CITY OF LANCASTER
TRANSPORTATION COMMUNICATIONS MASTER PLAN
2017 UPDATE

Technical Report

Prepared for:

The City of Lancaster

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TECHNICAL MEMORANDUM

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11-15-17	**Version 1.0 – For Distribution**	**JC**	**JG/ME**

List of Acronyms

ATSC	Advanced Television Standards Committee
ATM	Asynchronous Transfer Mode
ATMS	Advanced Traffic Management System
AWG	American Wire Gauge
CCTV	Closed Circuit Television
CMS	Changeable Message Sign
DCRR	Dual Counter Redundant Ring
DMT	Discrete Multi-tone
DS	Digital Signal
DSL	Digital Subscriber Line
DVD	Digital Video Disc
EOC	Emergency Operations Center
FDM	Frequency Division Multiplexing
FSK	Frequency Shift Key
Gbps	Gigabits per second
IEEE	Institute of Electrical and Electronics Engineers
IT	Information Technology
ITS	Intelligent Transportation System
Kbps	Kilobits per second
LAN	Local Area Network
MAC	Media Access Control
Mbps	Megabits per second
MMFO	Multi-Mode Fiber Optic
MPEG	Moving Pictures Expert Group
NTCIP	National Transportation Communications for ITS Protocol
NTSC	National Television Standards Committee
OC	Optical Carrier
OSI	Open Systems Interconnection
PTZ	Pan-Tilt-Zoom
QAM	Quadrature Amplitude Modulation
SMFO	Single-Mode Fiber Optic
SONET	Synchronous Optical Networking
TMC	Transportation Management Center
VoIP	Voice over Internet Protocol
WAN	Wide Area Network

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NOTE: *The 2017 Transportation Communications Master Plan Technical Report revises and updates the 2008 Transportation Communications Master Plan by addressing current technologies and incorporating system improvements planned by the City as part of recently approved grant applications.*

1. BACKGROUND

The City of Lancaster is in northern Los Angeles County adjacent to the City of Palmdale and the County of Los Angeles in the heart of Antelope Valley. Interstate 14 (I-14) freeway traverses north-south through the center of the city and provides a junction to Route 138 that travels east-west through-out the Mojave Desert. Other major routes/roadways include Sierra Highway and 10th Street West that traverse north-south through the City. Traffic signals located along I-14 on/off-ramps are owned, operated, and maintained by Caltrans. Select traffic signals along the City border are owned, operated, and co-maintained by City of Palmdale or the County of Los Angeles. All other traffic signals are owned, operated, and maintained by the City of Lancaster.

The City of Lancaster operates over 140+ traffic signals citywide by means of a communications network consisting of a hybrid system of fiber optic cables, copper signal interconnect cables and wireless Ethernet radio.

In general, the existing traffic signal system within the City of Lancaster consists of the following:

- 140 traffic local signals with no on-street master controllers
- Local communications occur mainly over twisted-pair/copper signal interconnect cable (SIC) to designated communications HUBs.
- Six (6) designated communications HUBs transmit local copper SIC data to central by use of fiber optic cable backbone in a ‘Ring’ topology. The fiber optic transmission type is analog.
- 5GHz unlicensed wireless broadband radio is used at select locations where no underground conduit exists.
- At City Hall, an existing server rack houses the traffic server equipment that hosts all legacy Traffic Management Systems and analog CCTV video systems.
- At the Maintenance Yard, a fiber optic link between both the City Hall and Maintenance Yard buildings provides traffic signal maintenance staff monitor the traffic signal system via remote client access.

In 2008, a Transportation Communications Master Plan was developed for the City of Lancaster recommending upgrades to the City’s traffic signal communications network. As part of the Master Plan process, a stakeholders meeting with various city departments was organized to identify needs and potential shared uses of the City's traffic signal communications network. At the time, the City's Information Technology (IT) Department completed an IT Strategic Plan recommending upgrades and improvements to provide higher bandwidth to support additional functions such as imaging, Geographic Information Systems (GIS), and web-based applications. The IT Strategic Plan also identified communications support to 14 remote sites using leased Digital Subscriber Line (DSL) connections, and recommended that the City upgrade the municipal fiber optic system and retained a consultant to evaluate fiber commonality.

In 2010, the City of Lancaster, in partnership with the City of Palmdale, received grant funds for the **North County Traffic Forum ITS Expansion Project**. The grant funds were programmed over six Fiscal Years (2010-2016). The scope of the project within the City of Lancaster includes: the upgrade of the City's Central Traffic Control Management Software to allow for Adaptive Traffic Control System deployment on applicable corridors; connection to the Los Angeles County Information Exchange Network (IEN); modification of traffic signal timing to accommodate Adaptive Traffic Control System deployment; installation of new traffic signal controllers; upgrade and installation of new communications equipment to connect traffic signals to the fiber optics ring/backbone and central system.

In 2015, the City was awarded grant funds for the **Traffic Signal System Modernization Project**. The grant funds were programmed over two Fiscal Years (2015-2017). The scope of this project was to modernize the City's aging traffic signal communications system infrastructure to a more reliable, redundant, and faster system based on current ITS architecture. The project will replace approximately 28 miles of copper cable with fiber optic cable in existing conduit, install Ethernet switches, upgrade fiber backbone equipment, install video transmission equipment, and install wireless communications to remote traffic signals. Both the **North County Traffic Forum ITS Expansion Project** and **Traffic Signal System Modernization Project** are currently under design and will be used as a reference in this Master Plan design report.

Overall, the Transportation Communications Master Plan goals and objectives are built around previous investments made by the City of Lancaster and partnering agencies, regional ITS architecture and by maintaining consensus to expedite delivery of the project's initiatives. The vision of this project is not only to assist the City of Lancaster in the development, management, and implementation of current ITS initiatives, but also objectives that will improve multimodal mobility, maximize highway and arterial system capacity, improve operational efficiency, safety and the environment throughout the Antelope Valley. The master plan will also be used as a planning tool to prepare the City and adjoining agencies for future emerging transportation technologies including Connected Vehicles (CV), Autonomous Vehicles (AV), big data, integrated corridor management (ICM), and Smart Cities initiatives. This provides a flexible platform that will enhance the sharing of real-time information between agencies and the public using existing and next generation ITS technologies that will take the City and partner agencies well into the 21st century.

2. EXISTING TRAFFIC SIGNAL SYSTEM

2.1 Signal System

The City of Lancaster currently has 140 signalized intersections operated by Type 170 traffic signal controllers using BiTran 200SA or 233RV2 local firmware programs. The City manages the traffic signals using McCain's "QuicNet Pro" Traffic Management System (TMS).

The existing Traffic Signal Central System server (QuicNet Pro) is centrally located at City Hall and connects to each traffic signal controller through a mix of copper and analog fiber optic interconnect system. The server communications interface that connects to each intersection is located in the Maintenance Yard building. A separate IT Department fiber connection allows these two devices to communicate.

An existing dedicated communication network covers a large portion of the city. No leased lines are currently being used for communications. Serial RS232 is currently used between field devices and modems. Existing modems use Frequency Shift Keyed (FSK) modulation to transfer data over the copper cables. Data is then transferred using serial RS232 from hub modems to a fiber optic card which converts the analog signal into an optical signal for use in the fiber optic network.

The QuicNet server uses a communications interface card (Digi Port) which creates up to sixteen (16) multiple addressable serial communication ports. Nine (9) ports are currently in use, each having from 14 to 22 signal controllers on each of the 9 telemetry circuits. Data is transceived on each circuit over single mode fiber optic cable to fiber hubs located at strategic points and then converted to RS232 over copper twisted wire pairs.

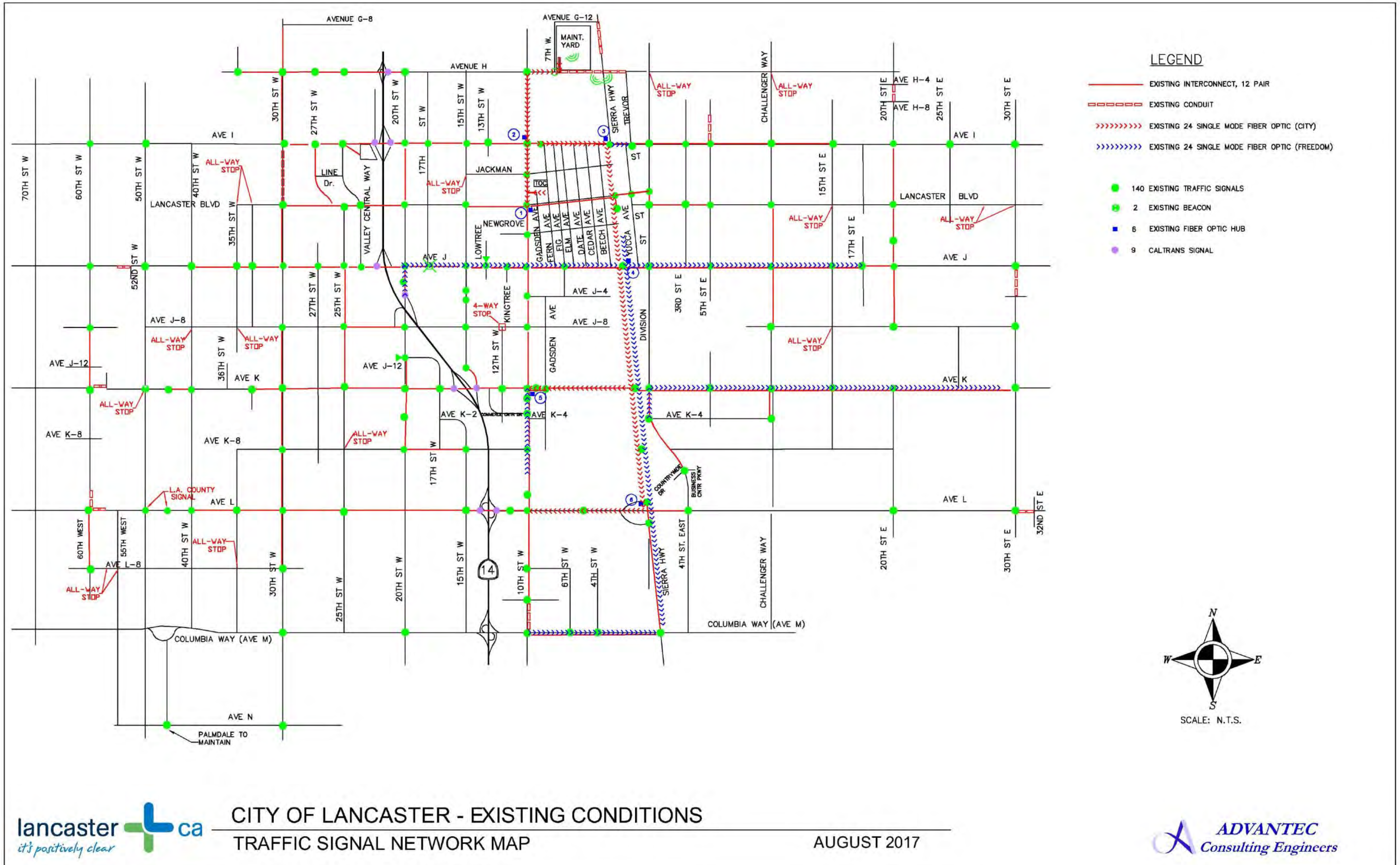
Overall, the existing TMS system and legacy analog fiber optic/copper communications system has been in place for many years and are no longer the industry standard protocol for ITS communications. Generally, these systems are independently owned, operated and maintained by the City, without communications or connectivity to share information to an adjacent agency or across jurisdictional boundaries. Aside from the institutional factors, there are physical and technological limitations and capabilities of the existing TMS that need to be understood including:

- Legacy type TMS and communication systems are considered outdated and have limited to no capabilities to communicate with other systems
- Proprietary TMS and traffic signal controller protocol
- Physical or wireless connections
- Geographic location where each central system is housed

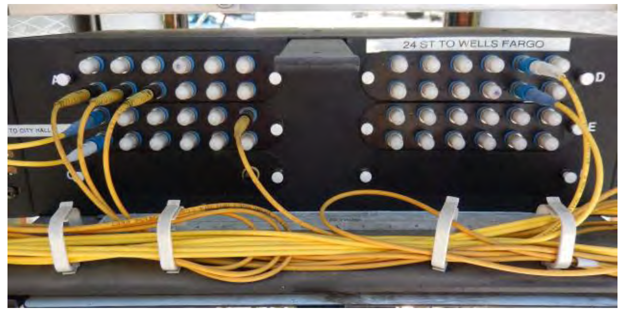
As part of the **ITS Expansion** and **Traffic Signal Modernization** projects, it is recommended that all local traffic signal controllers upgrade to the latest ATC specification and the legacy TMS central system be upgraded to an Advanced TMS system. New Advanced Traffic Management Systems (ATMS) provide the functionality of full Ethernet/IP-based communication, integration of ATC controllers and upgraded capabilities such as high-resolution data and peer-to-peer communication. Additionally, they also support expanded functions such as Adaptive Traffic Signal Control (ATCS), CCTV view and control, and 3rd party integration of isolated sub-systems like Arterial Management Systems, Changeable Message Signs (CMS) software and advanced traffic signal performance measures (ATSPM). Legacy Traffic Management Systems (TMS) do not have this capability. Therefore, the City should consider upgrading concurrently with other late model ITS technologies to provide the total visibility and control of these systems.

Figure 2.1 illustrate the existing traffic signal and communication network.

Figure 4.1. - Existing Traffic Signal System



2.2 Fiber Optic Backbone System

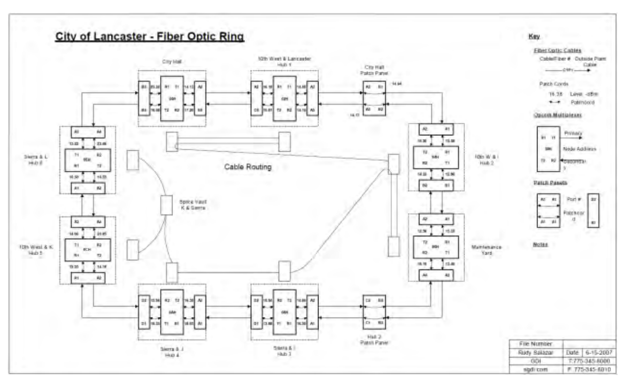


The existing fiber optic backbone system consists of approximately 5 miles of 24-strand single mode fiber optic (SMFO) cables that are connected to six (6) dedicated communication HUB cabinets, the Maintenance Yard and City Hall. This system is the back-haul for all existing traffic signal communications. The 24-strand fiber trunk line cables are brought up and terminated to Fiber Distribution Units (FDU) inside Type 334 cabinets. The six communication HUB locations are as follows:

- **HUB #1** - 10th Street West and Lancaster Boulevard
- **HUB #2** - 10th Street West and Avenue I
- **HUB #3** - Sierra Highway and Avenue I
- **HUB #4** - Sierra Highway and Avenue J
- **HUB #5** - 10th Street West and Avenue K
- **HUB #6** - Sierra Highway and Avenue L

The communication HUBs currently house legacy analog fiber optic equipment, copper FSK modem card chassis, analog copper video distribution equipment and UPS power equipment. Local traffic controllers utilize copper interconnect cable in a drop and repeat fashion that terminate in each hub for backhaul transmission to City Hall/ Maintenance Yard.

HUB's are typically installed at a centralized location in the field as a collection point for the ITS elements on a private local area network, and for creating redundant sites for Ethernet communication back to central. The existing 24-strand SMFO cables used to interconnect the six HUBs date back to the year 1998, therefore they are approaching close to 20 years in age. Sunlight, heat and exposure to the elements all influence the existing fiber optic cable condition, as it tends to turn brittle with age. However, depending on the age, condition and weathering of the backbone fiber cables, the cables may be re-used for future installations as other existing fiber optic systems have been in use for 30 years or more.



In general, the legacy analog fiber optic/copper communications system has been in place for many years and are no longer the industry standard protocol for ITS communications. Ethernet IP protocol is the industry standard for all new traffic signal deployments. ATC specification traffic controllers, ATMS software and other ITS elements all rely on Ethernet IP communication for integration of the system. Based on our inventory and evaluation of the City's existing and future traffic signal system, ITS elements, communication system, and the TMC; there are existing equipment that do and do not have the ability to be upgraded to provide Ethernet/IP communications.

