Systems Architecture for the Next Generation COMPASS Software

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Abstract:

COMPASS is a freeway traffic management system implemented by the Ontario Ministry of Transportation (MTO). Through prompt detection and management of freeway incidents and the provision of accurate and timely traffic information to motorists and the public at large, it improves safety, optimizes capacity and delivers a better level of service to motorists on Ontario's major highways. The first generation of the COMPASS software was deployed in 1990. It has far exceeded its designed life and had undergone numerous functional enhancements and systems expansions.

As a preliminary step towards the development of the Next Generation COMPASS Software (NGCS), the need for Systems Architecture was identified that provides the framework in implementing the NGCS. Through this exercise, we reviewed and identified functions that will continue to be supported, the lessons learned from years of operational experience, application of the latest software technologies that are end-user friendly and reduce development and maintenance costs. The Intelligent Transportation System (ITS) standards were also examined and we identified the applicable user services that will be adopted and formulated strategic plans for implementation that minimize downtime of the existing operational system.

The NGCS will be gradually developed over time as the data and technologies required become available. The functional requirements therefore have also been grouped under different deployment terms (namely, short, medium and long term) based on their readiness and user requirements.

1.0 Introduction

COMPASS is an integrated traffic management system designed to improve safety, optimize capacity and provide a better level of service to motorists on Ontario's major highways without the addition of more traffic lanes.

The primary objective of COMPASS is to manage traffic on the highway through the application of advanced and emerging technologies in transportation (e.g., computers, sensors, control, communications, and electronic devices) to save lives, time, money, energy and the environment.

The objective is achieved by:

- Allowing for the prompt detection and removal of incidents and vehicle breakdowns on the highway;
- Providing accurate and timely incident and travel delay information to motorists; and
- Effectively managing traffic flow through innovative traffic control devices.

The COMPASS hardware/software currently in operation was originally developed in 1986 and commissioned for production use in 1990. The designed life cycle of the application is 10 years. As we have already far exceeded its design life, the Ministry of Transportation is in the process of developing the Next Generation COMPASS Software (**NGCS**) to replace the current legacy systems. The NGCS will adopt the latest transportation standards and protocols and implement state-of-the-art computer hardware and software programming language.

2.0 Evolution of COMPASS

The Mississauga COMPASS System, constructed on the Queen Elizabeth Way in 1975, was the first freeway traffic management system installed in Ontario. It was designed to smooth the flow of traffic between Erin Mills Parkway and Hurontario Street, where large numbers of vehicles entering the freeway during morning rush hours created stop-and-go driving conditions. Building on the success of this initial system installation, the MTO implemented a state-of-the-art freeway traffic management, known as COMPASS, on a 16 km section of Highway 401 between Martin Grove Road and Yonge Street. Since its initial operation in early 1991, COMPASS has continued to be a valuable and successful traffic management tool, undergoing constant expansion from both a geographic and functional perspective. From its original roots as a traffic system managing a linear section of highway on QEW in 1975, COMPASS has evolved into a system managing a complex highway network, and an array of subsystems including vehicle detectors, CCTV cameras, changeable messages signs, ramp metering, travel time and queue-end warning.

The current COMPASS system covers Highway 401 in the GTA, Highway 403 and QEW in the Golden Horseshoe area, Highway 417 in the Ottawa area and Highway 402 in Sarnia.

3.0 Need for COMPASS Software Upgrade

The current COMPASS software has been in operation since 1990. It runs on a legacy hardware platform and it has already far exceeded beyond its designed life. Since its original deployment, it had undergone several enhancements to include graphical user interface, dissemination of traffic information through the MTO website, and instant incident notifications via email. In spite of all these enhancements, the core application programs are still the same, executed in Fortran computer language. We have therefore reached the point where the capability to expand and add more functionality to the existing COMPASS software is very limited.

