private network to carry the Activu and Genetec applications. A KVM software, called Input Director was deployed to bring a seamless operation interface between these two computers. The Corporate IT firewall had specific ports opened to accommodate the instant communication via UDP and TCP protocol for this purpose.

7. Computer System Architecture

The logical architecture illustrated below (Figure 10) identifies the hardware and networking required to support the core ATMS platform. Due to security concerns, the Corporate IT LAN/WAN (right side of the green dash line) is isolated physically from the RESCU private LAN (left side of the green dash line). The connection between these two networks is through a firewall managed by Corporate IT. The proposed architecture for ATMS is based on a “Private Cloud” setup which consists of a small number of powerful and highly efficient servers. The servers use cloud virtualization software to interface with high-speed networks to securely deliver and operate the ATMS software and integrate the existing ITS devices.

7.1 Physical Platform

System Architecture is based on a high-availability resource pool where network load balanced web servers, application servers, and auxiliary functions are hosted in the “virtual cloud”. These virtualized systems commonly referred to as virtual Applications (vApps). The virtualized systems include vApps on Corporate Network in City of Toronto Data Centre environment, and gateway servers/SAN storage servers located within the RESCU private network.

Each physical node of ATMS cloud could be configured to run VMware vSphere ESXi v5.0 (or above) or Citrix XenServer Enterprise Edition 6.0 (or above) virtualization software as its Intel server virtualization platform. Private cloud is then utilized to host virtual machines with individual ATMS software components utilizing Windows and/or Linux OS as guests. Each virtual machine together with its hosted application is then designated as a virtual Application (vApp).

The vApps are to be configured in the cloud infrastructure on a separated VLAN of Corporate network using multiple virtual machines configured on a small number of high-performance servers. The existing hypervisor for Transportation Services document server (137.15.55.152) is the VMware vSphere with the high availability function that monitors the physical hosts and dynamically reassigns Virtual Machines (VM) to maintain uptime. Two or three physical servers hosting the ATMS application environment on the Corporate side can be managed by this Hypervisor. The load can therefore be shouldered by two or three machines in case of any problems.

7.2 Physical Platform Components

The physical architecture for the City of Toronto TMC consists of the following components:

Field devices: VDS, VMS, PVMS and CCTV are on the four (4) City of Toronto owned fibre optic backbones (i.e. North Ring, Allen Ring, West Ring and East Ring) that are connected directly to the existing WAN communications path within the TMC and land on the RESCU private network.

Central System: The central system is comprised of existing City of Toronto hardware and network and the proposed ATMS hardware. The ATMS includes:

- two physical servers (one primary and one failover) residing on Corporate IT LAN to run as the database for the ATMS related applications, including GIS mapping, incident declaration, planned road closure management and reporting; and

- two physical servers (one primary and one failover) residing on RESCU private LAN as a gateway and database to transmit and store information obtained from RESCU field devices, including still video images, UPS and VDS data, and VMS messages. The storage component of the system is based on SAN with RAID-6 and 10 disk drives set as well as spare hot standby disks. Microsoft SQL is the recommended data storage.

- All components shall have the redundant hot-standby power supplies, RAID-6 and 10 configured local OS storage and redundant network interfaces to stacked switches. Virtual machines are required for the production environment, staging and training environment, and related databases.

- The exiting Activu Display Wall management and Genetec Omnicast will remain on the RESCU private LAN. Activu Display Suite interacts with the main GIS interface generated on the Corporate side and bring the display map from designated desktop to the wall. Genetec Omnicast functions relatively independently from the ATMS as the firewall between Corporate IT and RESCU private network won't be able to handle the amount of video streaming traffic. For instance, a 4CIF quality video stream requires a bandwidth of 3-4 mbps, a total of 150 cameras would need at least a total of 1GB accommodation in the firewall which exceeds the exiting firewall capacity (100mbps).

This system hardware design provides the following benefits:

- The ease of accessing internet services (e.g., Google Map and Bing Map) and City's mapping repository, and various exiting applications including the City's RoDARS, Email Service, LDAP, TMMS, and RACS through the corporate IT network.