The proposed design in both **ITS Expansion** and **Traffic Signal Modernization** projects will seek to re-utilize the existing 6 HUB locations, as the dedicated HUBs are a beneficial means to collect and group local communications and provide redundancy in a Wide-Area Network (WAN) design. The upgrade of the communication field devices to communicate with a centralized traffic management center will depend on reliable Ethernet/IP-based communications over a fiber optic/wireless topology. The components of the system that will require integration include the following at a minimum:

- Fiber Optic Cable allocations:
  - Backbone trunk lines – 24 strands
  - Secondary trunk lines - 72 strands
  - Drop cable lines - 12 strands
- An Ethernet Access Switch (EAS) installed at each traffic signal cabinet to forward information from various devices including the traffic signal controller
- A fiber patch panel at each traffic signal cabinet to connect the Ethernet switch to the fiber optic drop cable
- A splice enclosure that connects the fiber optic drop cable to the fiber distribution cable
- The fiber distribution unit (FDU) at the central field communication HUB/or other primary location that connects the fiber distribution cable to the central TMC location over a Gigabit Core Ethernet switch
- A Layer 3 Ethernet switch installed at the central field communication HUB/TMC location that forward information from various devices including traffic controllers and central traffic management software

2.3 Citywide Fiber Optic System (Dark)

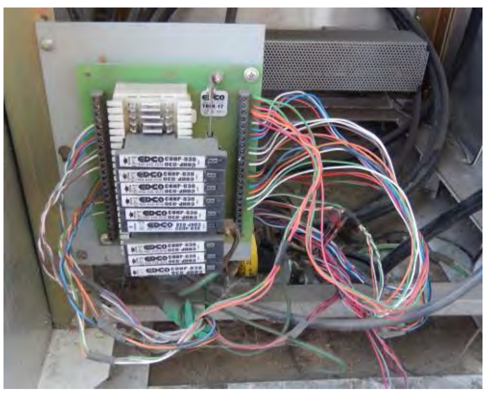
In addition to the traffic signal fiber optic backbone system, in 2014 the City entered into an agreement to lease a portion of its underground conduit system to Freedom Telecommunications, Inc. for installing additional fiber optic cables in existing underground conduit/new 2" HDPE conduit. As part of this improvement project, over 16 miles of new fiber optic cables were installed along major City routes for both private/public use. Primarily, the Freedom fiber communications system consists of the following:

- 7 miles - 96 strand fiber optic cable (Privately owned/operated – Freedom Inc.)

- 9 miles - 48 strand fiber optic cable (Privately owned/operated - Freedom Inc.)
- 11 miles - 24 strand fiber optic cable (Publicly owned/dark - City of Lancaster)

As such, the City has an opportunity to leverage the existing 24 strand fiber optic cable (dark) along major roadways throughout the City. This allows the City the opportunity to utilize 11 miles of underground fiber optic cable for use in the proposed Ethernet IP traffic signal network. The fiber optic cable installed by Freedom Inc. has been identified as ITU compliant single-mode fiber optic cable, therefore it should be both forwards/ backwards compatible with existing legacy backbone cable and proposed 72 strand SMFO cable.

2.4 Copper Distribution System



The existing copper distribution system consists of approximately 35 miles of 19 AWG copper signal interconnect cable. Typically, a string of interconnected signals operates in full duplex (4 wire) mode via two twisted copper pairs, one pair for transmit and one pair for receive, allows the communication system to be asynchronous. The controller cabinets are interconnected with the communication hubs in a daisy chain, or drop-and-repeat fashion. Each Type 170 Controller has an internal 1200 baud FSK Model 400 modem. These modems convert electronic signals in the controller and communicate data between the fiber optic hubs. The optical signals are then converted to serial electronic signals prior to the Digi Ports for the QuicNET Pro Traffic Management System.

The legacy copper FSK communications will be removed and replaced with a full fiber optic communications system. It is proposed during the **ITS Expansion** and **Traffic Signal Modernization** improvement projects that most of the local SIC cable along the major east-west corridors will be removed and replaced with new 72 strand SMFO cable. Other areas where existing fiber optic cable will be utilized to provide a singular citywide fiber optic network.

2.5 Video Detection System

There are approximately 70+ signalized intersections equipped with existing video detection equipment. Most the City's video detection hardware is manufactured by Traficon, with cameras manufactured by Traficon (color video display) and FLIR (infrared video display). Iteris video detection is also found in a small number of locations. Existing hardware installed at selected cabinet locations allows analog video from the video detection cameras to be

transmitted to City Hall using copper interconnect pairs and fiber optic cable. A single copper twisted pair is used to connect a string of video detection camera sites to each communication hub. The hub contains video transceivers that interface the dedicated video fibers to the copper wires from the field. A video matrix switcher resides at City Hall to enable viewing of various analog video feeds.

It has been determined during the field investigation that the existing analog video matrix system at City Hall and video transmission back-haul system is currently offline and not in use. However, the video detection systems continue to operate normally at the local intersection level via local display monitors.

For maintenance purposes, traffic signal technician staff currently use DVR equipment connected at traffic signal locations for video recording. The DVR equipment is then transferred back to the Maintenance Yard signal shop to view/monitor for any known issues. As part of the **ITS Expansion** and **Traffic Signal Modernization** improvement projects, over 50 locations will have upgrades to transmit the video detection camera feeds back to the City Hall TMC / Maintenance Yard TOC for remote surveillance and control. To achieve this goal, existing analog coaxial video signals would need to be digitally encoded for transfer over the new Ethernet IP network. A new Video Detection Management software will be deployed to collectively manage the video detection database vis web GUI.

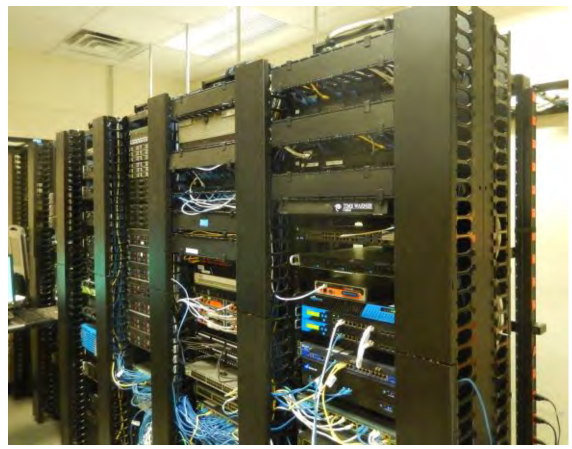
2.6 Closed Circuit Television (CCTV) System

The City currently does not have CCTV camera systems.

New HD IP CCTV cameras are recommended in the **ITS Expansion** and **Traffic Signal Modernization** improvement projects for remote viewing and monitoring of local intersection conditions in real-time at major intersections, crossing arterials, or strategic viewing locations. When considering the installation of new CCTV cameras systems, it is important to understand that there are various types of CCTV camera manufacturers to choose from. This includes the type of camera (top mounted or dome) and the preferred type of installation; typically, they are mounted to an existing pole or on a standalone pole. This also includes the selection and installation of a video management system (VMS) hardware/software at the local TMC for remote viewing, monitoring, and control of the system. All of these elements should be considered when planning and designing new CCTV camera systems.

2.7 Municipal Communication System

The City of Lancaster IT Department maintains a municipal IT communications network. Remote sites, City Maintenance Yard, and other locations are connected using the traffic signal fiber optic backbone cables and by other dedicated City IT fiber cables. By utilizing the existing traffic signal fiber optic backbone cable, the City IT department is able to provide a hardline fiber connection between City Hall and Maintenance Yard, allowing remote client access to the QuicNet Pro TMS system. In addition to the fiber optic backbone network, field investigation has identified that the City IT department also shares two (2) separate direct 24 strand fiber optic connections to the Lancaster Performing Arts Center (LPAC) and the Museum of Arts History (MOAH) that share similar routing to the fiber backbone network. Therefore, additional planning and relocation will be necessary during the design/ construction phase of the project to identify and maintain these connections in place.



As part of the **ITS Expansion** and **Traffic Signal Modernization** improvement projects, a new hardline fiber optic connection will be provided for a high-speed 2.5Gbps fiber optic link between City Hall and Maintenance Yard using the existing fiber backbone network. This will allow traffic signal maintenance staff to monitor and maintain the ATMS system remotely from the Maintenance Yard in real-time.

At City Hall, coordination with City IT staff will be required for interface requirements of the new ATMS system; including network time protocol (NTP), outgoing alarms/messages (SMTP) and internet access (world wide web). Since the City IT department currently provides these services at City Hall where the new ATMS system will be deployed, it is logical and cost effective that both parties work in tandem to provide these essential services for the normal operation of the ATMS system.

2.8 Traffic Management Center

The City of Lancaster does not have a Traffic Management Center (TMC) for remote command and control of traffic signal operations. However, The City has internal workstations configured with client TMS access located within City Hall/ Maintenance Yard. The workstations are configured and utilize a McCain "QuicNet Pro" central system for command and control of all traffic signal operations. QuicNet Pro communicates to all local intersections via the hybrid copper SIC/fiber optic communication system, providing traffic signal timing/Time-of-Day (TOD) operation and allowing real-time monitoring through the system's Graphic User Interface (GUI).

In general, a Traffic Management Center typically includes dedicated ATMS/ VMS workstations, Audio/Video equipment, console furnishings and an overhead LED Video Wall/ Monitor for displaying and managing traffic operations in real-time. For future TMC improvements, consideration should be given to the physical location where workstations (computer/monitors) are located for operators and/or managers that require access to the system. This requires physical communication link from the workstation to the IT server room.

An evaluation has been performed on the existing Traffic Management Center equipment at both City Hall and Maintenance Yard locations. **Table 2.1** and **Table 2.2** describe both the existing and proposed Traffic Management System equipment at both City Hall and the Maintenance Yard.

Table 2.1 - Traffic Management System Equipment – City Hall

ELEMENT	EXISTING EQUIPMENT	PROPOSED EQUIPMENT
Traffic Management System	McCain QuicNet Pro system	**Intelight MaxView ATMS System**
Traffic Server	Dell PowerEdge 2850 traffic server	**Dedicated Database/ Communication server(s) KVM**
Workstation PC	City owned PC for remote command and control (hosting McCain QuicNet)	**TMC Workstations LED Display monitor**
Communications Equipment	Opcom fiber optic data modems (analog data) Optelecom 9002 card chassis (analog video)	**Layer 3 Core Switch Layer 2 Aggregation Switch**
Hardwire Communications	(1) 48 SMFO cable, (1) 24 SMFO cable, (1) 24 SMFO cable (City IT) (1) Fiber Distribution Units (FDU's) Copper SIC punchdown block (abandoned)	**Re-utilize Fiber Optic Backbone Cable Fiber Distribution Unit (FDU)**
Wireless Communications	No wireless communications equipment	
Video Management System	Vicon V6680 Nova video matrix switcher Robot MV96p digital video multiplexer	**Video Management System (VMS) & dedicated CCTV system server**

Table 2.2 - Traffic Management System Equipment - Maintenance Yard

ELEMENT	EXISTING EQUIPMENT	PROPOSED EQUIPMENT
Workstation PC	City owned workstation PC for remote command and control	**TMC Workstation with link to MaxView ATMS system** **LED Display monitor**
Communications Equipment	Opcom fiber optic data modems (analog data) Optelecom 9002 card chassis (analog video) 16 channel Digiport terminal server (2) GDI 400SA modems	**Layer 2 Aggregation Switch**
Hardwire Communications	(1) 24 SMFO cable (1) Fiber Distribution Unit (FDU)	**Fiber Distribution unit (FDU)** **New Ring Communication Topology**
Wireless Communications	Encom wireless 5.8GHZ Commpak BB radio antenna	
Video Management System	Pelco CM6700 controller/ mux Robot MV96p digital video multiplexer	**Workstation with link to City VMS system**
Miscellaneous	Clary UPS unit & batteries	

During the evaluation process of existing space at both City Hall and Maintenance Yard buildings for improvements under the **ITS Expansion** and **Traffic Signal Modernization** projects, the need has been identified by the City for a new Traffic Management Center and dedicated space. The City is currently in the process of obtaining approval to build a dedicated TMC center at City Hall. It is anticipated that a new TMC will be deployed sometime in the year 2020 as part of a future project. Special consideration should be given during the design process of the future TMC to integrate near-term improvements under the **ITS Expansion** and **Traffic Signal Modernization** projects, as integration of future TMC and near-term improvement projects will be key in providing a singular TMC center for unified traffic signal operations and maintenance.

3. ASSESSMENT OF INTELLIGENT TRANSPORTATION SYSTEMS (ITS) OPPORTUNITIES

This section provides an assessment of current ITS needs and opportunities using proven technologies available today. This includes a myriad of ITS technologies that are commonly being used by various agencies in surrounding areas, including Caltrans. The assessment of current ITS needs and opportunities are presented in five main areas:

- Roadside ITS Technologies
- Centralized/TMC ITS Technologies
- Communication Network ITS Technologies
- Multi-Modal Transportation Solutions
- Smart ITS Technologies

3.1 Roadside ITS Technologies

3.1.1 Traffic Signal Controllers

Fully adopted in 2009, a new traffic controller standard evolved in the form of Advanced Traffic Controller (ATC) specification and is now the standard for newly deployed controllers. The new ATC allows open-sourced Linux based architecture and other key advancements such as peer-to-peer communication, high-resolution data, and the ability to provide vehicle-to-everything (V2X) connected vehicle data (includes vehicle to vehicle/vehicle to infrastructure). Currently, City's traffic signal controllers are unable to accommodate these functions, and cannot fully integrate into newer ITS technologies.

Type 170 / 2070 Traffic Signal Controllers

In order to understand the differences between the legacy and ATC controllers on the Types 170/2070 traffic signal controller platform. **Table 3.3** summarizes the different types of controllers, the types of software that is supported by the local controller, key features, and the manufacturers that supply these controllers.

Table 3.3 - 170 / 2070 Traffic Controller Matrix

Controller Type	Compatible Software	Key Features	Manufacturer
170E	BiTran 200/233	Low Cost, Easy to maintain	McCain, SafeTran, Intelight
2070E	BiTran2033, ASC/3-2070, Maxtime software	Interchangeable modules provide flexibility	McCain, SafeTran, Intelight

Controller Type	Compatible Software	Key Features	Manufacturer
ATC 2070	Omni eX, ASC/3, ATC-2000, Intelight, OS9	Current ATC spec, most advanced	McCain, SafeTran, PEEK, Intelight Siemens
Cobalt Rackmount	Cobalt Software	Current ATC spec, most advanced	Econolite

As shown in **Table 3.3**, there are four main types of 170/2070 traffic signal controllers, of which, two types (ATC 2070 and Cobalt Rackmount) support the latest ATC specifications. The key takeaway from this table is to understand the capabilities of legacy controllers (currently deployed) and the capabilities of next generation controllers that are available when agencies are considering upgrades. The following subsections provide additional details for each controller.

Type 170E Controller

Type 170E Controllers are the original workhorse of intersection control. These controllers were designed for ease of installation, use, and maintenance. Key features include:

- Operate in any environment
- Maintain with ease
- Use for intersection control, ramp metering, sign control, traffic monitoring and more
- Microprocessors
  - 6802 operating at 3 or 6 MHz
- Memory
  - 32 KB EPROM
  - 32 KB RAM
- Applicable Standards
  - Caltrans Transportation Electrical Equipment Specifications (TEES)

Type 2070E Controller

Type 2070E controllers are a rugged, multi-tasking field processor and communications system configurable for a variety of traffic management applications. Interchangeable with standard 170 controllers, 2070E controllers allow users to upgrade existing intersections to a higher performance platform without replacing cabinet hardware. Key features include:

- Support a variety of applications through modular design
- Enhance cabinet capabilities without replacing hardware
- Ensure compatibility with off-the-shelf products and intersection control software
- Microprocessors
  - CPU Module: Freescale MC68EN360, 32 Bit, 24.576 MHz microprocessor
  - I/O Module: Freescale microprocessor, running at 24 MHz

- Memory
  - 8 MB Flash memory
  - 32 MB PSRAM
  - 2 MB non-volatile SRAM
- Applicable Standards
  - Caltrans Transportation Electrical Equipment Specifications (TEES)

2070 ATC Controller

2070 ATC Controllers are an advanced, multi-application controller that simultaneously supports multiple software applications through a single platform. Designed from the ground up, the unit provides enhanced flexibility and control. Key features include:

- Leverage the ATC standard's open architecture functionality
- Upgrade 170 or 2070 controllers without replacing cabinet hardware
- Connect to any environment through a wide variety of communication options
- Operate McCain or third-party NTCIP software
- Microprocessors
  - Freescale PowerQUICC II Pro
- Memory
  - 16 MB Flash memory
  - 128 MB DDR RAM (expandable)
  - 2 MB non-volatile SRAM
- Applicable Standards
  - ATC 5.2b
- Caltrans TEES (where applicable)
- NTCIP base standards (where applicable)

Cobalt Rackmount Controller

Fully meeting the industry's ATC standard 5.2b and proposed standard 6.10, Cobalt is designed to provide a combination of ATC standard open architecture functionality with the latest handheld technology and applications. Key features include:

- Large seven-inch color TFT LCD display
- Touch-screen display for intuitive, graphical programming
- High brightness and contrast display for better outdoor readability
- Linux, open architecture real-time multi-tasking operating system

3.1.2 Traffic Controller Cabinets

Traffic controller cabinets play an equally important role and work in conjunction with advanced traffic signal controllers in operating a safe and efficient intersection. The Advanced Traffic Controller (ATC) standard also extends over into traffic controller cabinets and provides a new reference for upgraded traffic control cabinet construction. The many advantages of ATC controller cabinets include low power consumption, no exposed AC current, efficient operation, and more space within the cabinet itself. **Table 3.4** summarizes the types of controller cabinets currently available which are compatible with the City's signal system:

Table 3.4 - Traffic Controller Cabinet Matrix

Cabinet Standard	Cabinet Type	Key Features	Manufacturer
Caltrans	Type 33x	Low cost, standardized	McCain/Safetran/Intelight/ Eagle
ATC	Type 33x	ATC spec, most advanced	McCain/Econolite/ Intelight/Eagle
BBS, other	Side mount, Stand-alone	Add-on storage	Various

As shown in **Table 3.4**, there are three primary types of traffic signal controller cabinets, with the third type being used to house additional equipment such as batteries for a battery backup system (BBS) or as stand-alone.