Recognizing these limitations and the needs to continue to expand and enhance COMPASS, the Ministry is undertaking a program to develop the Next Generation COMPASS. The key functional goals of the NGCS that have been identified include:

- Streamline the daily routines of the Traffic Operations Centre (TOC) operators by eliminating some of the unnecessary manual tasks that can be executed more effectively by the system;
- Enable the operational staff to focus more on managing traffic and handling incident responses effectively;
- Enable efficient internal scheduling and coordination of planned events such as lane closures for construction works; and
- Enable better regional coordination and sharing of information among other Ministry and municipal Traffic Operation Centres to provide a coordinated area-wide traffic management network.
- Wider distribution of traffic data through Value Added Service Providers.

4.0 COMPASS Software Overview

The functional features of NGCS can be broadly summarized under the following four areas:

- Traffic monitoring;
- Traffic management;
- Information dissemination; and
- Multiple control centre operations.

4.1 Traffic Monitoring

Vehicle detectors embedded underneath the roadway or mounted along roadside structures continuously monitor traffic flow on the roadway. The raw traffic data collected is transmitted to the Traffic Operations Centre (**TOC**) where it is processed into volume, speed and occupancy data and through the application of complex algorithms, automatically detect incidents, congestions, traffic queues, determine the averaged travel time between key zones within the highway network and control the timing cycles of ramp metering signals and display messages on the changeable message signs advising motorist of traffic conditions ahead. Live video images from CCTV camera installed along the highway are also used to visually confirm the traffic conditions.

Incidents can be detected through a variety of means including:

- Passive methods where road users (e.g., MTO maintenance staff, Area Maintenance Contractors, OPP, media, other TOC's, etc.) are relied on to report incidents;
- Manual methods by the TOC operators through use of CCTV cameras; and
- Automatic methods where traffic flow characteristics measured by vehicle detectors are monitored using an Automatic Incident Detection (AID) algorithm.

Congestion levels indicative of traffic conditions within specific roadway sections are calculated for display purposes as well as for automatic determination of advisory information. Speed, volume and occupancy data are used in an algorithm to determine the various congestion levels.

Route travel time is another measure of traffic conditions that is estimated between specific origin and destination points. Estimated route travel time is based on both instantaneous and historical traffic data.

Traffic queue resulting from an incident or a scheduled event is monitored for its length (more specifically its queue end location). Continually comparing traffic data (e.g., occupancy) between consecutive detector locations along a highway can be used to determine where a queue starts and also track the queue-end position as it grows and dissipates over time.

Traffic conditions on the mainline and highway entrance ramp are jointly used to determine the optimum metering rate for a ramp. Periodically adjusting the metering rate (rate at which traffic can enter the freeway) based on current traffic flow conditions can maintain a predetermined level of service and therefore improve operational efficiency on the freeway.

4.2 Traffic Management

COMPASS responds to both unscheduled and scheduled traffic events along the highway. Unscheduled traffic events include all unplanned events occurring at random locations such as collisions, breakdowns, emergency roadwork, vehicle fire, spill, road conditions, etc. Scheduled traffic events include all the planned events that affect a continuous section of freeway, such as maintenance, construction, special events, etc.

COMPASS manages traffic under these scheduled and unscheduled events through the application of various subsystems including incident management, congestion management, queue-end warning, ramp metering, and route travel time display.

Upon confirmation of an incident by the operator through the CCTV cameras and/or by OPP or MTO staff on site, the operator in the TOC will coordinate with the appropriate emergency response agencies and other TOCs, as the situation warrants. In the case where an incident (i.e., unscheduled traffic event) is identified by the AID algorithm, it will be brought to the operator's attention through an alarm on the workstation where operator confirmation is required and coordination of activities in response to the incident can occur.

For scheduled traffic events, all planned lane or road closures related to roadway maintenance or construction activities will be coordinated and approved by an appropriate authorization unit in advance of a closure permit being issued to a contractor. All information pertaining to the approved/planned events are stored in a centralized database system and the same database system can be accessed by the TOC operators for updating other fields within the database, thereby eliminating double entry of the same information. When the TOC operator enters the actual scheduled closures (and their removals) into the system, appropriate response messages are activated to deal with the lane closures. The closure events will be recorded and displayed for real-time monitoring and historical reporting purposes and the system will provide a checklist of actions to be performed in relation to the scheduled closure.

Except incident management where an operator's acknowledgement is required, other subsystems within COMPASS software - congestion management, route travel time display, queue-end warning, and ramp metering - can run automatically without operator intervention.