- The ease of server replication. Systems Administration staff can quickly and easily replicate a virtual server to test and demonstrate new versions with new features without risking disruption or downtime to the live instance of the ATM system during the routine maintenance and OS security upgrades.

- Backup and disaster recovery: Inherent in the basic concept through VM replication and snapshots.

- Access anywhere, anytime: ATMS cloud applications are delivered to any workstation, laptop, tablet or smartphone, and across wired and wireless networks, maintaining a consistent look and feel. Compliance and security of applications is enforced in and by the private cloud, not on the user device.

- Improved redundancy and reliability: The system has zero downtime maintenance, automatically recovers from hardware failures, and provides failover capabilities in disaster situations. End users never lose access to a mission-critical transportation application in all scenarios and at all times.

- Dynamic adaptation: ATMS Private cloud applications easily adapt to changing datacentre and computing needs by dynamically increasing capacity in response to user demand, optimizing resource placement and automating repetitive management tasks.

- Reduced capital costs: Fewer physical servers reduce overall system capital hardware costs by 20 - 25% which is passed on to City of Toronto as costs savings on the project.

- Reduced recurring costs: Fewer physical servers means lower costs for facility power and cooling. Maintenance is reduced because IT staff will have fewer physical servers to manage.

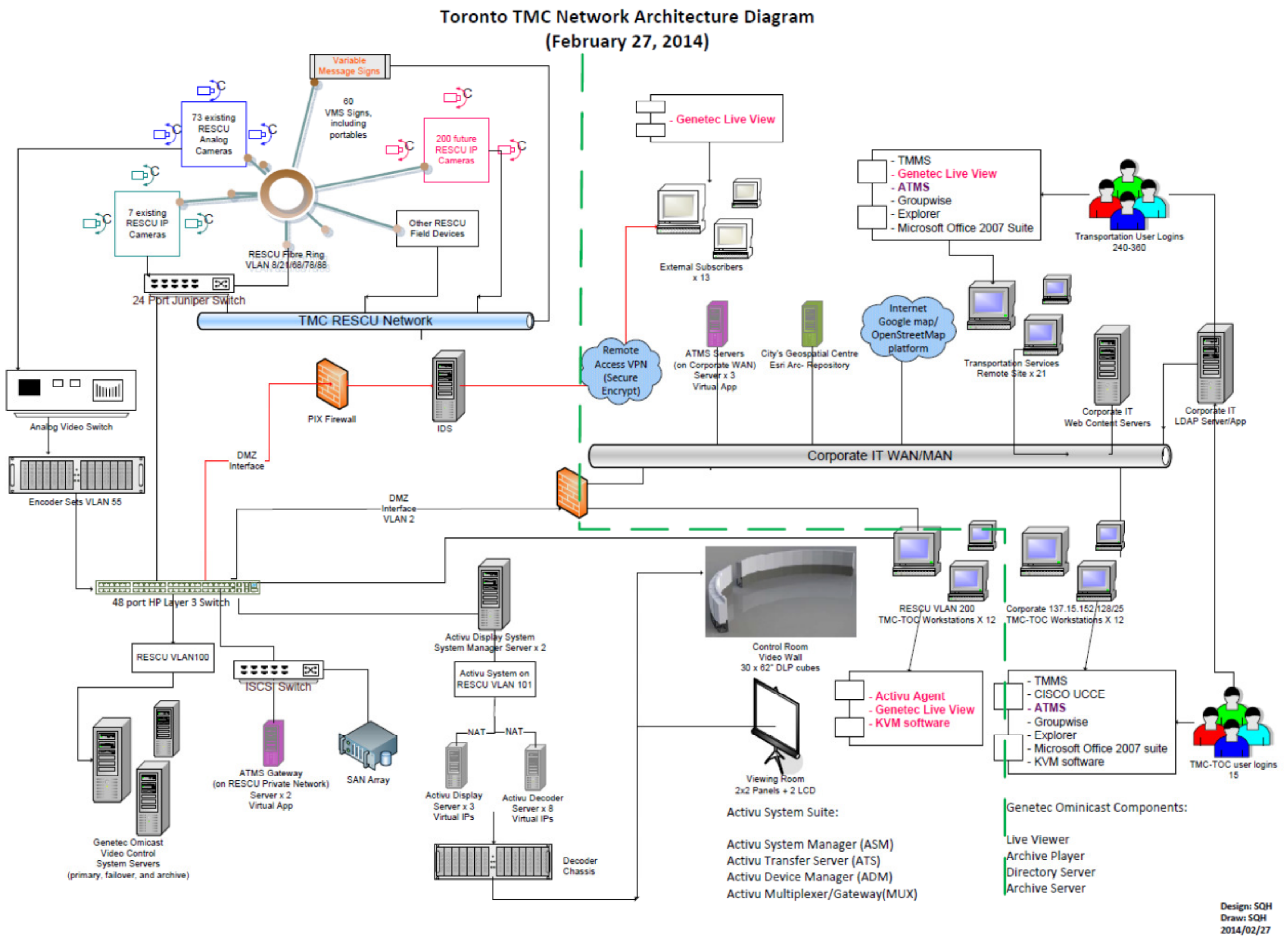

Figure 10. Toronto TMC Video Display and Control System Network Architecture

PROJECT ACCOPLISHMENTS

The TOC inner facilities, video display and control systems were to be built to operate at their full capacity with an expected design life of 15 years. The project implementation was undertaken via five months in 2014 (comprised of three construction stages) and accomplished the following:

Video Wall Project

- Video Display Systems and associated Display Controllers and Control Software along with multiple video display devices, being installed in two areas within the City's TMC. These are:

  ◊ TOC - A video display wall consisting of 30 (2×9 plus 2×6) Mitsubishi 62" DLP cubes with view size approximately 21.5m (width) by 1.5m (height) which allows TOC to display up to 156 steamed video feeds as well as multiple Windows applications, i.e., GIS maps.

  ◊ VR - A video display wall view consisting of a 2×2 Mitsubishi 55" LCD panel (LM55S1, Full HD, Direct –Lit LED Super-Narrow Bezel LCD Monitors) and two 52" SONY panels, which fits the functional needs of the VR as a Divisional Operation Centre as well as a conference room.

- Video Control Systems consisting of three servers and one network devices (HP 48 port Giga Bit, three layer) , video encoder/decoders, and software for video management and camera control for RESCU cameras monitoring the City's road network. These allow TOC and Transportation remote sites to view and control traffic cameras through the intranet.

- Performance dash board development.

Renovation Construction Project

- HVAC revitalization in control room
  - ◊ Liebert Mini-Mate2 In-door air conditioning unit, CRU-9;
  - ◊ Fan Motor horsepower:149 Kw
  - ◊ Air Volume – High Speed: 750 CFM / Low Speed:600 CFM
  - ◊ Sensible cooling – 13,000 BTHR
  - ◊ Moderate noise level: 30 dB
- Glass wall installation
  - ◊ One-way see through full glass wall between the TOC and the VR
  - ◊ Balance of aesthetics and functionalities
- Power supply revision
  - ◊ Reduced redundant power outlets previously installed
  - ◊ Reorganized power supplies for TOC equipments to bring energy efficiency
  - ◊ Reduced total power consumptions by 30%
- Control room console and meeting room conference table procurement and installation
  - ◊ 10 height-adjustable console, height ranging from 25" to 55"
  - ◊ Each equipped with three 24" monitors
  - ◊ In accordance with human factors and ergonomics
- Lighting and ceiling installation in control room

    - ◊ Energy efficient lighting provided
    - ◊ Five lighting zones
- Raised floor revision in control room
    - ◊ Balance of accessibility requirements with functional factors
- Building security revision
    - ◊ Enhanced access management policy
- New conference table in the viewing room
    - ◊ A 24 ft by 5ft boat shape conference table
    - ◊ Five top-mounted power and communication modules