Type 33x Controller Cabinets

Type 33x Cabinets are enhanced versions of the 332-style cabinet designed for improved safety and energy efficiency. The cabinet's innovative features increase roadside safety in the event of a malfunction or failure, while the eco-friendly design reduces energy consumption using a high-efficiency power supply. The cabinet is also made without the use of the harmful toxin mercury. Key features include:

- Enhance roadside safety
- Reduce energy consumption
- Versatile, weatherproof, and secure cabinet
- Interchange assemblies between manufacturers
- Reduce the effects of vandalism with optional anti-graffiti coating
- Mercury-free, eco-friendly design

Type 33x controller cabinets are also commonly used to house communications equipment (e.g. communication hubs). These hubs typical house communications equipment, such as Ethernet switches, and fiber distribution units (FDU).

ATC Controller Cabinets

ATC cabinets combine the best of rack mount and serial-based designs to meet the needs of today's LED intersections. Using smarter, high-density components, the cabinets offer unparalleled control capabilities for intersections that would otherwise require unorthodox wiring or a second cabinet. Users rave about the drastically reduced assembly size that leaves ample room for auxiliary equipment. Key features include:

- Manage up to 72 detector inputs and 32-channel outputs
- Safeguard against accidental shock from inadvertent contact with high voltages
- Comply with leading standards on electrical safety, including NEC and NFPA 70E
- Detect a dark approach for increased driver safety
- Monitor FTR and flasher continuously to ensure operability
- Allow for hot swappable output assembly for improved intersection safety
- Upgrade existing installations - matches 332 Caltrans and ITS 342 cabinet footprints

Although these ATC cabinets are the latest on the market, it should be noted that they have not been fully tested and approved by Caltrans. Therefore, when considering future upgrades, each agency should be aware of Caltrans approval status prior to considering these new controller cabinets.

BBS/Other Controller Cabinets

Battery Backup System (BBS) cabinets are typically NEMA 3R rated and designed to be base mounted, side-of-cabinet mounted or side-of-pole mounted. Built to withstand harsh weather and operate in extreme temperatures, this cabinet will keep the BBS safe during severe weather like high winds, blizzards, and thunderstorms. BBS cabinets come in several different styles to be used with third-party batteries and backup systems. Key features include:

- Store and secure batteries and backup equipment
- Rugged, weatherproof, and secure cabinet
- Available in a Caltrans TEES approved version
- Available in general purpose and third-party styles

3.1.3 Detection Systems

Detection systems play a critical role in providing accurate and dependable multi-modal detection for all vehicles, buses, trucks, pedestrians, and bicycles. Detection systems are widely deployed not only locally at the intersection level, but also at advanced, mid-block or downstream locations. For example, Adaptive Traffic Control Systems (ACTS) rely on mid-block and lane-by-lane detection for accurate system operation. In addition, new ITS detection systems now incorporate video analytics such as vehicle counts and speeds for verification purposes. The newer video detection systems also offer high definition (HD) video and hybrid video/radar solutions that are more accurate, and detect vehicles and bicycles from further distances with tracking technology as they approach an intersection. There are several different types of detection technologies on the market today. **Table 3.5** summarizes the various detection types, key features, and the manufacturers that supply these systems.

Table 3.5 - Detection System Matrix

Detection Type	Key Features	Manufacturer
Loop Detection	Low Cost, Durable	Various
Video Detection	High Flexibility	Iteris/Econolite/Gridsmart
Radar Detection	Advanced Detection	Wavetronix/Econolite
Infrared Video	Not susceptible to shadowing	FLIR
Wireless Magnetometer	Flexible install, no DLC needed	Sensys/Trafficware
Hybrid Video/Radar detection	Detects both Cars/Bikes	Iteris/Econolite
HD Video detection	Detects both Cars/Bikes	Econolite

As shown on **Table 3.5**, there are seven types of detection systems currently available on the market. Some of the newer/improved detection systems include the magnetometer (wireless), hybrid video/radar detection, and HD video detection.

Loop Detection

Loop detection is a tried and true method of vehicle and bicycle detection that involves a saw-cut in the pavement to place copper loop wire in specific patterns to detect vehicles/bikes. Pre-formed loops are placed in the street before final pavement is laid; these are commonly installed in bridge decks, concrete, or under decorative pavement. Recently, loop detector design has evolved to effectively detect bicycles.

Key features include:

- Allows the system to detect and provide safe passage time for vehicles/bicycles without compromising the intersection's operating efficiency
- The unique capability to identify bicycles from other vehicles allows the user to program initial time and extension time for bicycles only, thus providing a safe passage time through the

intersection. When a bicycle is detected passing through the bicycle loop the channel's output is latched in the call state

Video Detection

Video detection solutions combine state-of-the-art video technology with video image processing algorithms to deliver dependable vehicle detection required for today's complex transportation systems. The video processor features single, dual, or quad video inputs to maximize configuration efficiencies for intersection control, highway monitoring, and ramp metering flow control applications. Many video detection systems today can be configured for remote video streaming back to the agencies TMC.
Key features include:

- "Plug and play" operation enables use of existing detector rack
- Expandable and modular system allows for optimal configuration that helps to reduce cost while preserving room for incremental growth
- Ease of set up and minimal lane closure time reduces manpower cost and keeps traffic flowing during equipment installation
- Video monitors are installed within the traffic signal cabinets in order monitor and make changes of detection zones on-site

Radar Detection

The advance detection capabilities of radar based detection is an ideal solution to enhance safety at all intersections, especially for arterials with high speed approaches – 35 MPH or faster. By providing lane-by-lane advance detection out to 1,000 feet from the radar unit, it minimizes the number of vehicles exposed to an intersection dilemma zone by enabling the traffic signal controller to adjust the start time of yellow phases earlier or later based on detected vehicle location and speed. "Plug and play" operation enables use of existing detector rack. Key features include:

- Typical sensor is a robust low cost 24 GHz radar for traffic management solutions
- It works in adverse conditions, almost unaffected by weather
- The antenna is designed for long ranges with narrow horizontal angular coverage
- The field of view typically covers up to four lanes

Infrared Detection

Infrared detection sensors deliver superior accuracy and reliability for any traffic monitoring application. Using advanced thermal imaging sensors, infrared cameras can detect vehicles in a wider variety of conditions than traditional color-only sensors. By detecting the heat of all objects in the scene, it operates in broad daylight or total darkness, poor weather and even light fog. Key features include:

- Equipped with an internally developed, uncooled micro bolometer that produces crisp thermal imagery and reveals critical details

- Extremely rugged systems built to rigorous IP66 standards and protected from dust and water ingress. Their broad operational temperature range (-50°C to +75°C) makes them ideal for any climate
- Works perfectly together with video analytics, such as FLIR's VIP 3D Detection Boards. Thermal images are often used for vehicle presence detection at signalized intersections, and for 24/7 traffic monitoring

Wireless Magnetometer Detection

Advanced magnetometer-based vehicle detection is state-of-the-art magneto-resistive sensing devices in each wireless sensor that measure the x-, y-, and z-axis components of the Earth's magnetic field at a 128 Hz sampling rate. As vehicles come within range, changes in the x, y, or z axes of the measured magnetic field become apparent. When no vehicles are present, sensors continually measure the background magnetic field to estimate a reference. Each sensor automatically self-calibrates to the local environment, and to any long-term variations of the local magnetic field, by allowing this reference value to change over time.

- Lower power consumption 3-axis magnetometer for vehicle detection
- Flush mount or up to 4.25" (10.8 cm) depth (to top of sensor) in-pavement installation with no wires or lead-in cabling fast and simple installation
- Readily deployed where other systems cannot be used

Hybrid Video/Radar Detection

Hybrid Video/Radar vehicle detection system work together as one unit. The first in a new generation of hybrid sensor-based above ground detection, the type of application provides superior detection accuracy in all traffic, lighting, weather, and pavement conditions, with the lowest cost of ownership. The video/radar sensor provides a consistent vehicle detection solution, and inspires ITS applications of continuous data collection and traffic monitoring capabilities. Key features include:

- Provides vehicle detection for intersection stop line and advance extension applications
- Connectivity for broadband communications
- Streaming digital MPEG-4 video output
- User-definable password protection
- Vehicle detection, traffic data measures, speed, and incident detection
- Bicycle detection and differentiation

HD Video Detection

HD video detection is an integrated camera-processor sensor solution that provides high performance stop bar vehicle detection, bicycle detection and differentiation, advance vehicle detection, traffic data collection, and HD video surveillance. It also supports local Wi-Fi and streaming video to mobile computing devices. Manager supports SDLC and wired I/O interface. Key features include:

- Stop bar vehicle detection
- Bicycle detection and differentiation
- Advance vehicle detection up to 600 feet from Vision sensor
- Vehicle and bicycle tracking analytics
- Traffic data collection
- HD video surveillance

3.1.4 Battery Backup Systems (BBS)

Specifically designed for electronics equipment in ITS and traffic applications, Battery Backup Systems (BBS) are industry proven. BBS units deliver on-line double-conversion protection 100% of the time for reliable, continuous, and error-free operation regardless of utility power quality.

Most products are engineered to meet NEMA standards for traffic backup systems with an operational temperature range of -40°C to +74°C. Designed to side-mount onto existing traffic cabinets or in adjacent stand-alone cabinets. Optional NEMA 3R Type II and Type III cabinets are available.

- Alarms can be configured for integration into ATMS system for remote flash conditions, uptime and unit status conditions

3.1.5 Transit Signal Priority/ Bus Signal Priority (BSP)

Transit Signal Priority (TSP) for public transit allows transit agencies to extend or truncate green cycle times at traffic signals for more accurate schedule adherence. In turn, transit vehicles — including buses, light-rail, trains, and streetcars — are on the road less, which reduces fuel and fleet costs for more profitable operations.

Bus Service Priority (BSP) offers local transit agencies priority at signalized intersections or along dedicated project corridors. BSP uses the similar technology to Emergency Vehicle Preemption (EVP), however, modern day BSP programs typically use Wi-Fi and GPS type systems that provide local interfaces to the traffic signal controller to trigger a bus pre-emption event with minimum impacts to a synchronized corridor. In addition, BSP equipped buses can preempt a signalized intersection while traveling through a corridor and announcing itself to the upstream intersections. Therefore, the result is a continuous steady green band through-out the corridor. Local agencies would have to install additional equipment at the signal controller cabinet level, while the transit agency installs BSP equipment on-board. Furthermore, the system is typically operated separate from a centralized traffic management system and requires its own centralized hardware and software. Key benefits include:

- Reduce transit delays
- Minimize commute times
- Cut fuel costs
- Lower greenhouse gas emissions
- Improve schedule adherence

3.1.6 Emergency Vehicle Pre-emption (EVP)

Emergency Vehicle Pre-Emption (EVP) uses Infrared (IR) system based emitters or global positioning systems (GPS) based unit detection mounted on emergency vehicles with detectors and phase selectors at the intersection. Traffic signals can be pre-empted or extended to help first responders reach an emergency scene more quickly. Combined with an EVP central management software the EVP system can help operators manage traffic signal priority control and reduce maintenance costs at intersections in real-time from their TMC and/or workstation. Key benefits include:

- Reduce intersection crash rates by up to 70 percent
- Improve response times by up to 25 percent
- Eliminate priority conflict; grant right-of-way on a “first come, first served” basis
- Restrict access to authorized users only through system coding
- Receive data reports logging vehicles and preemption activity

3.1.7 Arterial Management Systems (Bluetooth/Wi-Fi/Magnetometer)

Arterial and Freeway Management Systems are becoming more mainstream for operating and managing signalized intersections and arterial roadway networks. These systems are used as a tool to measure origin-destination timestamps, travel time, and speed reports along a subject route using modern day Bluetooth devices normally found in driver's smart phones, tablets, lap tops, and onboard vehicle systems. More traditional detection systems, such as inductive loop system, are utilized by Caltrans District 8 along Interstate 10 freeway. Additional arterial management systems include video, Wi-Fi, radar, and magnetometer based detection.

These types of systems can generate volume, occupancy, and speed reports that can be used to assess arterial and freeway status and congestion. These real-time traffic data measures enable monitoring of congestion to optimize traffic operations. Arterial management solutions generally consist of roadside detection hardware and front-end management software to generate real-time travel time graphs and reports along certain roadway segments. Bluetooth technology detects anonymous Bluetooth signals broadcast from mobile devices to determine accurate travel times and speeds. Software calculates travel times and speeds in real-time to provide route management capabilities. Data can be viewed in real-time or analyzed historically through a web interface, which provides travel times, road speeds, and MAC address detection counts. Key features include:

- Algorithms for filtering and processing data inputs to compute real-time travel times and speeds. Speeds/travel times updated in real-time on a secure web “Dashboard” and speed maps
- XML language is available for third-party integration such as an Advanced Traffic Management System (ATMS), agency website, or Dynamic Message Sign (DMS) software control
- Secure web interface for generating statistical and analytical reports covering: speeds, travel times, origin/destination, and before and after comparisons
- Real-time monitoring of device status and performance

3.1.8 CCTV Camera Systems

High Definition (HD) Internet Protocol (IP) Close Circuit Television (CCTV) camera systems are capable of remote direction and zoom control. It gives the operator a wide field of view, but it is also able to zoom into an incident wherever it occurs within the original field of view. HD IP CCTV cameras deployed on this project shall have full pan/tilt/zoom (PTZ) functionality. Through open architecture ONVIF (Open Network Video Interface Forum) compliancy, the selection of CCTV camera/hardware and video management software (VMS) are no longer required through the same vendor. This gives the local cities/agencies an opportunity to evaluate the latest CCTV camera assemblies and select a HD camera based on the factors most important to them. Overall, a modern IP camera utilized in the ITS market should meet the following criteria:

- IEEE Ethernet based, IP compatible
- High Definition camera resolution (1080p) or greater
- Ruggedized, built for use in harsh roadside environments
- Open Architecture, ONVIF compliant
- Multiple Streams for shared video use

HD network surveillance cameras used in the ITS market today employ many advanced features derived from the private security and public defense markets. Some of these important specifications include:

- **Wide Dynamic Range (WDR):** Helps in stabilizing the image quality for scenes with extremely bright and dark areas
- **Video Stream Capability:** Each camera has a specific number of stream capabilities varying from two (2) to eight (8) or more. This provides the opportunity to share video streams among different agencies including type MPEG-2, MPEG-4, and H.264 protocols
- **IR Cut Filter:** An IP camera delivers a colored image during the day. As light diminishes below a certain level, the camera can automatically switch to night mode to produce high quality black and white images

Design and placement of an IP camera affects the cameras visibility, range, and coverage. This includes considering the following:

- **Field of View:** The amount of a given scene captured by a camera. It is affected by the focal length of the lens, size of the sensor element and the height of the camera position in relation to the road
- **Target Height:** As the height of the object to be monitored is increased, the angle of view is also increased

Table 3.6 summarizes the typical HD IP CCTV camera types that are on the market, key features, and the manufacturers that supply these systems.

Table 3.6 - CCTV Camera System Matrix

Camera Type	Key Features	Manufacturer
Digital Network Camera	Low cost, Easy to deploy	Bosch/Pelco/Cohu/WTI/Axis
High Definition Camera	Broad field of view, High quality camera	Bosch/Pelco/Cohu/WTI/Axis
Infrared camera	Weather, Day/Night	FLIR
Video Analytics	Advanced functions	Various 3rd party

As shown in **Table 3.6**, there are a variety of CCTV camera systems that offer various features. The selection of the systems is user driven. The following subsections provide additional details for each CCTV camera type.