4.3 Information Dissemination

As the information for any scheduled or unscheduled traffic event is entered into the system, it will be combined and prioritized with real-time traffic conditions as well as other concurrent events in order to generate the most appropriate response possible. Advanced warning or advisory information about incidents, congestion, queue-end and route travel time will generally be disseminated via Dynamic Message Signs (DMS), faxes, emails or information displayed on the web site to the motorists, general public, the media, operators in other TOCs, etc.

The Next Generation COMPASS software will make the basic processed data available. Traveller information service providers may add value to the processed data by personalizing the information through a subscription service, etc. with the general public. In addition to the traffic information displayed on the DMSs along the highway, traffic and traveller information will be available to the motorists through other means such as highway advisory radio, digital audio broadcasting, 511, 800 telephone numbers, and other subscription services such as short message system, paging, etc.

The information entered either by the operators in the TOC or the MTO's staff of the appropriate authorization unit will be organized as real-time traffic reports that will be sent automatically to other information subscribers (e.g., media, etc.) via email and/or fax for further distribution to the general public.

The Next Generation COMPASS software will provide real-time traffic conditions along the highway in a map-based GIS graphic display format on the web for the general public to access. COMPASS will also publish the real-time information on traffic reports, the road construction reports (in summer months) and winter road conditions (in winter months) on provincially maintained highways. In addition to the static CCTV camera images showing traffic conditions, selected CCTV camera live images may be provided through web-based streaming video technologies as the Internet bandwidth cost become reasonable.

All traffic information that has location reference is geo-coded to facilitate the presentation on a Geographic Information System (GIS) mapping interface.

4.4 Multiple Control Centre Operations

While each TOC will operate independently within their respective geographical jurisdictions, they will coordinate regional traffic management by sharing traffic information. Under predefined cooperation arrangements, each TOC will publish and subscribe information (e.g., traffic data, etc.) with other TOCs, agencies, emergency management centres, transit management centres, information services providers, etc. For example, under certain circumstances (e.g., during a TOC's operating periods), one TOC will be able to control the field equipment (e.g., DMS, CCTV, etc.) that is normally under the control of another TOC.

Coordination among control centres also includes sharing events that occur in the event that the incident may have an impact on another control centre's area of operation and response. This is particularly true should an incident occur near the boundary of the two adjacent jurisdictions or if the occurring event is serious enough to have a global impact.

Identical COMPASS software will be employed in each control centre within MTO's jurisdiction. Only the size and type of system configuration, and the enabling or disabling of specific functions will differ for different control centres.

5.0 Systems Architecture Framework - ITS Architecture for Canada

Figure I illustrates the principal structural elements of the various subsystems of the Physical Architecture within the ITS Architecture for Canada. The 23 subsystems in the ITS Architecture for Canada are grouped into four classes; namely, Centres, Wayside, Vehicles, and Travellers. Example subsystems are the Traffic Management Subsystem, the Vehicle Subsystem, and the Roadway Subsystem. These subsystems correspond to existing entities in the physical world respectively, traffic operations centres, automobiles, and roadside signal controllers.

The Physical and Logical Architecture published in the ITS Architecture for Canada website describe the architecture flows and data flows, respectively, among the 23 subsystems. The frameworks in developing the Systems Architecture of NGCS can be mapped to the subset "Traffic Management Subsystem" (TMS) within the class "Centres". The ITS Architecture for Canada does not describe the internal data flows within the subsystem itself. However it can serve, as a valuable reference resource for systems developers in identifying the software data/objects required from/to other external subsystem elements.

The development of NGCS is primarily focused at the internal data flows, software objects/components, distributed functions and database elements within Traffic Management subsystem. This is not necessarily a daunting task as we already have over 15 years of operational experience to leverage from. In fact, most of the traffic management functions and algorithms are simply a "porting" exercise from the current operational system to the new one. Since the field infrastructure is essentially untouched, the communications protocol is also the same. A more challenging feat is how to design the internal workings of the NGCS architecture so that the transition from the current operational system to the new is less painful, considering the current system operates 7x24 and it will be difficult to find a window to test the new systems without operational impacts.