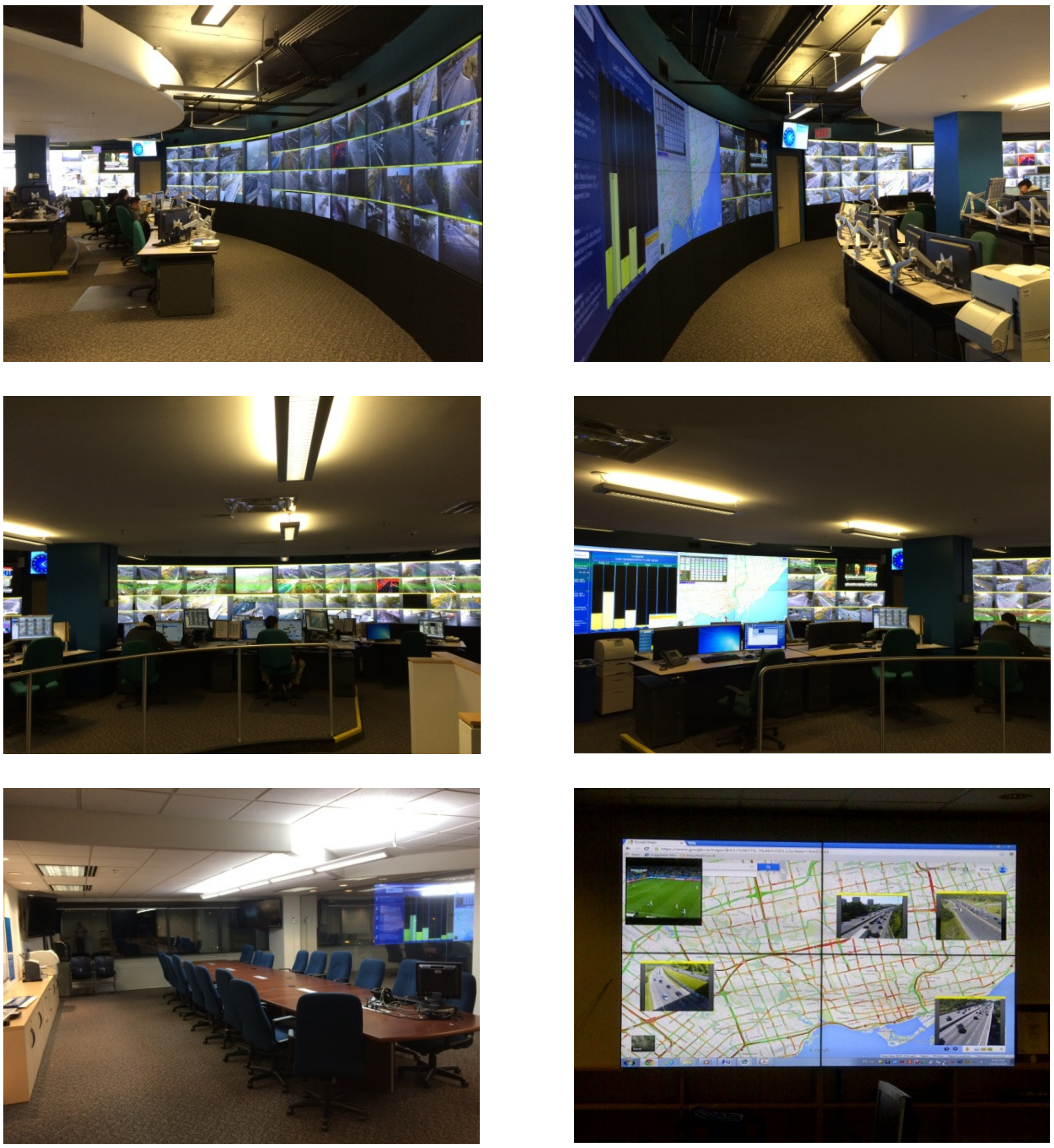

Figure 12. Toronto TMC-TOC After-Reno Photos

CONCLUSIONS

Overall, the project was successful and met the objectives. A number of project goals were achieved through the project, including:

- Display wall and interior work environment upgraded
- IP video stream established
- Facility improvements, such as lighting, power supply, HVAC, layout, consoles and conference tables were completed
- Future expansion capability

Most importantly, City staff involved and handled all critical project phase items and thus ensured that all operational, ergonomical and sustainable needs were met.

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