Digital Network Cameras

Digital network or Dome CCTV cameras enable surveillance of a large area and great details when zooming in. With quick and reliable installation features, the cameras are ideal for city and perimeter surveillance. They are usually a more cost-effective approach than full positioner PTZ cameras. However, the drawback is that they cannot pan above 180 degrees above the horizon. Key features include:

- Continuous 360° pan
- Outdoor-ready HDTV 1080p/720p models
- Day/night functionality
- Focus recall
- 120 dB Wide Dynamic Range – Forensic Capture

High Definition CCTV Camera Systems

High Definition or Positioner style PTZ cameras typically provide full 1080p imaging with 30x optical zoom or more, delivering full frame rate HD images over the entire zoom range for very cost effective long-range surveillance applications. True day/night technology using a removable IR cut filter produces exceptional low light sensitivity. For installations subject to wind or vibration, electronic image stabilization assures steady, clear images and enables the system engineer to utilize existing bridge sign and traffic light poles for camera mounting. Key features include:

- Powerful 30x optical zoom with 12x digital zoom (360x total)
- Image defog/de-haze analytics
- Electronic image stabilization (EIS)
- Dark scene enhanced intensity
- Bright source whiteout reduction
- Presets, tours, sectors, and privacy zones

Infrared CCTV Camera Systems

Infrared multi-sensor pan/tilt cameras bring thermal and visible-light imaging together in a system that gives you video and control over both IP and analog networks. This type of camera application lends itself to light sensitive or weather-related images. The precision pan/tilt mechanism gives you accurate pointing control while providing fully programmable scan patterns, radar slew-to-cue, and slew-to-alarm functions. It includes a new standard of performance that provides full 640 × 480 thermal resolutions. Key features include:

- Sharper thermal images that provide greater scene detail; improves threat detection and alarm assessment capabilities
- Long-range threat detection; see smaller details from farther away
- Enhanced analytics performance gives you more reliable feedback with fewer nuisance alarms
- Wider fields of view improve coverage without compromising range performance; optimize coverage efficiency while lowering overall installation cost

Video Based Analytics

Today's modern cameras are usually classified as a 'network' camera with advanced technology borrowed from the security industry. As such, today's modern cameras have the ability to incorporate and utilize video analytics. Video analytics technology allows analyzing real-time video streams in full HD and providing a broad range of tasks and object filters, including providing a wide range of detection of people, vehicles and statics objects, automatic classification of person, bike, cars and trucks, wrong-way motion detection, stopped vehicles, and alarm notification tool for real-time events to end users. Video analytics can be built-in to the network camera or provided by a 3rd party integrator into a VMS system. Key features include:

- Detect objects within, entering, or leaving an area
- Detect multiple line crossing from single line up to three lines combined in a logical row
- Detect objects traversing a route

- Detect wrong way projection
- Detect objects which are idle for a predefined time span
- Count objects crossing a virtual line or entering a certain area

3.1.9 Changeable/Dynamic Message Signs (CMS/DMS)

Every day on U.S. roadways, millions of motorists look to dynamic message signs (DMS) for useful instructions, such as toll rates, travel times, incidents, detours, roadway status, and amber alert messages. DMS conveys clear, effective messages to motorists. They are available in monochrome or full-color models, these are full-matrix DMS, that can show MUTCD symbols and text to increase comprehension in very short viewing times.

Freeway DMS require large character heights for legibility in fast-moving traffic. Higher-resolution, full-color DMS improves comprehension of messages and provides crisp MUTCD graphics and text.

ITS dynamic message signs deployed in the industry today typically utilize full LED technology for increased brightness and reduced power consumption. When deploying DMS, there are many factors to consider, including driver viewing angles and set-back distance. The placement DMS should be installed at strategic locations in order for motorists to make informed decisions about the posted message. DMS can be installed on the freeway and arterial roadway networks, and they come in a range of sizes. Communications to DMS sign are based on the owner's preference (e.g. cellular, wireless, hardwired, fiber optic), and are typically NTCIP compliant. Key features include:

- Convenient access for maintenance personnel
- Safe working environment with OSHA tie-offs, ventilation and lighting
- Full monitoring capability with complete diagnostics for systems and pixels
- Full-color or monochrome amber models
- Meets industry standards and codes such as NTCIP 1203 v02, NEMA TS-4, AASHTO, ANSI/AWS

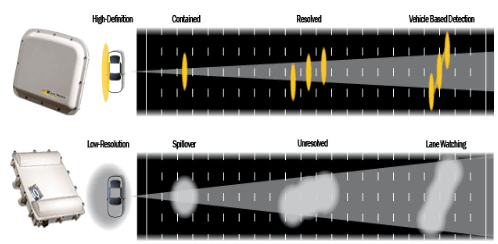
Managing all DMS in a system, central control software is another important role in administering messages to the motoring public. Similar to other ITS sub-systems, DMS control software is an independent control system that requires separate hardware and software. It allows to create quick, professional messages through advanced editing software. Security is built-in and users can verify real-time use of "on" pixels for a DMS. Integration into centralized ATMS systems can also be accomplished. Key features include:

- View, group and monitor multiple DMS in real time
- Controls any NTCIP-compliant DMS

- Any sized character, line or full-matrix DMS
- Variable speed limit signs and Vanguard VM-1020 DMS
- Portable NTCIP message displays

- Seamless network management with list view or map view
- Pre-schedule scenarios manage entire events with a few clicks of the mouse

3.1.10 Traffic Monitoring Stations



Traffic monitoring stations (TMS) collect data that describe the use and performance of the roadway system. TMS typically collects traffic volumes, speed, and occupancy depending on the type of technology. TMS data can also be used to indicate congestion levels and predict travel times. Proven Freeway/arterial traffic monitoring stations (TMS) have traditionally utilized loops. However, new technology such as side-firing radar has improved detection. Accurate vehicle detection is not based on lanes, but based on vehicles, so detections are consistently accurate, even if a vehicle changes lanes. This technology can virtually provide two radars in one case — capable of reporting highly accurate per vehicle speeds and accurately detect up to 22 lanes of traffic. Caltrans has deployed this type of technology on their freeway network, but primarily uses detector loops.

Typical deployments of this technology are used on freeways and major arterials, where consistent vehicle detection counts. Other technologies similar to Bluetooth or Wi-Fi offer easy expandable roadside deployments, TMS typically have dedicated mast poles and roadside cabinets to house the equipment. Communications to TMS are based on the owner’s preference (e.g. cellular, wireless, hardwired, fiber optic). Other agencies could benefit from this type of roadway monitoring.

3.2 Centralized ITS Technologies

3.2.1 Advanced Traffic Management Systems (ATMS)

The overview of Advanced Traffic Management Systems (ATMS) is set to provide an understanding of the various available ATMS capabilities, requirements, protocols, bandwidth demands based on multiple scenarios, system integration with existing equipment and protocols, other required upgrades, and user's needs.

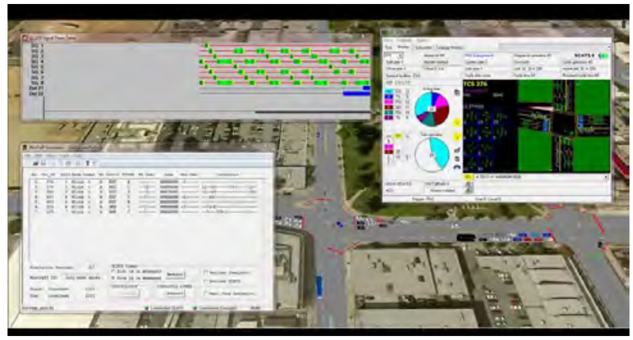


Table 3.7 summarizes ATMS software that are on the market, key features, and the manufacturers that supply these systems.

Table 3.7 - ATMS System Matrix

ATMS Software	Key Features	Manufacturer
Maxview	Works with different controllers	Intelight
ATMS.now	Updated interface	Trafficware
Transparity	Robust feature set	McCain
TransSuite	Good 3rd party integration, works with different controllers	TransCore
Centracs	Robust feature set	Econolite
KITS	User friendly, works with different controllers	Kimley-Horn

The following sections summarize each ATMS in more detail about the client interface (e.g. from a workstation and/or web browser), ease of use through the graphic user interface (GUI), system mapping functionality, required operating protocols in order to communicate with the traffic signal controllers (e.g. compatible controllers), CCTV camera control options, typical cost for how the system is bid (e.g. lump sum), additional costs per controller/intersection to implement the system, and when typical annual maintenance costs begin. This information provides a high level of understanding, and it can be used to compare each system's features as shown.

Intelight - Maxview ATMS

Client	• Uses web browser interface. Workstation is a thin client • Server can be accessed anywhere in the network
Graphic User interface	• Graphic User Interface is very easy to use • Uses latest Microsoft windows "look and feel"
System Map	• System Map is easy to set up, and displays Bing Map with traffic conditions • Shows increased detail with zoom in • Allows selection and apply command to multiple intersections, groups and system wide • Allows editing multiple controllers at same time
Compatible controllers	• Works with NTCIP and AB3418E controller protocols
CCTV control	• Built-in. Support for ONVIF compliant cameras

Trafficware - ATMS.now ATMS

Client	• Workstation client requires program on desktop, however program is automatically updated by the server when user logs in
Graphic User interface	• Graphic User Interface is very easy to use. Uses latest Microsoft windows "look and feel"
System Map	• System Map is easy to set up, and displays Bing Map (No traffic conditions) • Shows increased detail with zoom in. • Allows selection and apply command to multiple intersections • Allows editing multiple controllers at same time
Compatible controllers	• Works with NTCIP and AB3418E controller protocols
CCTV control	• Integrated module: IP cameras

McCain - Transparity ATMS

Client	• Workstation client requires program on desktop
Graphic User interface	• Graphic User Interface is easy to use. Microsoft windows "look and feel" is not as good
System Map	• System Map is easy to set up, and displays OpenStreet Maps (no traffic conditions) • Shows increased detail with zoom in • Allows selection and apply command to multiple intersections • Does not allow editing multiple controllers at same time
Compatible controllers	• Works with NTCIP controllers and legacy McCain controllers
CCTV control	• Additional costs are associated for separate module. Supports Iteris video detection cameras

TransCore - TransSuite ATMS

Client	• Workstation client requires program on desktop • Thin client is available – for access through the cloud
Graphic User interface	• Graphic User Interface is easy to use. Microsoft windows "look and feel" is dated. New version under development
System Map	• System Map is easy to set up, and displays Shape files, OpenStreet Maps, and Bing Maps (no traffic conditions). Can show traffic data from Inrix, TomTom or HERE • Shows increased detail with zoom in. Allows equipment layers to be turned on/off • Allows selection and apply command to multiple intersections • Does not allow editing multiple controllers at same time
Compatible controllers	• Works with NTCIP and AB3418E controller protocols
CCTV control	• Integrated module. Additional costs are associated

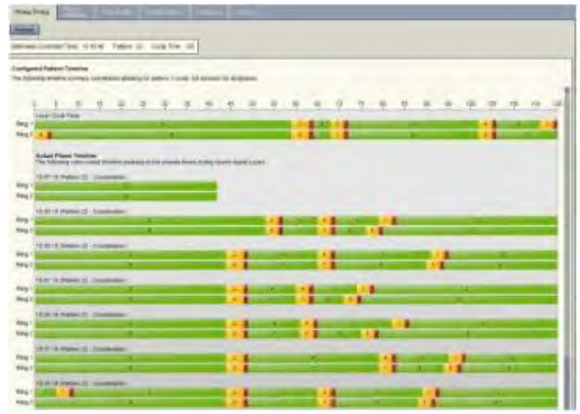
Econolite - Centracs ATMS

Client	• Workstation client requires program on desktop, however program is automatically updated by the server when user logs in
Graphic User interface	• Graphic User Interface is very easy to use. Microsoft windows "look and feel" is dated. New version under development
System Map	• System Map is easy to set up, and displays HERE, Bing Maps, WMS Maps, Open Street Maps, Map.net/ESRI shape files (No traffic conditions) • Shows increased detail with zoom in • Allows selection and apply command to multiple intersections • Does not allow editing multiple controllers at same time
Compatible controllers	• Works with NTCIP, Cobalt, 2070 (ASC/3, Sepac, Oasis), 170 (Wapiti)
CCTV control	• Integrated module: Axis cameras (no cost). Advanced modules for additional cost

Kimley-Horn - KITS

Client	• Workstation client requires program on desktop
Graphic User interface	• Graphic User Interface is very easy to use Uses latest Microsoft windows "look and feel"
System Map	• System Map is easy to set up, and displays Bing Map (No traffic conditions) • Shows increased detail with zoom in • Allows selection and apply command to multiple intersections • Does not allow editing multiple controllers at same time
Compatible controllers	• Works with NTCIP controller protocols. Type 170 (BiTran 233), Siemens Sepac, Intelight MaxTime., TSCP, and D4
CCTV control	• Integrated module. Additional costs are associated

3.2.2 Adaptive Traffic Control System



Adaptive Traffic Control System (ATCS) is a separate traffic management tool that works in tandem with centralized Advanced Traffic Management Systems (ATMS). The benefits of ATCS includes: having fully autonomous signal operations; to preserve capacity and improve mobility in congested networks; adjusting to real time traffic demand; queue management; adapting to unexpected traffic changes; using big-data analytics to enhance signal operations; and providing big-data analytics for performance measurements. ATCS is most effective when managing heavy directional traffic flow, unpredictable traffic changes results in delays or stops that cannot be addressed by conventional signal timing, and where frequent and unpredictable changes in of demand, events, weather, etc. creates major unexpected fluctuations in the system. Although ATCS may not be applicable to all situations, successful ATCS deployments occur with the proper evaluation, selection, and implementation through the systems engineering approach.

Due to its higher complexity over the traditional ATMS software, ATCS requires: additional training; operators that understand the system, initially more monitoring of the system performance for system evaluation and calibration, fine tuning, and maintaining communications and detection. The following are common items associated with the deployment of an ATCS:

- Infrastructure upgrade/system installation
- Possible communication upgrades
    - Ethernet/IP-based communications
- Possible detection upgrades or add-ons
- Staff training (initial and continuing)
- Infrastructure maintenance
- Software maintenance and operations contracts
- Potential additional staffing/contract staff/contractor (consulting firm)

There are two important requirements for a successful ATCS deployment: reliable communications, and adequate vehicle detection Typically, communications will be provided by the Ethernet/IP-based connections, from controller to controller, from controller to field communication hub, and all communications back to the TMC. Most adaptive systems require that vehicle detection be provided for each lane, for all approaches. Both advance detection and presence (or limit line) detection should be separated by lane. **Table 3.8** summarizes ATCS software systems that are on the market, key features, and the manufacturers that supply these systems.

Table 3.8 - Adaptive Traffic Control Systems Matrix

ATCS Software	Key Features	Manufacturer
MaxAdapt	No separate server needed	Intelight
SynchroGreen	Calculates every cycle	Trafficware
Transparity Adaptive	Edge driven	McCain
Adaptive Control Decision Support System (ACDSS)	Pre-configured applications	TransCore/KLD
Centracs Adaptive	Best for arterials	Econolite
Kadence	Adjust every 3 cycles	Kimley-Horn

The following sections summarize each ATCS in more detail about the server/client interface (e.g. from a workstation and/or web browser), communications requirements, required traffic signal controller hardware/software, adaptive control strategies, and typical cost for how the system is bid (e.g. lump sum, on a per intersection basis), and if it requires annual maintenance costs. This information provides a high level of understanding, and it can be used to compare each system's features.

Intelight MaxAdapt

Server/Client	• Does not require server • Works at the controller level • Accessible through Web browse
Communications	• Require Ethernet communications
Detection	• Uses existing detection • Best if detection is provided on a per lane basis
Controllers	• Requires Intelight's ATC 5201 controllers with MaxTime software
Adaptive Strategies	• Optimizes Cycles, Offsets and Splits • Timing calculated every cycle. Recommends cycle change every 3 cycles • Algorithm based on Signal Performance Metrics by UDOT, Purdue and INDOT

Trafficware SynchroGreen

Server/Client	• Installed in Central Server, can interface with ATMS.now or Web browser
Communications	• Requires Ethernet communications
Detection	• Uses existing detection • Best if detection is provided on a per lane basis
Controllers	• Require ATC/2070 controller with Naztec firmware and SynchroGreen
Adaptive Strategies	• Optimizes Cycles, Offsets and Splits • Timing update with every cycle (Real time) • Strategies: Balanced Mode, Progression Mode, and Critical Movement Mode

McCain Transparity Adaptive

Server/Client	• Client/server architecture. Interfaces with Central System
Communications	• Supports serial and Ethernet communications
Detection	• Uses existing detection • Best if detection is provided on a per lane basis
Controllers	• Compatible with McCain 2070 ATC with Omni eX software
Adaptive Strategies	• Optimizes Cycles, Offsets and Splits • Cycle change can happen every cycle. No transition • Adaptive operation starts by selection of Fixed Base pattern (TOD) or Dynamic Base pattern (Traffic Responsive)

TransCore/KLD ACDSS

Server/Client	• Client/server architecture. It is a module of TransSuite
Communications	• Supports serial and Ethernet communications
Detection	• Uses existing detection • Best if detection is provided on a per lane basis • Uses advanced loops as system detection
Controllers	• Compatible with NTCIP controllers, currently integrated with McCain 2070/ATC with Omni eX software, D4, Econolite ASC/3 and Cobalt • Works with NTCIP and AB3418E controller protocols
Adaptive Strategies	• Optimizes Cycles, Offsets and Splits. Real time (every cycle) • Arterial application: optimizes cycle, offsets and splits • Urban network application: selects plans and balance queue utilization at critical intersections

Econolite Centracs Adaptive

Server/Client	• Client/server architecture. It is a module of Centracs
Communications	• Requires Ethernet communications
Detection	• Uses existing detection • Best if detection is provided on a per lane basis
Controllers	• Requires Econolite Cobalt controller with software key
Adaptive Strategies	• Optimizes Offsets and Split (<u>No Cycle Optimization</u>) • Updates timing after 3 cycles • Few parameters to set up

Kimley-Horn Kadence

Server/Client	• Client/server architecture. It is a module of KITS
Communications	• Requires Ethernet communications
Detection	• Uses existing detection • Best if detection is provided on a per lane basis
Controllers	• Works with NTCIP and AB3418E controller protocols
Adaptive Strategies	• Optimizes Cycle, Splits, Offsets, Phase Sequences, and adjust TOD start and end times • Updates timing after 3 cycles

Each ATCS should be evaluated to determine if the systems meet the agency's needs and develop a Pros and Cons system evaluation list related to the system's functionality, performance, operations, maintenance, annual cost, etc. When considering a new ATCS, a systems engineering approach should take place to consider the candidate systems, the candidate corridors, concepts of operations, system selection, implementation, operations and maintenance, and all costs (hardware/ software/ staffing/ maintenance) associated with these types of systems.