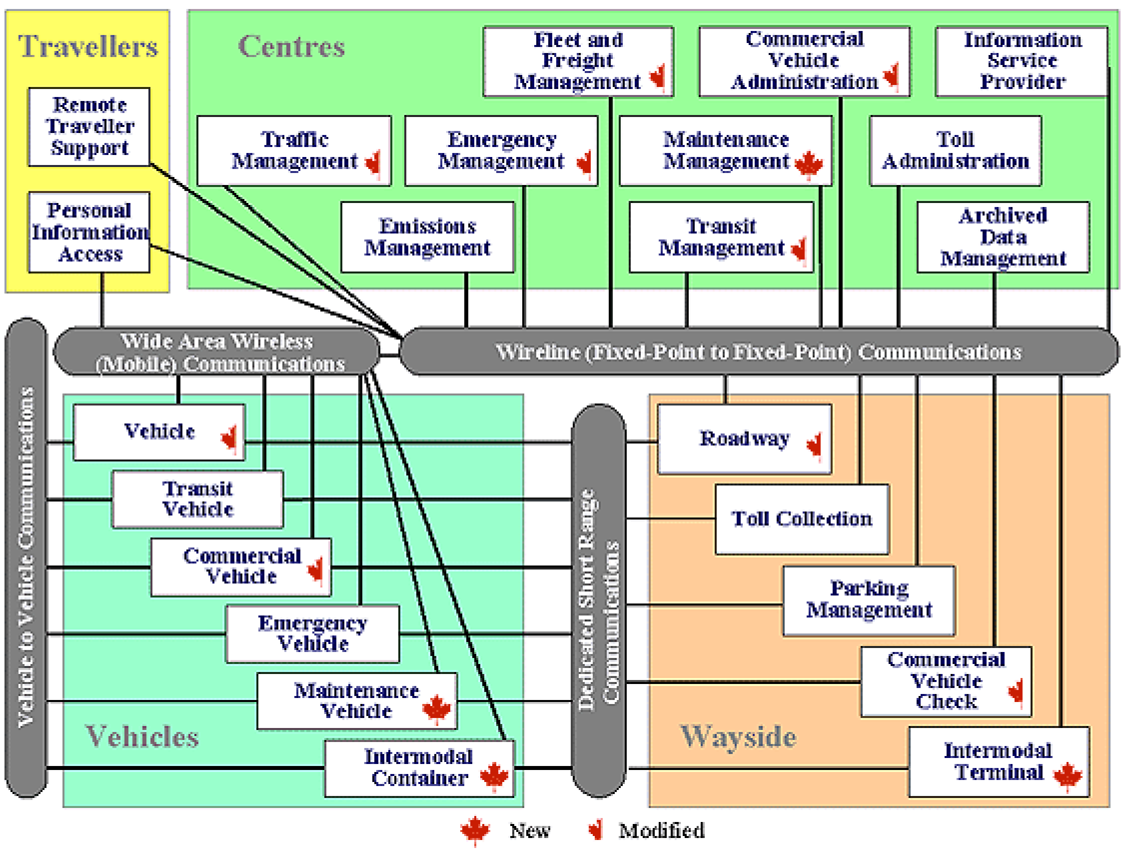

Figure I: Physical ITS Architecture for Canada (http://www.its-sti.gc.ca/)

6.0 Make-up of the Distributed Functions of NGCS

Distributed functions are groups of software components that perform related software functions. The software components within each distributed function communicate among themselves as well as communicate with software components of other distributed functions in a system to collectively achieve an overall specific traffic application. These distributed functions are also capable of being executed from any where within a distributed computer network in order to gain maximum deployment flexibility. Besides reducing the interactions among software components, the distributed functions concept also allows software packages to be conveniently developed by different software developers with specific expertise. Within the COMPASS software architecture, these distributed functions can be categorized into the following:

- Traffic Manager (**TM**)
- Web Based GUI
- Infrastructure Maintenance Management
- Database Manager (**DM**)
- Dynamic Message Signs (**DMS**) Message Writer
- Centre-to-Centre (**C2C**)
- Traffic Road Information Writer (**TRIW**)
- Dynamic Message Signs (**DMS**) Device Manager
- Vehicle Detection Stations (**VDS**) Device Manager

As a result, distributed functions are able to reap the benefits of many physical and general requirements that affect system operation and performance. For example, physical requirements like redundancy and availability are more attainable for a system when distributed functions can reside anywhere within the network. General requirements like scalability and security are much easier to be satisfied when these distributed functions are loosely coupled in a network environment versus tightly coupled within a single computer node.