3.2.3 Video Management Systems (VMS)

The core of any advanced video surveillance network is its Video Management System (VMS). Essentially the interface to the users and field elements alike, the correct central system is an all-encompassing platform that shall be the correct size and scale to match each agency needs. Many of the advanced VMS features now found in the ITS field are derived from the security industry. Through open architecture ONVIF (Open Network Video Interface Forum) compliancy, the selection of the VMS system and CCTV hardware is no longer required through the same vendor.

Most video management systems operate via a server-client type architecture where robust servers act as the host which render and process the data intensive CCTV images. Client CCTV workstations require additional horsepower (higher-level specifications) in order to process HD 1080p video. For agencies that wish to record CCTV video, additional servers/storage devices with ample hard drive (terabytes) storage are required. VMS systems from the vendors below typically include a "tier" system model for design and deployment based on the agency's needs. **Table 3.9** summarizes current VMS that are on the market, key features, and the manufacturers that supply these systems.

Table 3.9 – Video Management System Matrix

VMS Software	Key Features	Manufacturer
BVMS	Standardized across CCTV and VMS alike	Bosch
VideoXpert	Low cost, easy to deploy	Pelco
S-VMX	Modular system	Teleste
Ocularis 5	Scalable system	OnSSI
Xprotect	Can add modules/services	Milestone
Control Center v14.0	Feature rich	IndigoVision

The following sections summarize each VMS in more detail about their system and key system features. This information provides a high level of understanding, and it can be used to compare each system.

Bosch VMS

The Bosch Video Management System is a unique enterprise IP video security solution that provides seamless management of digital video, audio and data across any IP network. It provides a seamless VMS to go with Bosch CCTV devices, leveraging the unique capabilities of Bosch cameras and recording solutions. It offers interfaces and standards to integrate other systems and manufacturers.

The system is equipped with a unique embedded resilience. It keeps operations up and running even when both, management and recording servers fail. Using the latest state-of-the-art intelligent video analyses and recording technology, the VMS can manage up to 2,000 cameras (including up to 500 ONVIF cameras) with a single server. Key features include:

- Maximum resilience to ensure continuous operation
- Up to 2,000 cameras with a single recording server mean high savings
- A scalable system
- Best integration with Bosch Video hardware
- Version 6.0 offers integration with selected 3rd party cameras and storage systems, as well as other hardware and software

Pelco VideoXpert

Video management systems by nature are complex – a complexity that often overwhelms the user experience, resulting in a steep learning curve and misplaced focus. Key features include:

- Eliminate single points of failure and ensure reliability though fault-tolerant software, distributed architecture, and multiple levels of redundancy
- Flexible scale with reliable modular architecture
- Migration paths for Endura and Digital Sentry systems
- Aggregate VMS networks and manage all video through a single system
- Deploy as a hardware or software solution
- Create and assign tags, organizing network resources as you see fit
- Fully immersive, 180° views when used with OpteraTM Panoramic Cameras
- Leverage third-party solutions for simplified integrations, including:
    - Event/Alarm Management
    - Analytics
    - License Plate Recognition
    - Point of Sale
- ONVIF Profile S compliant

Teleste S-VMX

Teleste's S-VMX is the new generation video management software platform designed in terms of high modularity, open architecture, and the use of industry standards. S-VMX is used for managing traffic, transportation and public security tasks. S-VMX is a modular system, and can be expanded as needed for adding more cameras, having other system components or clients, or adding the respective amount of engine power to the core system. Key features include:

- Open architecture for smooth integration
- A standardized, IT friendly solution
- Web services and mobility
- GIS assisted operation
- Collective metadata handling
- Automated tasks

OnSSI Ocularis 5

OnSSI Ocularis 5 is a scalable video management for small to medium single-site and multi-site applications. Ocularis offers easy installation, scalability, high-speed performance, and intuitive controls. Ocularis software enables third-party integrations and makes compatibility and expandability easy with other systems. Key features include:

- Centrally manage camera views, events, and operator user rights
- Advanced investigation tools provide fast access to incidents
- User friendly built-in, multi-level maps for ease of navigation
- Receive analytics and smart alerts from cameras and recorders
- Camera-based motion detection and server-based motion detection with ability to designate areas for motion alarms
- On-demand or scheduled video exports from mobile or remote locations
- A wide range of third-party integrations

Milestone XProtect Expert

XProtect Expert is an advanced open platform IP video management software (VMS) for medium and large installations. Its central management helps simplify the installation and daily operation of larger systems with multiple recording servers.

XProtect Expert offers reliable video access through failover recording servers, and uninterrupted video recording when complemented with camera-associated edge storage. Using schedule and event-driven driven rules, it is easy to automate security actions and control external systems, reducing the number of manual tasks.

Three unique viewing clients provide seamless access to live and recorded video for different personnel responsibilities. With multi-layered maps, alarm handling and the option of adding XProtect® Smart Wall, XProtect Expert is ideal for installations with active situational live monitoring. Key features include:

- High performance recording server: Building on a native 64-bit windows implementation

- Unlimited system scalability: Full flexibility to add additional Recording Servers and expand the system
- Edge Storage: Uses camera-based storage as a complement to the central storage
- Reliable video recording: Hot and cold standby failover recording servers maintain video viewing and recording capabilities with minimal interruption in the event of network problems, server failure, loss of power or any other system problems
- H.265: Support for H.265 compression: H.265 has the potential to be up to 50% more efficient than H.264

IndigoVision Control Center V14.0

IndigoVisions Control Center is a fully integrated user interface for managing video, access control and alarms. It's easy to install and intuitive to operate. The control center video management software allows viewing, sound and oversight of all cameras, from 1 to 100,000. Its capabilities include map-based monitoring that allows the operator to navigate across cameras, and pursuit mode allows to instantly follow any moving object from one camera to the next. The operator can respond to any event with fast forensic search.

IndigoVision's unique Distributed Network Architecture (DNA) removes the need for a central server – so no single point of failure, greater resilience, dramatically reduced latency and no network bottlenecks. It allows control center to integrate and manage data from other systems. ONVIF conformance allows integration with open standards cameras and devices. IndigoVision's Camera Gateway™ connects cameras from all major manufacturers using native protocols. Key features include:

- Access Control
- Alarm Systems
- Building Management
- Perimeter Detection
- LPR
- PSIM
- Facial Recognition
- Video Analytics

3.2.4 Data Analysis/Performance Measurement Tools

Traffic data and analysis output and tools provides automated statistical processing platform for managing corridors and intersections using precise traffic detection data. These background data systems leverage detections systems such Bluetooth/Wi-Fi, magnetometer, and traffic monitoring stations (TMS) for export of metadata for integration into any software environment. This data is commonly known as high resolution data that can be exported for analysis, and the result is detailed automated performance measures that can be used for network managing, monitoring, and diagnostics. What this means – It provides agency professionals with the information needed to proactively identify and correct deficiencies. They can then manage traffic signal maintenance and operations in support of an agency's safety, livability and mobility goals.

This technology is cost effective, as performance measures can be applied to a wide range of signalized intersections and use existing infrastructure to the greatest extent possible. These performance measures will also support the validation of other technologies and operational strategies, such as adaptive signal control and emerging connected vehicle applications. Some of the benefits include:

- **Increased Safety** – A shift to proactive operations and maintenance practices can improve safety by reducing the traffic congestion that results from poor and outdated signal timing.
- **Targeted Maintenance** – Performance measures provide the actionable information needed to deliver high-quality service to customers, with significant cost savings to agencies.
- **Improved Operations –** Active monitoring of signalized intersection performance lets agencies address problems before they become complaints.

The following sections summarize these technologies including their capabilities and key features.

<u>Wi-Fi/Bluetooth/Magnetometer Identification</u>

Bluetooth or Wi-Fi travel time system leverages a universal detection platform (e.g. magnetometer) for additional powerful metrics such as vehicle miles traveled and vehicle hours traveled and more. Typically, these systems include easy to use travel time and speed reports, intersection delay analysis, volume, occupancy, and speed, and origin/destination patterns for user configured routes and time periods. Users can view congestion maps in order to focus system operations on hot spots. This information is obtained by either Wi-Fi or Bluetooth re-identification with anonymous MAC addresses. Key features and benefits include:

- Cost effective travel times and congestion management
- Pole mounted for ease of installation
- Bluetooth or Wi-Fi supported

- Detection-enabled
- Platform for future enhancements

Traffic Monitoring Stations

As mentioned previously, traffic monitoring stations (TMS) are commonly used for arterial and freeway traffic data collection, this program provides accurate volume, occupancy and speed reports. TMS are included in this section because they are a technology that provides data analysis/performance measurements. These real-time traffic data measures enable monitoring of congestion to optimize traffic operations. Leveraged in conjunction with TMS station data, users will have insight into complete corridor utilization statistics, including Vehicle Miles Travelled (VMT) and Vehicle Hours Travelled (VHT).

Data Analytics for Signal Optimization

Data analytics for signal optimization includes the use of high resolution data and performance measure reporting in order to improve mobility and safety on a 24/7/365 basis, which is derived from a traffic monitoring platform that automates performance measure reporting and ongoing data collection. These systems continuously collect and reports how well signalized intersections are performing, they can accurately capture turn movement counts and other critical data. With this information, operators can use the data in order to identify seasonal or day of week trends or other traffic pattern changes, and be able to update signal timing accordingly.

By capturing and analyzing detailed performance measures such as volume-to-capacity (V/C) ratios, arrivals on green, and even accurate turn movement counts; it provides the capability of monitoring signal performance, and use the data to re-time and optimize traffic signal timing. It can also obtain speed and red-light violations, which enables an extra layer of analysis and safety review.

Typically, these Data Analysis/Performance Management systems can be operated as stand-alone software management platforms or integrated into advanced traffic management systems (ATMS).

3.2.5 Cloud Technology for ITS Infrastructure

Cloud technology enables cities to collect, store, and analyze data of all kinds. Today, every government asset is a sensor, and data is what makes a city “smart.” The insights that can be derived through this analysis are limitless, helping cities identify gaps, issues, and trends that will help them deploy their resources more effectively and focus on their core mission.

Smart transportation solutions born in the cloud, such as smart parking, smart lighting, connected intersections, smart routing, fleet monitoring, and connected vehicles. These solutions are important across both the private and public sector because infrastructure is critical to economic growth. Just as traditional

infrastructure was the catalyst for growth in the 20th century, cloud and digital technology will be the catalyst for the 21st century.

An example of cloud based computing is Amazon Web Service (AWS). AWS Internet of Things (IoT) is a managed cloud platform that lets connected devices easily and securely interact with cloud applications and other devices. AWS IoT can support billions of devices and trillions of messages, and can process and route those messages to AWS endpoints and to other devices reliably and securely. With AWS IoT, applications can keep track of and communicate with all devices, all the time, even when they are not connected.

AWS IoT makes it easy to use AWS services and build IoT applications that gather, process, analyze and act on data generated by connected devices, without having to manage any infrastructure.

Cloud based infrastructure can host not only connected devices, ATMS, VMS, and ITS technologies, it can also host and provide an ever-connected database for other smart city technologies such as smart lighting and smart parking systems.

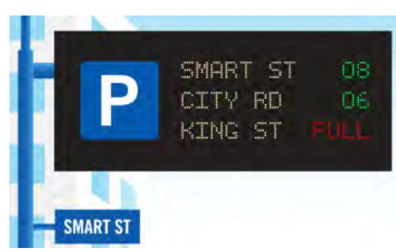
Since cloud based connectivity is provided by 3rd party hosts, re-occurring costs for these services can vary based on the use case, demand, and access by end users. Typically, costs can range from a few hundred to a few thousand dollars per month, per subscription.

3.2.6 Smart Lighting systems

Modern commercial outdoor lighting systems are being asked to do more than ever before. In addition to fulfilling their primary purpose of casting light onto dark roadways, parking areas, and public spaces, outdoor lighting systems are increasingly evaluated for how well they reduce energy consumption, improve safety for both pedestrians and drivers, and serve as the foundation for a range of Internet of Things (IoT) applications.

Intelligent street lighting refers to public street lighting that adapts to movement by pedestrians, cyclists and cars. Intelligent street lighting also referred to as adaptive street lighting, dims when no activity is detected, but brightens when movement is detected. This type of lighting also has the ability of dimmable street lighting that dims at pre-determined times.

3.2.7 ITS for Parking Facilities



Today's ever-increasing traffic volumes also require increasingly efficient solutions for parking information and guidance. Up to 25% of inner city traffic is due to motorists looking for a parking space. Parking guidance systems not only reduce search and transit times, but also contribute to better traffic flows on city streets and reduced vehicle emissions in our cities. Clear guidance for the drivers is a key element for this.

LED parking signs are designed to assist motorists in getting quickly to a free parking space by directing them to parking lots/locations where occupancy levels are low. The objective is to reduce search and transit times, which in turn reduces congestion on the city road network with subsequent benefits for air quality and living conditions in the urban landscape.

3.2.8 Smart Parking Systems

Smart parking systems can improve a “Smart” City's parking revenues by 20-30%. The latest generation of these systems combines low cost, in-street sensors with payment stations, back-end management and enforcement software, and smart phone customer access portals, to deliver:

- New conveniences for visitors and residents – created by available parking spot locations, flexible payments, fees, and parking spot reservations – all through an easy to use smart phone applications
- Increased revenues are created from the introduction of new services and fees, such as: time of use charging, premiums for reservation services, and less meter downtime
- More efficient directed parking enforcement, achievable through real time violation notifications sent to patrolling enforcement officers
- Significant reduction in city-wide traffic volumes and emissions due to reduction in driving time to find open parking spots

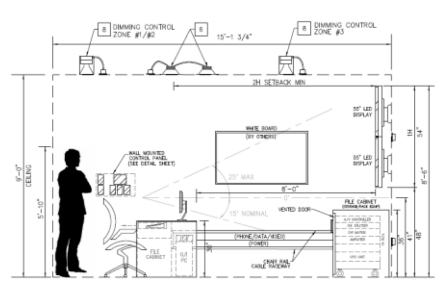
Intelligent Parking Systems (IPS) single-space meters provide customers and patrons with a simple and consistent parking user experience which is more cost-effective, customer friendly, and more reliable than older technologies/alternatives. The IPS smart meters provide a credit card enabled single-space meter mechanism that retrofits into current on-street parking meter housing. IPS smart meters offer multiple payment options (credit/debit card, contactless payment, coins, smart card, and tokens), access to real-time data, solar power technology, and a comprehensive web-based management system.

The IPS Data Management System (DMS) is a secure, web-based application that allows clients to manage an entire parking meter network with ease. The DMS provides clients with a comprehensive set of financial, technical, and administrative reporting features and remote meter configuration capabilities, forming an intuitive and powerful smart parking solution. Key features include:

- Ability to seamlessly integrate meters, vehicle sensors, and pay-by-cell applications into a single back end system.
- No need for local software or new hardware installation.
- Maintains the latest in encryption and internet security.
- Real-time data available 24/7/365 from any web-enabled device.

3.2.9 Traffic Management Center

A Traffic Management Center (TMC) is essentially the heartbeat of a traffic network, and provides a physical operations center for traffic signal staff and operators to view the ATMS traffic data network and CCTV surveillance system in real-time, provide incident management, arterial management to review recorded/historical data, generate reports and make adjustments as necessary to facilitate traffic operations through-out the city/region. Typically, TMCs are a single facility that will house all centralized functions necessary for traffic signal and ITS operations. The TMC is capable of supporting all operations and maintenance functions associated with the ATMS, TMS, VMS, communications network, and other ITS related systems. Overall, the goal is to view and manage the city/region's arterial traffic, maintain and monitor traffic signal timing and synchronization; and as a result, to reduce traveler commuter times and maximize roadway capacity from a centralized location.



TMCs are dedicated rooms or centers comprised of operator workstations, video display walls (15'-20' preferred), data or server centers, and storage capable of supporting all host systems and personnel to operate and maintain the system. There are many other factors to consider when designing and deploying a TMC, such as: architectural enhancements, furniture, lighting, HVAC, electrical, mechanical, plumbing requirements, accessibility and security.

ATMS hardware and software costs are often a concern to any TMC budget. A centralized ATMS software should be capable of interfacing with several other systems including traffic monitoring systems (TMS), video management systems (VMS), communications network and other ITS sub-systems, such as changeable message signs (CMS) or arterial management systems. It should be noted that each of these sub-systems represents additional costs and staffing to operate and maintain.

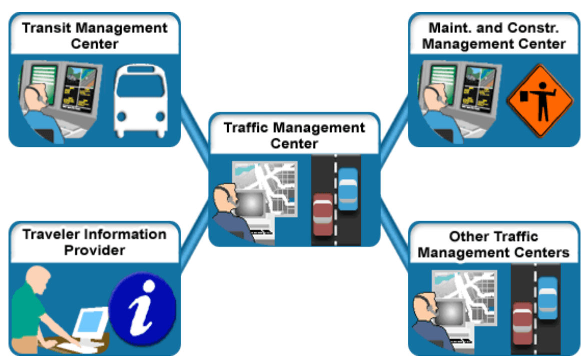
In addition to core central systems, planning and design of LED video walls would give the TMC operator a greater field of view to remotely manage and maintain the traffic signal network. LED video walls and video wall controllers feature bandwidth for high resolution and high frame rate performance. If there is not enough space LED video walls; large wall mounted video monitors are typical for smaller TMC installations. Overall, the TMC should provide the operator with the capability to view and manage CCTV systems and ATMS.

Center-to-Center (C2C) communications is another important factor when determining the design and deployment of a traffic management center(s) where the goal is to provide shared two-way traffic data and CCTV video feeds across jurisdictional boundaries. The first step in establishing C2C communications is identifying center-to-center intertie points. For instance, locations along city boundaries with shared fiber optics can provide for a high-bandwidth connection to each TMC center for shared traffic data and video images. A fiber sharing plan should be established, with dedicated fiber strands physically connecting to each TMC. This shall be implemented through the planning process and agreements shall be established to maintain the physical connection including the use of traffic data and video feeds.

Other types of connections between centers such as site-to-site Virtual Private Network (VPN) access could provide traffic data transfer; however, it may have latency issues/support of full streaming video images as these are much more data intensive. NTCIP compliancy and ONVIF standards requires open source communications between modern ATMS and CCTV systems that are supplied by different manufacturers. Therefore, these systems should be able to interface. However, further investigation needs to be performed to identify exactly what messages and data flags are sent through the standard protocols, either locally from center to field, or from center to center, in order to determine compliancy. Different manufacturer's often use different protocols for communication; therefore, a thorough review must be performed during the design phase of the project to identify potential C2C communications between local agency and regional TMCs.

3.2.10 Regional Traffic Management Center

For a successful deployment of corridor synchronization and signal operations across adjacent agencies, a regional and/or area wide Traffic Management Center (TMC) should be considered. Many local cities/agencies traffic signal systems operate on different traffic controller firmware and/or TMS software; therefore, center-to-center (C2C) communications or an area wide TMC would provide for shared traffic signal information on an arterial between regions and with other local cities/agencies.



A regional TMC would provide the capability to monitor, optimize and maintain coordination of traffic signals between agencies, shared data and video on major arterials including performance measure reporting, with shared maintenance practices and resources. Agencies can maintain control of their systems and through cooperative agreements or memorandums of understanding, traffic data and video can be shared with partner agencies and stakeholders for viewing purposes only. This may be accomplished by implementing strategies like C2C communications, sharing communications over fiber optic, copper or wireless, and remote access to traffic and/or video management systems. It can facilitate the operations and maintenance of inter-agency signal synchronization programs based on selected signal timing plans approved by the stakeholders. Overall, there is a potential cost/time savings through addressing regional operations across jurisdictional boundaries, rather than monitoring within City boundary to City boundary at the local agency level. This requires coordination and cooperation with partner agencies that share major arterial roadways.

3.2.11 TMC Operations and Maintenance Costs

The purpose of this section is to provide an overview of the typical operations and maintenance level of effort and associated costs after installation and deployment of a local or regional TMC. Operations and maintenance costs should be understood during the planning stages and programmed into each agency's budget to maximize their return on investment.

After approved design and deployment of a local or regional TMC, there are operations and maintenance (O&M) costs associated with operating and staffing a dedicated TMC. Generally, staffing requirements can be broken down into three (3) distinct areas: in-house, outsourcing or facilities management staffing. Staffing can further be broken down into different sub-roles, such as: System Administrator or Traffic Engineer (TE), TMC operator and Technology (IT) support.

In-house staffing would comprise of a team of dedicated staff to perform daily traffic operation tasks and regular maintenance on their traffic signal system. It is envisioned a new system will require additional training regarding operations and maintenance on the new ATMS, CCTV and other ITS systems. Ideally, this would be a preferred option since all operations and maintenance is performed within the same organization.

Outsourcing of TMC staffing results in additional costs to the organization on an annual basis, however could be the solution for agencies without the resources for dedicated Traffic Engineers, TMC operators and IT support. Private consulting firms often have the knowledge and expertise to manage independent traffic systems either remotely via VPN or on-site for dedicated number of hours per day.

Facilities management or traffic technicians (outsourced or in-house) can provide a part-time overview and surveillance of the system remotely at a city yard; however, mostly do not have 4 or more hours dedicated in a day to perform TMC daily tasks.

Actual costs associated with operations and maintenance staffing is not detailed in this chapter, but it is important to understand the type of staffing required to perform the proper TMC maintenance and operations.

3.3 Communication Network ITS Technologies

3.3.1 Communication Systems

Today's communication systems typically rely on Ethernet/IP-based communication protocol and is one of the single most important factors when considering deploying new ITS technologies. Conforming to Institute of Electrical and Electronics Engineers (IEEE) industry standards, IP is the method of transmitting information across a data (digital) network and will be used through-out the design phase of this project. As Intelligent Transportation Systems (ITS) migrate towards full digital systems, IP is used increasingly to connect controllers, cameras, Ethernet switches and other ITS devices throughout a traffic signal and arterial communcation network. It's usage can be over both hardwired and wireless technologies, including fiber optic cable, Ethernet-over-Copper, and wireless Ethernet broadband applications. Using IP-based systems can provide other operational benefits. Device configuration, control and adjustment can be acheived remotely when deployed over a suitable Ethernet/IP-based data network.

Its important to understand the advantages/disadvantages of each communication medium in addition to the different sub-system interface requirements, such as high bandwidth CCTV video feeds. Therefore, during the final design stages, bandwidth calculations shall be provided to determine optimum type of communication medium (e.g. fiber, hardwired, wireless) and to verify that adequate bandwidth is provided for near and future term conditions. **Table 3.10** summarizes the various communication types, key features, various/typical manufacturers (not all), and estimate costs in terms of low ($) to high ($$$).

Table 3.10 - Communication Systems Matrix

Communication Type	Key Features	Manufacturer	Estimated Cost
Hardwired/Twisted-pair SIC	Low/medium (VDSL) bandwidth, lower cost, easier to maintain	Various	$
Fiber Optic Cable	Highest bandwidth, low MTBF	Corning/ Draka/ AFL	$$$
Wireless Ethernet Broadband	Medium/high bandwidth, Flexible deployment	Various	$$

The following sections summarize each communication medium in more detail about their system and key system features. This information provides a high level of understanding, and it can be used to compare each system.

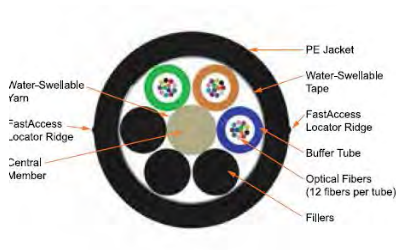
The following summarizes the three primary communication mediums:

Hardwired/Twisted-pair Signal Interconnect Cable (SIC)

- Dedicated communication line. Costs are associated with conduit/cable installation and maintenance
- Types/Sizes
  - 6/12/25 Pair #19-22 AWG
- Communication Equipment
  - Modems (Analog)
    - Provides Low Bandwidth over a long segment
  - Ethernet-over-Copper (VDSL) (Digital)
    - Dedicated communication line. Costs are associated with new switching equipment. Savings are provided by utilizing existing SIC cable
    - Managed Ethernet/IP Switch (VDSL protocol)
    - Provides low/medium bandwidth depending on the amount of data/video transmissions and segment length

Fiber Optic Cable (FOC)

- Dedicated communication line. Higher costs are associated with conduit/cable installation and maintenance
- Types/Sizes
  - "Single mode" fiber optic (SMFO) cable typically used for long transmissions distances
    - Industry standard for traffic signal and ITS communications (outdoor)
    - Strand numbers range from 6 to 244+ count
  - "Multimode" fiber optic (MMFO) cable typically used for shorter transmissions distances
    - Primarily used for computer networks (indoor)
    - Strand numbers range from 6 to 244+ count
- Communication Equipment
  - Ethernet/IP Switch
  - Modem (Analog)
  - Transceiver (Analog)
- Provides highest bandwidth and reliability over any distance



Wireless Communications (Ethernet Broadband)

- Dedicated wireless communications. Costs are associated with the initial installation and maintenance
- Types
  - Microwave, V/E Band

- Spread Spectrum
- Radio
- Network Types
  - Point-to-Point network
  - Point-to-Multipoint network
  - Star
  - Mesh
- 4G/5G Cellular wireless

- Communication Equipment
  - Injector of Power over Ethernet (PoE) device
  - IP over managed Ethernet switch
- Provides medium/high bandwidth over a medium segment length

3.3.2 Layer 2 / Layer 3 Ethernet Switches (Managed)

Ethernet based Layer 2 / Layer 3 swicthes are a crucial component in the transmission of two-way traffic data and video communication. Also conforming to IEEE standards, Layer 2/ Layer 3 managed switches used in the traffic industry are typically hardened units used to withstand the extreme temperatures and vibrations in a roadside cabinet environment. Edge based Layer 2 switches are typically found in the cabinet, while high-bandwidth core Layer 3 switches are usually deployed at TMC and field communication hub locations for aggregation and routing of key traffic networks. Layer 3 switches has more management capabilities such as the ability to create multiple sub networks together at the core level, commonly known as Virtual Local Area Networks (VLANs), and built in security (e.g. firewalls). Both Layer 2/ Layer 3 switches typically provide RJ-45 network and Small Form-Factor Pluggable (SFP) modules/fiber optic interfaces.

3.3.3 Layer 2 Hardened Ethernet Switch (Managed)

Layer 2 hardened switches typically have a 4-12 port count and are used to connect to the traffic signal controller, CCTV, wireless or other ITS interface located inside the controller cabinet. The fully managed switching platform combines high performance switching backbone with robust and secure management features required for mission critical and harsh environments where sustained connectivity is crucial. Users are able to access management features such as: port security, IGMP snooping, VLANs, GARP protocols, LACP, and via web browser, Telnet, SNMP, RMON, TFTP, and RS-232 console interfaces.

- Wide operating temperature range from -40°C to 75°C (-40°F to 167°F) for extreme environments (NEMA Rated)
- Fanless and ruggedized housings
- IEEE802.1x, ACL (Access Control List), and RADIUS support

3.3.4 Layer 3 Ethernet Switch (Managed)

Layer 3 switches typically have 24 port count or higher and combine multiple sub networks together at the core level. Layer 3 routing technology can integrate and efficiently manage all ITS components over the entire communication network. At the Layer 2 level, this cannot be achieved. The Layer 3 non-blocking architecture delivers extremely fast functionality; in addition to static and dynamic routing, this also includes multicast routing and router redundancy. This performance-enhanced routing platform delivers wire-speed Wide Area Network (WAN) throughput, even with advanced services like VQM, QoS, NAT, etc. Key features include:

- Gigabit Ethernet (GE) ports with non-blocking architecture
- PTP IEEE1588v2 on board, accuracy 30 ns
- Highest flexibility through GE combo ports
- Extensive Layer 3 software
- Fastest ring recovery times
- Ability to create Virtual Local Area Networks (VLANs) for traffic signal, communications, and ITS element management
- Built in security (e.g. firewalls)

3.3.5 Ethernet-over-Copper Switch (VDSL)

Upgrading an existing legacy control or surveillance system to a new IP-based system is a complicated task, especially when existing cable infrastructure is hardwired/twisted pair copper cable. In areas where there are existing hardwired/twisted pair cable, this fully managed switch allows Ethernet/IP-based communications and seamless integration with existing network infrastructure (e.g. hardwired/twisted-pair copper cable). Based on VDSL2 technology, RJ11 terminal block extender ports provide long distance up to 7,200 feet over existing hardwired/twisted-pair copper (SIC cable). Typically, all pairs of copper cable are tested prior to connectivity in order to ensure continuity and provide the best communications. It should be noted that bandwidth is limited and degrades over distance between devices.

3.3.6 Small Form Factor Pluggable (SFP) Module(s)

Small Form-Factor Pluggable (SFP) modules allow for an optical or electrical interface when using an Ethernet/IP-based managed switch, unmanaged switch or media converter. These interchangeable SFP modules are available for use with copper media, multimode optical fiber, or single mode optical fiber. The optical fiber SFP modules are available in fast Ethernet, one Gigabit or ten Gigabit fiber versions. They also are available with LC or SC optical connectors. Different SFP modules offer different wavelengths and optical power budget to allow distances from 1,000 feet to 75 miles. Most traffic rated

SFP modules are industrially rated to perform in the most difficult operating environments. Typically, number and type of SFPs are specified when ordering the equipment to accommodate the current design, but they can also be added if the system gets expanded at a later date (as long as there are available ports).

3.3.7 Security Appliance (Firewall)

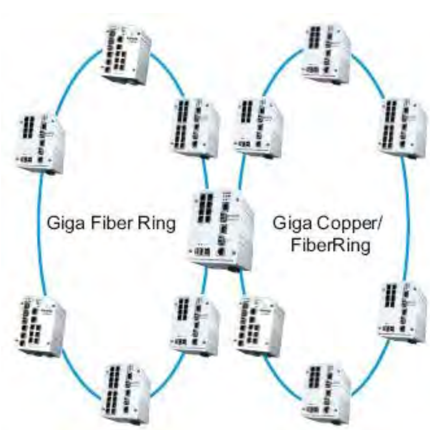
As we migrate to the digital Ethernet/IP-based and cloud-based networks, cyber security is an increasing concern throughout the industry; therefore, transportation system owners/operators are in need of a resource for identifying, alerting, and advising on cyber security incidents specific to transportation systems. Network firewalls are a software appliance running on general purpose hardware or hardware-based firewall computer appliances that filter traffic between two or more networks. Host-based firewalls provide a layer of software on one host that controls network traffic in and out of that single machine. Today's next-generation firewalls can protect a traffic network from outside intrusion and advanced malware protection.

Network security firewalls also provide other advanced functions such as:

- Site-to-Site remote access and remote VPN login access
- Heirarchial visibility & control
- Highly effective threat prevention with full awareness to users, infrastructure, applications and content
- High availability

3.3.8 Networking Practices

Networking practices in the ITS field is much different than traditional networking inside of a building. A traffic network deployment requires an outreach to all roadside elements that are spread across entire City limits. This type of layout is commonly referred to as a WAN (wide-area network) or MAN (metropolitan-area network). Connection to all roadside devices requires careful design and layout as an unplanned break or cut in a fiber, hardwire or wireless link could disrupt traffic to all downstream devices. Therefore, a commonly deployed topology in a WAN traffic network layout is a "self-healing" ring topology. Many times, communication hubs are established in the field and are connected to the ring to facilitate the topology, while ring typically terminates at the TMC or the network core.



There are key considerations in networking design and layout. As shown in the image below, a fiber optic "ring" provides redundancy and failsafe within a system. By designing and providing both physical and logical links throughout the network, we are able to overcome physical layout constraints as they arise. Additional key considerations are:

- **Reliability:** Reliability of fiber optic cable systems in telecommunications systems is an important consideration of the system design. Cable reliability is directly related to the number of cable breaks and failures in a telecommunication system. In general, fiber optic cable has been proven to be more reliable and have a longer service life than hardwired/twisted-pair copper cable. Fiber optic cable installations have been in service for 30 years and longer.
- **Redundancy:** Redundant links between field equipment have been established so that a break in any single fiber will not result in a system failure. In addition, field switches with redundant links helps provide load sharing between devices and ensure stable network performance should a switch fail or a power disruption occur.
- **Routing Protocols:** Ethernet ring protocols are a technology implemented on Ethernet switching devices and intelligent service edge routers. Requiring no hardware upgrades, ring protocols are designed to provide network and application convergence typically within 50 ms.

In addition to topology layout, common practice for two-way transmission of multiple ITS networks over the same physical link is implementation of VLAN's (Virtual Local Area Network). Creating VLAN's can keep network data and video separated; VLAN's can be created to virtually separate communications for each type of ITS element. The benefit of setting up VLAN's per ITS element, is that it reduces the likelihood of failures and cross-talk if one system goes down or malfunctions. For example: if the CCTV camera system malfunctions or fails, it will not disrupt the communications to traffic controllers and vice versa. Layer 2 and Layer 3 functionality provide management of VLAN's so each agency has better control over their entire ITS network. Additionally, it provides scalability and the ability to combine different networks or connect different agencies for Inter-Agency or Center-to-Center communication.