The logical architecture of NGCS identifies data flows for each of the distributed function. No ITS external subsystem shall be permitted to directly communicate with any NGCS distributed function. An ITS External Subsystem Server will be developed in the future to handle the requests and responses among the ITS external subsystems and NGCS. As the focus of this project is to de-commission the current legacy computer systems, the detailed functionality of the ITS External Subsystem Server will be dealt with as Phase 2 implementation.

6.1 Traffic Manager

The Traffic Manager communicates with the VDS Device Manager to gather and process the raw traffic data on a periodic basis. This function is primarily responsible for performing the various algorithms and models to detect the presence (or clearance) of potential incidents on the roadway, the start/end of recurring congestions (e.g. stop and go traffic not necessarily caused by incidents/collisions) and averaged (or predicted) travel times between strategic milestones within the highway network. Based on the latest acquired traffic data and coupled with historical traffic patterns, the highway network is evaluated as a whole to determine the best ramp metering rates to maximize throughput.

By separating the functions for determining the traffic flow conditions from the acquisition of the raw traffic sensor data, future enhancements can be achieved more effectively that minimizes the number of source code dependencies from other parts of the system.

For the initial rollout of the NGCS, the algorithms used for detecting incidents will be based on the two algorithms that are well known to date: the All Purpose Incident Detection (APID) and the McMaster incident detection algorithm. As these algorithms are already employed in the current COMPASS software, this function is merely a rewrite of the current Fortran language to Java.

The TM function also analyzes all the traffic data and subdivides them into congestions zones. Each congestion zones will be classified into three levels, e.g. moving well, moving slowly and moving very slowly.

TM also calculates travel times between milestone points of the highway network periodically. As there are multiple routes (e.g. collector/express system in Hwy 401) between milestone points, TM will calculate the minimum, average and maximum travel times between two milestone points.

All traffic data and field controller status that are managed by the Traffic Manager function are stored in a centralized database management system and periodically updated. In addition, Traffic Manager also publishes all its real-time traffic information through a Java Messaging Service (JMS) so that any client or consumer of the data can easily subscribe to it. This architecture provides for the foundation of easily expanding the functional features of NGCS As future logic and programs are added to the NGCS that requires TM's data, it can easily subscribe to such data without modifying the source codes of TM.

6.2 Database Manager

The Database Manager function acts as the central repository for all equipment configurations (including thresholds and parameters), all long term (historical) data, as well as real-time state/status and device control information (e.g. current queue status, scheduled events, DMS message, RMS metering rate, etc.). In particular, the DM maintains all pertinent and persistent data provided by other distributed functions of NGCS.

Although DM is a major component in the NGCS architecture not much software development is required as the intention is to purchase a commercial database management system. The vendor supplies the development and management tools used for administering the database. This includes specifying the access levels of the different types of users, centralized repository of all NGCS stored procedures, generating reports and data backup. The database management system specified for the NGCS is configured in a redundant cluster environment to balance the transactions and to maximize the availability of the system.

6.3 WEB Based GUI

The WEB Based UI provides the interface through which the traffic operations personnel can obtain access to the current traffic data and information as well as provide a response to control or manage situations. This includes a GIS map based interface that shows locations of incidents, scheduled roadwork, congestions, ramp metering rates, travel time calculations between designated routes, start and end of queues, messages currently displaying on the Dynamic Message Signs (DMS), streaming video of highway cameras, U.S. border delay information, lift bridge status and more.

The WEB based UI also provides the interface for operators to select and control the cameras along the highway, e.g. panning, tilting, zooming, video recording/retrieval, defining camera tour cycles, etc...