3.3.9 Wireless Communication Systems

Wireless Etherent broadband communication systems is a growing market with many different products available off the shelf. Most modern wireless radios rely on Ethernet/IP-based communication protocol conforming to Institute of Electrical and Electronics Engineers (IEEE) and Federal Communications Commission (FCC) regulations. Multiple frequencies exist in the licensed/unlicensed range. The most common unlicensed frequencies used in the traffic industry are; 2.4 GHz, 4.9 GHz, and 5 GHz (5.1-5.8 GHz) range. Very recently, the 5.9 Ghz range has been reserved by the FCC for Dedicated Short Range Communications (DSRC) for use by Connected Vehicles and V2X infrastructure. Standard radio configurations are point-to-point, point-to-multipoint, star or mesh topology. Wireless communication systems have an advantage over hardwire communications in that it costs less intially to install and operate. However, hardwire communications are typically more stable long term as wireless communication systems are more subsceptable to interference/data loss in the form of weather, rain, wind, vibration and distance. **Table 3.11** summarizes the various wireless frequency types, key features, and various/typical manufacturers of these systems.

Table 3.11 - Wireless Broadband Matrix

Wireless Frequency Type	Key Features	Manufacturer
2.4 GHz	Wi-Fi hotspot	Various
4.9 GHz	Public Safety band	Various
5 GHz	Unlicensed band, up to 300 mbps	Various
5.9 GHz DSRC	Dedicated for V2X	Various
Microwave E/V Band	High-bandwidth, fiber like performance	Proxim/Siklu/Cambium

The following sections summarize each type of frequency bands in more detail including the typical usage or application.

2.4 GHz Wireless

Once used as the primary band for legacy wireless broadband transmission, 2.4 GHz range is seldom used for ITS traffic data and video transmission. However, a resurgence of the 2.4 GHz band can be used via a Wi-Fi "hotspot" for motorists or other users' transverse a traffic signal within 300 meters (typical). Integration of a 2.4 GHz band can be incorporated into a 5 GHz radio for both use cases within a single roadside unit.

4.9 GHz Wireless

Similar to 2.4 GHz or 5 GHz wireless outdoor units, 4.9 GHz frequency band is reserved for the public safety spectrum and mobile services. Therefore, various city traffic divisions may successfully utilize this band for wireless Ethernet broadband communications in parallel or conjunction with police or public safety efforts.

5 GHz Wireless

The open range of 5 GHz wireless radios have enabled the traffic industry to deploy local point-to-point and point-to-multipoint configurations to establish local traffic signal communication. Ranging from 5.1 GHz - 5.8 GHz, these rugged outdoor units are capable of providing a 300 Mbps Ethernet bridge reaching up to 15 miles. New units typicall utilize state of the art Multiple-Input Multiple-Output (MIMO) technology that achieves a very high data rate through a combination of multiple spacial streams and higher level OFDM modulation. Typically used to link fringe IP devices such as video surveillance cameras needing robust and secure high data rates, or other last-mile ITS components or siganlized intersections.

5.9 GHz DSRC Wireless

Dedicated Short-Range Communications (DSRC) technology is the dedicated network space reserved exclusively for transportation-related uses. The Federal Communications Commission (FCC) set aside 75 MHz of spectrum around the 5.9 GHz band (5.850-5.925 GHz) to be used for vehicle-related safety and mobility systems only.

DSRC will be used for both vehicle-to-vehicle (V2V) communications as well as vehicle-to-infrastructure (V2I) communications. The spectrum is seen as particularly useful for vehicle-to-everything (V2X) communications because it can support very low-latency secure transmissions, fast network acquisition. In general, this technology has the ability to handle rapid and frequent handovers that are inherent in a vehicle environment; as well as being highly robust in adverse weather conditions. The 75 MHz spectrum makes it tolerant of multi-path transmission. Modern day vehicles deployed today are already using this techonology to talk to like vehicles (of the same manufacturer) or roadside signal infrastructure in smart city locations.

Microwave, E/V Band (Back-Haul) Wireless

Typically reserved for backhaul links from site-to-site locations, microwave and E/V band offer fiber optic like wireless performance. High speed licensed Point-to-Point (PtP) microwave and E/V band typically operate in the 23 GHz, 60 GHz, 70 GHz, or 80 GHz licensed bands with up to 2 Gbps full duplex capacity for backhaul networks, broadband or video surveillance connectivity. It supports an array of user configurable channel bandwidths and hitless automatic modulation up to QAM 256. It is a suitable replacement for fiber optic cable where installation on underground conduit is not feasible. Key features include:

- Interference-free band facilitates fast frequency planning with carrier-grade performance
- Field proven advanced all-silicon integration increases reliability
- Hitless adaptive bandwidth coding and modulation, synched with user configurable 8 levels H-QoS, ensure correlated payload prioritization
- Highest full-duplex 2 Gbps capacity can be achieved

3.3.10 Center-to-Center Communications (C2C)

A standards-based NTCIP approach can assist system applications, regardless of operating system or programming language, to communicate using simple encoded messages that both applications understand. Specifically, the goal related to development of an XML-based C2C standard is to support the inter-agency communication of traffic data information and/or control commands between traffic operations centers.

ITS communications requirements are often divided into two categories according to the general environment in which the communications take place. One category is center-to-field communications, such as occurs for remote management of field devices and fleet vehicles. The other category is center-to-center communications. Many C2C platforms today communicate over industry standard Simple Object Access Protocol (SOAP) messages or XML file based approach. The implementation of C2C communication is the foundation of Inter-Agency communication, where an ATMS from one agency can be connected to an ATMS from another agency, and have the capability to share data between systems from the same or different manufacturers.

3.3.11 ITS Asset and Maintenance Management Software

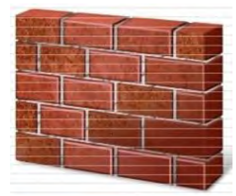
When in comes to the system integration and connectivity to switches in the field and other offices, there are assset and maintenance management software that is available in order to set-up and configure the network (e.g. network scheme, assigned IP addresses, map asset locations, etc.). This software is typically included with the type of network switch purchased, it may also come from a third party.

Software such as Industrial IT asset and maintenance software management tools enable the integration of SNMP-enabled devices from different manufacturers into a single network management application. This includes network switches, CCTV's, controllers or other SNMP ITS devices. Therefore, this software offers maximum network visibility to the end-user. Using MultiConfig, hundreds of devices can be configured simultaneously, even while they are in operation. This not only saves time, but also ensures consistent configuration of the network infrastructure. Since the network topology is recognized automatically, all the network nodes and links are accurately displayed on screen, including any unmanaged switches and hubs. This means that the display always shows the exact network status, including security threats, and faults can be located quickly. Industrial clients are made available free of charge and license fees are payable only for the server. Key features include:

- Assign various rights and levels of access to the network through the new user roles feature, increasing application security and regulatory compliance. These rights include read-only, read/write, the ability to create additional users, and whether a user can access the Industrial server through a web browser

- Access all systems they need with one username and password through the single sign-on function, review a comprehensive history of user actions through the audit trail feature and apply standard security functions with the security lockdown feature across all devices with just a few clicks

3.3.12 Cyber Security



Network security is the process of taking physical and software based approach and measures to protect underlying networking infrastructure from unauthorized access and misuse. Cyber security is an increasing concern in the industry; therefore, transportation system owners/operators are in need of a resource for identifying, alerting, and advising on cyber security incidents specific to transportation systems. This includes infrastructure, investigating potential system vulnerabilities, and education and awareness training. Traditionally, front-end hardware security devices such as a firewall, provided security intrusion; however, network security needs to be broken down into two of the following common segments for local agencies to adhere:

- *Physical Security*
  - Each traffic control cabinet on the street should have an applicable locking mechanism to prevent intrusion. An unauthorized person that enters a traffic control cabinet could access the IP network and have unlimited access to the entire network – both cabinet to cabinet and cabinet to central operations

- *Logical Security*
  - Wired Networks – To help restrict unwanted traffic onto the network, firewalls are the easiest first step. Additionally, port security should be enabled
  - Wireless Networks – With wireless connectivity its recommend to enable encryption. Also, if it is not needed, disable the Service Set Identification (SSID) Broadcast feature

3.4 Multi-Modal Transportation Solutions

3.4.1 Traffic Signal Synchronization

Traffic Signal Synchronization is a traffic engineering technique to coordinate the green lights for a series of intersections along a corridor to enable the maximum number of vehicles to pass through, thereby reducing vehicle travel time and stops, fuel consumption and emissions of greenhouse gases (GHG), and other air pollutants from vehicles.

Traffic signal synchronization works by calculating the arrival time for a group of vehicles at each intersection traveling at a specified speed, and then strategically timing the traffic signals to turn green just as the group of vehicles arrive at each intersection. In order for the traffic signals to be synchronized, a group of signals must all be set to run on the same cycle length (the amount of time it takes for the signal to go from green to yellow to red; and back to green again, after the cross street has been serviced).

A key consideration in performing regional signal synchronization projects is to ensure that the ITS planning process is followed closely. This process is a systems engineering process that outline the steps to develop a successful system involving multiple agencies, multiple travel modes, and different operators. It starts with identifying the systems engineering management plan framework, developing a Concept of Operations, identifying system requirements and project architecture, designing components and infrastructure, and conducting software development, testing, systems integration and validation, leading to an operations and maintenance manual.

Sustaining effective traffic signal coordination, both within and across jurisdictional boundaries, has proven to be a daunting task for an increasing number of transportation agencies responsible for managing and operating traffic signal systems. An increasing number of agencies are realizing that a regional approach to managing and operating traffic signal systems may be a viable alternative to independently sustaining the funding and technical expertise essential to effectively managing a traffic signal program. Interestingly, the challenges to regional traffic signal operations are typically not technical, but rather institutional. Cross-jurisdictional traffic signal coordination provides substantial benefits to the motorists by establishing consistent signal operations across a region, as well as making the typical reductions in travel times, stops, fuel consumption, emissions, and delays. Transportation agencies responsible for managing and operating traffic signals can benefit from a regionalized approach to traffic signal management by pooling resources to provide ongoing staff training, development of signal timing plans, operations, and performance of maintenance activities.

The following are typical steps necessary for planning, development, and maintenance of regional synchronization corridors:

- ***Planning Phase***
  - Conduct data collection of as-built plans, timing sheets and turning movement counts
  - Perform 'Before-Study' to establish existing traffic conditions
  - Conduct field reviews of traffic signal configuration, signal timing parameters, intersection lane configuration and posted speed limit. Review signal operations at Traffic Management Centers (TMC)
  - Conduct field reviews of hardware, communication status and clocks; review controller timings.

- ***Design Phase***
  - Design communications and traffic signal hardware upgrades to allow local agencies to manage and monitor traffic operations from their respective central traffic signal management system.
  - Troubleshoot hardware and communication problems and resolve hardware maintenance issues.
  - Develop signal timing coordination parameters.
  - Provide revised signal timing sheets (that reflect the change on coordination timing), Updated Time-Space diagrams and central traffic signal system database for local agencies to maintain

- ***Implementation Phase***
  - Implement and fine-tune signal timing coordination parameters
  - Perform 'After-Study' and compare results with 'Before Study' to evaluate the 'Measures of Effectiveness' (MOE)
  - Conduct project benefit analysis and provide estimate of "Benefit/Cost ratio"
  - Prepare final report and present project results to City and the local jurisdictions

- ***Operations and Maintenance Phase***
  - Monitor coordination timing plans, intersection operations and TMC operations. Respond to jurisdictions and resident comments
  - Provide revised signal timing sheets (that reflect the change on coordination timing), as necessary
  - Maintain hardware and software installed. Also, troubleshoot hardware failures, and resolved all the hardware issues for equipment installed
  - Present timing plans updates to local jurisdictions

Overall Project Benefits

After a corridor has been synchronized, motorists will experience reduced travel time, stops and delays, as well as significant fuel savings, and the resulting reduction in emissions of air pollutants.

The travel characteristics of a synchronized corridor or measurements of travel performance can be developed based on the following:

- Travel time
- Delay (travel time difference from user-specified speed and distance)
- Number of stops
- Average speed

Evaluation of improvement for each corridor is performed by comparing the travel time performance results of "Before" and "After" conditions. For each parameter, average round-trip results can be computed to estimate the overall improvement from both directions in each corridor. The goal is to achieve optimal improvements in both directions throughout the course of work from design to implementation and fine-tuning, with priority given to the heavier traffic direction. The objective is to reduce travel times and delay, and reduce the number of stops for the highest number of drivers.

In addition to reducing vehicular travel time on the road, fuel savings and reduction of emissions from motor vehicles are other major goals of a synchronized corridor. Therefore, the quantification of fuel consumption and emissions for "Before" and "After" conditions are needed in order to evaluate the benefits of the project

3.4.2 Arterial Management System

Arterial management systems manage traffic along arterial roadways, employing traffic detectors, traffic signals, and various means of communicating information to travelers. These systems make use of information collected by traffic surveillance devices to smooth the flow of traffic along travel corridors. They also disseminate important information about travel conditions to travelers via technologies such as dynamic message signs (DMS), and/or highway advisory radio (HAR), and/or mobile applications and websites.

Many of the services possible through arterial management systems are enabled by traffic surveillance technologies, such as sensors or cameras monitoring traffic flow. These same sensors may also be used to monitor critical transportation infrastructure for security purposes.

Traffic control systems address a number of objectives, primarily improving traffic flow and safety. Transit signal priority (TSP) systems can ease the travel of buses or light-rail vehicles traveling arterial corridors and improve on-time performance. Signal pre-emption for emergency vehicles enhances the safety of emergency responders, reducing the likelihood of crashes while improving response times. Adaptive traffic control systems (ATCS) coordinate control of traffic signals, across metropolitan areas, adjusting the lengths of signal phases based on prevailing traffic conditions. Advanced traffic management systems (ATMS) include coordinated signal operations across neighboring jurisdictions, as well as centralized control of traffic signals, which may include some necessary technologies for the later development of adaptive signal control. Pedestrian detectors, specialized signal heads, and bicycle-actuated signals can improve the safety of all road users at signalized intersections. Arterial management systems can also apply unique operating schemes for traffic signals, portable or dedicated dynamic message signs, and other ITS components to smooth traffic flow during special events.

A variety of techniques are available to manage the travel lanes available on arterial roadways, and ITS applications can support many of these strategies. Examples include parking management systems, most commonly deployed in urban centers or at modal transfer points such as airports, monitor the availability of parking and disseminate the information to drivers, reducing traveler frustration and congestion associated with searching for parking. Organizations operating ITS can share information collected by arterial management systems with road users through technologies within the arterial network, such as dynamic message signs, and/or highway advisory radio, and/or mobile applications and websites. Arterial management systems may also include automated enforcement programs that increase compliance with speed limits, traffic signals, and other traffic control devices.

Sharing information with other components of the ITS infrastructure can also have a positive impact on the operation of the transportation system. Examples include coordinating operations with a freeway management system or providing arterial information to a traveler information system covering multiple roadway and public transit facilities.

3.4.3 Traffic Surveillance and Monitoring System

There are various ITS technologies available in the transportation industry for traffic surveillance and monitoring, including closed circuit television (CCTV), Wi-Fi and Bluetooth travel systems, and system detections.

Traffic surveillance and monitoring systems can provide real-time travel information and video in real-time along selected regional corridors. The goal for implementing these technologies is to provide real-time roadway and intersection traffic conditions, improve traffic mobility and safety along the corridors, and it will enable agencies to respond quicker, and effectively plan special events and emergencies.

There are various CCTV traffic surveillance systems available for the transportation industry. It provides the ability to view in real-time traffic conditions and operations from a remote facility. Today's technology allows agencies' staff to monitor their roadways and intersections from their traffic management centers, mobile phones, or tablets. Key strengths lay on the ability to stream video, perform video analytics, and video management capabilities. Some state-of-the-art traffic surveillance systems have the ability to perform Traffic Video Analytics. These "smart" surveillance systems can provide information on traffic congestion, vehicle speed, wrong direction, vehicle classification, and license plate reader.

CCTV surveillance also supplies relevant information to help law enforcement agencies and emergency services deal with accidents. Road and highway crews can also be dispatched to remove hazards or repair malfunctioning equipment. Cameras can also help mitigate congestion by collecting data on traffic patterns. This information can then be used to reprogram traffic lights and improve traffic flows. IP video streams can be transmitted over wired or wireless networks, so all an agency's surveillance cameras can be easily monitored from a single operations center. The low bandwidth and advanced networking capabilities of IP cameras additionally facilitate this.

Any traffic-responsive control system depends on its ability to detect and manage traffic along arterials and for local intersection control and / or system-wide adjustment of timing plans. A system accomplishes this by using one or more of the following detector types:

- Pavement Invasive Detectors
  - ***Inductive Loop:*** Most common detector technology. Consists of one or more turns of insulated loop wire wound in a shallow slot sawed in the pavement. Loop detectors come in different sizes and shapes, and various configurations can be used depending on the area to be detected, the types of vehicles to be detected, and the objective (such as queue detection, vehicle counting, or speed measurements).
  - ***Magnetometer:*** Measures changes in both the horizontal and vertical components of the earth's magnetic field. Early magnetometers could only detect the vertical component, which made them unable to operate near the equator, where magnetic field lines are horizontal. Newer two-axis fluxgate magnetometers overcome this limitation. Magnetometers are useful on bridge decks and viaducts, where the steel support structure interferes with loop detectors, and loops can weaken the existing structure. Magnetometers are also useful for temporary installations in construction zones.