The WEB Based UI is implemented in a multi-tier computing model following the Java Enterprise Edition Version 2 (**J2EE**) framework. In such a framework, the main components are: presentation tier, business tier and database tier. The presentation tier is the client's browser program. The business tier resides at the server side and contains all the business/application logic. The database tier also resides at the server side and serves as the persistent repository of all data used by the application.

6.4 VDS Device Manager

The VDS Device Manager is essentially the data acquisition module of the NGCS that is responsible for communicating with the field controllers. Raw vehicle sensor data from multiple types of devices are aggregated to form the equivalent traffic data, e.g. volume, speed and occupancy. It also periodically communicates with the field elements to report on the state of the device and log faults.

By separating this function from other NGCS function (e.g. Traffic Manager), future vehicle detection technologies and protocols can be adopted for the NGCS without impacting other parts of the system.

6.5 DMS Message Writer

The DMS Message Writer function is responsible for determining the most appropriate message to be displayed on each DMS within the COMPASS Subsystem, based on the current traffic conditions (e.g. incidents, congestions, travel time, border delays) and other competing events like manual signage “Amber” alerts and scheduled road construction events. All of these conditions are collectively analyzed and event priority/importance are selected based on predefined set of rules. In addition, these display rules shall also consider the display capability and operating conditions of each DMS for the composition of all the messages at each decision point.

Congestion, travel time, end-of-queue and scheduled messages are automatically generated without user confirmation. Incidents (e.g. collisions, lane blocking roadwork and border delays) will require operator confirmation. Traffic balancing between the express and collector lanes (e.g. Hwy 401) can be achieved by displaying the traffic conditions beyond the next transfer, giving the motorist the opportunity to make decision whether to stay on the same course or transfer to either the collector or express lanes.

In the old system, messages (although automatically composed by the system) were limited to addressing one event at a time and other messages generated by the system as a result of occurrence of an event was held in a priority queue. The NGCS Message Writer has been modelled to take into account all the ongoing events and through the formulation of some knowledge-based message composition rules, multiple event messages are a combined to form a single message provided that it did not exceed the sign's capability as well as preserve driver comprehension.

6.6 DMS Device Manager

The DMS Device Manager communicates with the Roadway Subsystem to display DMS messages. It is also responsible for collecting DMS status, identifying faults, and logging faults. All transactions and device faults are being logged through the Database Manager. By de-coupling the DMS Device Manger from the DMS Message Writer, the burden of knowing all the intricacies and communications protocol for communicating to the field DMS has been delegated to the DMS Device Manager. This way the DMS Message Writer can concentrate its logic purely on composing and formatting the message. This separation allows for future enhancement to be easily and cleanly achieved. As future communications protocol is introduced (e.g. NTCIP Version 2), modifications to the DMS Device Manager can be done without touching the writer component. The analogy would be that a word processing program only deals with composing the document and the device driver provided by the printer manufacturer performs the actual logic of printing the document correctly for different models of printer.

6.7 Infrastructure Maintenance Management

This distributed function provides the interface for the exchange of data with the Construction and Maintenance terminator. The interface is used to both send data containing details of equipment faults, and to receive repair status of equipment when the faults are cleared. Sensor fault clearance received from the Construction Maintenance (terminator) will cause the removal of the sensor from the confirmed to the un-confirmed fault list in the Database Manager. The traffic operations personnel, upon receiving sensor fault information via distribution by the Database Manager subsystem, either confirms or "un-confirms" the sensor fault conditions before the Database Manager again sends it off to the Infrastructure Maintenance Management for distribution to the ITS Maintenance Management Subsystem. The sensor fault may sometimes be caused by construction work. In this case, the traffic operations should un-confirm the sensor fault event.

This function would be responsible for maintaining the records of the performance of the various field assets and physical infrastructure so that future statistical analysis can be conducted and plans made for the replacement of equipment as they reach the end of their useful life.

6.8 Centre-To-Centre (C2C)

The Centre-To-Centre distributed function manages the exchange of data between Traffic Operation Centres (TOC) both at regional and municipal level. The exchange of data is triggered by either a request from a remote TOC for data from the local TOC or because data needs to be sent from the local TOC to a remote TOC.

The type of data being exchanged between TOC's include: incidents, scheduled roadwork, congestion, ramp metering, travel time, DMS display, camera image links, lift bridge state, border delay, traffic data, traffic signal information, etc. Data received from the other regional TOC may affect the management and control of devices of the receiving TOC, including signing for major incidents occurring at the other centre's geographic location and or adjusting the timing cycle of traffic signals. This is typically the case in areas adjacent to each other's region and/or at the boundary locations where the decision points are shared by both centres.

Other Centres and Value Added Service Providers may subscribe to any traffic information managed and maintained by the individual TOCs.

6.9 Traffic and Roadwork Information Writer (TRIW)

The TRIW retrieves events and data from the Database Manager and provides current incident and planned event information as well as congestion information to MTO's public facing web servers, third party information service providers and email subscribers. As the target audience may vary in terms of its delivery medium and display capability of the receiving device, TRIW customizes the format of the information composition in accordance with the capability of the receiving end. For example, when sending traffic information to the web server, the formatting will be in Hypertext Mark-up Language (HTML). Since the display device has more real estate (higher screen resolution) to play with, the message will be composed with proper grammar and supplemented with graphics (e.g. logos).

For PDA subscribers, the same information will be composed in a more cryptic form (short form sentences without grammar) to accommodate a limited screen size. For RSS feeds, the information will be sent following the industry standard format of Extensible Mark-up Language (XML).

As the computer that hosts the TRIW program is exposed to the Internet, extra care is given to the architecture design so as appropriate firewalls are in place to isolate other NGCS components from the Internet. The information flow from TRIW to the Internet would be one-way and all incoming service request ports will be generally blocked.

7.0 Computer Systems Architecture of NGCS

As the NGCS is comprised of a number of distributed functions, the computer systems architecture was designed to enable the development of each of the functions independently. As several consultants were engaged to develop the individual functions, it is important to isolate each other's work environment until the time of systems integration. Each distributed function was therefore allocated its own computer.

To minimize the footprint of our computer hardware requirements, we employed CPU Blade Servers and Storage Array Network (SAN) architecture. The CPU Blade Servers are contained in a single chassis powered by four redundant power supplies. Similarly, the disk drive requirement for each CPU are contained in one chassis and assembled in an array formation. The SAN management software allows us to divide the pool of disk drives to individual CPU blade servers and allocate just the right amount of disk space based on application requirements. Blade servers and SAN technologies are available from the major computer manufacturer such as IBM, HP and Dell.

This architecture allows us to expand very easily by simply adding more blades or disk drives, whichever the case may be. The CPU blade servers come with its own dual Ethernet interface and are interconnected to each other through a high speed core switch. The core switch is a Layer 3 switch and can be programmed to create Virtual Local Array Network (VLAN). From the same Ethernet pipeline, multiple sub-networks can be created and applications that are exposed to external entities can be protected using a firewall. The Layer 3 switch can be programmed to serve as a gateway or firewall or both.

8.0 Conclusion

As COMPASS is a system that operates 7x24, transitioning its legacy systems to the next generation software imposes a very challenging task as it is difficult to find a window of opportunity to shutdown the existing application in order to test and integrate the new applications. This requires a careful transition planning and breaking up of subsystem functions into modules that can be independently tested in parallel with an ongoing operational system.

The first phase of the transition plan was initiated five years ago by replacing all the 500+ field controllers (in stages) with a more powerful processor capable of supporting concurrently, multiple communications protocol and interfaces (e.g. Ethernet and RS232). The field controller software was re-written from its original machine code language to a friendlier C programming language, while maintaining the same algorithmic logic. Central computer software (e.g. incident detection, congestion and queue monitoring, travel time, ramp metering) that require the field data are currently being tested and integrated in stages.

By adopting the Systems Engineering V model for software development, test plans and specifications have been developed even before the first line of code is written. This allowed us to determine the resources (technical, equipment and dollar funding) required in advance of the scheduled testing activities. Once all the background processes are verified to work continuously, we will begin integrating the functions that require operator interactions. Total systems integration and production rollout is targeted for completion by the end of March, 2009.

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