- *Magnetic:* Consists of a coil of wire with a highly permeable core. Measures the change in the lines of flux of the earth's magnetic field. Can only detect vehicles moving faster than a certain minimum speed, and therefore cannot be used as a presence detector. Useful where pavement cannot be cut, or where deteriorated pavement or frost activity break inductive loop wires.

- Non-pavement invasive detectors
  - *Video Image Processor:* Video cameras detect traffic, and the images are digitized, processed and converted into traffic data. Can replace several loop detectors, and measure traffic over a limited area, rather than just a single point.
  - *Microwave Radar:* Transmits microwave energy toward the roadway. CW (Continuous Wave) Doppler radar can only detect flow and speed. FMCW (Frequency Modulated Continuous Wave) radar can also act as presence detector. Certain bridges with large steel structures can cause problems with radar based systems.
  - *Active Infrared:* Transmits infrared energy from detector and detects the waves that are reflected back.
  - *Passive Infrared:* Does not transmit any energy; detects energy from vehicles, roadway and other objects, as well as energy from the sun that is reflected by vehicles, roadway, and other objects.
  - *Ultrasonic:* Transmits ultrasonic sound energy waves, and measures the distance that the reflected wave travels. Can detect vehicle count, presence, and lane occupancy.
  - Acoustic: Measure vehicle passage, presence, and speed by passively detecting acoustic energy or audible sounds produced by vehicular traffic.

- Specialized detector functions can be provided to monitor different transportation modes or use, including:
  - Transit – Transit Signal Priority.
  - Payment Toll - Automatic Vehicle Identification / Electronic Toll and Traffic Management.
  - Vehicle Height – Over height.
  - Emergency – Vehicle Pre-Emption.
  - Pedestrians – Pedestrian Push Buttons or other technology at signalized intersections.
  - Bicyclists – Detectors at signalized intersections to provide signal timing for bicyclists.

A system can use traffic detectors singly or in combination to measure variables such as presence, volume, speed, and occupancy. Occupancy refers to the percentage of time that there is a vehicle over the detector. Systems use these variables as control parameters at individual signalized intersections, and in other advanced signal control logic. For local control of intersections, the local controller will:

- Process these outputs.
- Compare processed detector information with some preset control parameter or parameters.
- Decide on intersection phasing and timing.

3.4.4 Advanced Traveler Information System (ATIS)

Advanced Traveler Information Systems (ATIS) allow motorists the opportunity to minimize trip delays by delivering accurate on-demand, real-time information on traffic conditions. By having access to up-to-the-minute traffic conditions, travelers can adjust travel routes, modify departure times and consider alternative modes of transportation to gain travel-time savings. The deployment of such traveler information systems could positively impact safety and efficiency in the transportation system. Traveler information falls into two broad categories: pre-trip and en-route. This information may be distributed using several existing and evolving communications technologies. Public agencies have historically collected the real-time information, although information distribution may be by either public or private channels.

Arterial travel information is the process of capturing and sharing performance data to provide real-time information about travel conditions specific to arterials. Disseminating information about road conditions can help travelers with pre-trip planning and en-route decision-making. Types of information that can be shared with the public include current travel times, weather, crashes, construction information, and events. Travelers can learn about conditions on their route that can influence their choice of mode, time of travel, and route choice. The region has an existing 511 system that could be the primary source for disseminating the information, but it current only displays I-10 freeway information and not arterials.

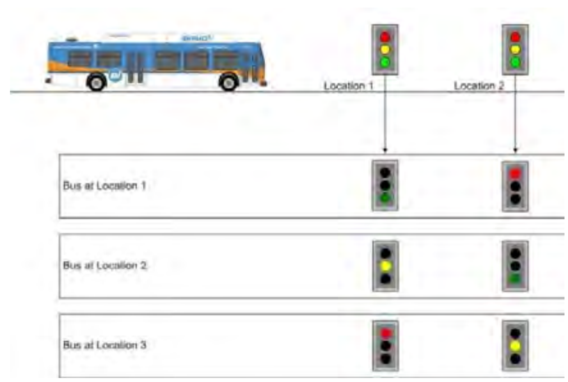
Traveler information options are in a state of significant growth and rapidly changing. User expectations, technologies, and the roles of the major participants in the transportation ecosystem are all in motion.

Traveler information data has moved from being a “siloed” set of data collected for transportation uses to being part of the overall “big data” stream that flows to and from consumers. This stream now includes information about drivers, vehicles, and the network that they both move in, from driving behavior patterns to real-time traffic status on freeways and arterials. Both mobile phones and connected infotainment and telematics-equipped vehicles have become a rich source of these valuable data for private companies, who have uncovered models for monetizing it. As a result, the private sector is moving aggressively to capture, process, and sell traveler information and the resulting services on a global scale. Major data mega-managers, like Waze and Google, have included these data in their offerings and continue to integrate it with an ever-expanding collection of new data and functionality.

Further progress in this direction should be expected, as continuing rapid adoption of smartphones and other smart devices provides a widely available platform for both collecting and sharing data and functionality with consumers. Longer term, further adoption of connected infotainment and connected safety solutions will also add to these capabilities.

3.4.5 Transit Management System

Fixed transit routes are often affected by unpredictable events such as incidents, construction, and weather that may close lanes or entire sections of roadway. The transit agency may be required to re-route buses around a lane-blocking event. It benefits the transit agency to have real-time information about these events when they occur and the approximate duration of the lane-blocking event in order to manage their transit routes, divert buses when needed, and inform customers of a temporary change in transit service. This scenario uses the real-time traffic information collected by the transportation agencies and distributes it through a region-wide interface for the transit agency or other stakeholders to use as support for actively managing the transit service routes.



Bus Rapid Transit (BRT) is a transit program designed to improve capacity and reliability relative to a conventional bus system. It promotes less stops, service reliability, and special amenities, including branding, transit stations with "Next Bus" arrival real-time signs, transit signal priority, signal synchronization, and personal trip planning. A major element is to provide proper communications between the bus and the signalized intersections to provide transit signal priority. It requires cooperative agreements between the transit agency and the local cities in order to implement transit signal priorities within their local signalized intersections.

3.4.6 Incident Management System

Traffic incident management aims to reduce the negative impacts incidents have on the performance of freeways and arterial roadways. Negative impacts can take the form of crashes, disabled vehicles, and weather events, to name a few, and these incidents can occur on a parallel roadway that causes traffic to divert onto adjacent facilities.

Traffic Incident Management is a planned and coordinated program process to detect, respond to, and remove traffic incidents and restore traffic capacity as safely and quickly as possible. This coordinated process involves several public and private sector partners, including: Law Enforcement, Fire and Rescue, Emergency Medical Services, Transportation, Public Safety Communications, Emergency Management, Towing and Recovery, Hazardous Materials Contractors, and Traffic Information Media.

Proactive management of the incident-induced traffic can help to reduce travel delay and the possibility of secondary crashes in the resulting congestion. Cross-jurisdictional planning and coordination, which includes real-time data exchange, is a necessary element of an effective arterial traffic incident management program.

Transportation agencies are typically responsible for the overall planning and implementation of traffic incident management programs. Typically, these agencies are also involved in the development, implementation, and operation of traffic management centers (TMC); reduce non-recurring congestion caused by incident; reduce incident related traveler delay to the absolute minimum while protecting the environment and maintaining safety for the victims, responders and travelers; and improve safety for responders and the travelling public by warning/informing the motorist of real-time unexpected conditions ahead.

3.4.7 Special Event Management System

Major attractions and events are commonly held throughout the year including music and art festivals, county fair, and parades. These planned special events can significantly impact travel safety, mobility, and travel time reliability.

Special event transportation management systems and the use of ITS technologies can facilitate the management and impact of congestion at facilities holding major planned events. By consistently integrating different system components and technologies, the benefits of increased mobility can be achieved. ITS can be applied in a variety of environments, including freeway and arterials, through the use of synchronized traffic signals, closed circuit television, area-wide traveler information services, travel mobile applications, and other technologies and systems. A key aspect of ITS is that these technologies will provide a core communications network, transportation system monitoring, and advanced information processing capabilities that can act as a foundation for the coordinated operation of the transportation system. These key elements make ITS potentially a powerful tool for localities that host planned special events.

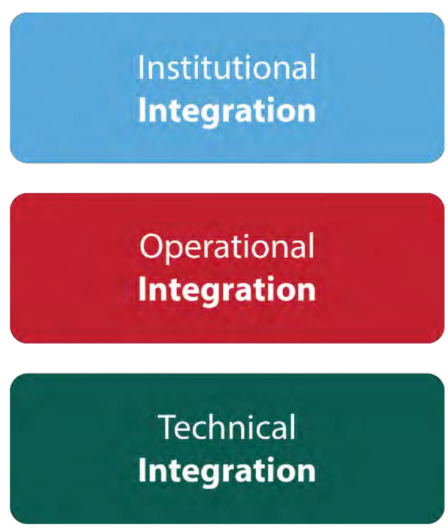
One of the primary goals of transportation agencies is to reduce the amount of travel time for motorists to and from an event. In addition, agencies must minimize the disruption of traffic flow for local motorists who may be passing through the same area or using the same roadways. Many agencies have developed innovative transportation management methods and technologies to help improve planned special event traffic management, including making use of the ITS already installed to manage daily operations and incidents. In addition, the efficiency and effectiveness of traffic operations during planned special events has been shown to be significantly improved by communication and coordination among participating agencies and event stakeholders.

3.4.8 Integrated Corridor Management (ICM)

Integrated Corridor Management (ICM) is an approach to improve mobility by integrating various networks together, so that partner agencies can manage the transportation corridor as a unified multi-modal system. According to the US Department of Transportation, “ICM seeks to optimize the use of existing infrastructure assets, making transportation investments go farther." ICM’s collaborative approach better utilizes scarce resources and aligns City, County, and State transportation goals for the betterment of the region.

The vision of ICM is that transportation networks will realize significant improvements in the efficient movement of people and goods through institutional collaboration and aggressive, proactive integration of existing infrastructure along major corridors. Through an ICM approach, transportation professionals manage the corridor as a multimodal system and make operational decisions for the benefit of the corridor as a whole.

The key to ICM is integrating existing ITS and management efforts with new concepts and relationships to develop a coherent multi-modal, multi-jurisdiction, corridor-wide transportation management system. ICM promotes multi-modal management that supports real-time traffic management, cooperatively develop and implement real-time (active) traffic management to optimize flow, safety and aid regions and the State to meet greenhouse gas reduction (GHG) targets from transportation. Key multi-agency support and commitment is required in order to successfully deliver an ICM Project, including:



***Institutional Integration* – Coordination to collaboration** between the County, Caltrans, and the local cities will be very essential if the corridor is to be managed as a cohesive system, and a large part of ICM involves developing a community of stakeholders who can address corridor needs in a collaborative way. This active collaboration, ongoing organizational cooperation and a more "corridor-centric" perspective, is at least as important as the technical tools available to manage the corridor.

Operation Integration – Joint multi-agency operational objectives and strategies to manage and balance the total capacity and demand of the corridor Multi-agency and cross-network operational strategies.

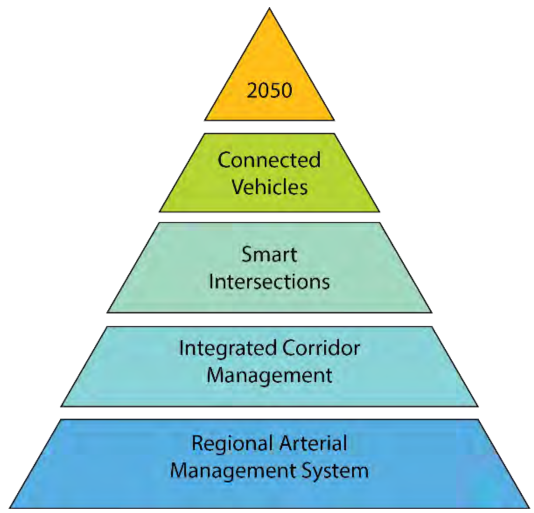
Technical Integration – Sharing and distribution of information, and system operations and control functions to support the immediate analysis and response.

The benefits of implementing an ICM program can be expected in the form of travel time savings, improvement of travel time reliability (reduction in travel time variance), gallons of fuel savings and tons of mobile emissions saved annually.

3.5 Smart ITS Technologies

3.5.1 Connected Vehicles (CV)

Our transportation system is going through some major changes due to advancements in vehicle and roadway, and communications technologies. Short-range dedicated radio and mobile phone technology allow drivers, pedestrians, transit passengers, freight operators, and transportation management personnel to communicate with each other within a connected transportation network. This Connected Vehicles (CV) concept is moving rapidly from the experimental phase into real-world deployments in New York City, Tampa, Florida and Wyoming. As this technology develops and spreads, the public will realize safety, mobility, and environmental benefits improving how we move about our daily lives.



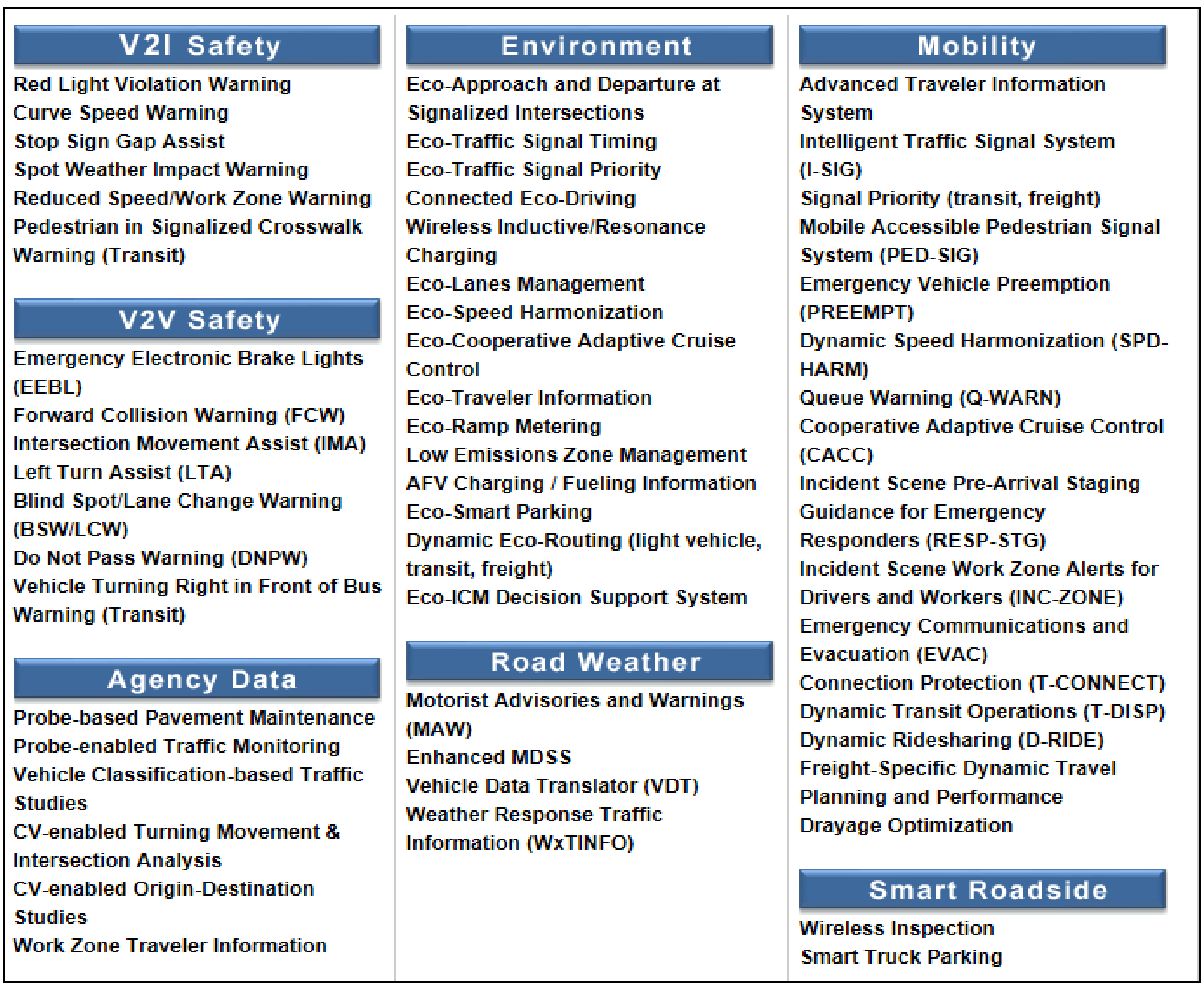
The CV concept refers to the capability of the various elements of our roadway transportation system (pedestrians, bicyclists, vehicles, transit, freight, roadside infrastructure, transportation management centers, etc.) to electronically communicate with each other in real-time. The U.S. Department of Transportation's (USDOT's) Connected Vehicle program is working with State and local transportation agencies, vehicle and device makers, and the public to test and evaluate technologies that will enable to "talk" to one another. Vehicles on the highway, for example, would use short-range radio signals to communicate with each other (vehicle-to-vehicle communications) so every vehicle on the road would be aware of where other nearby vehicles are located. Drivers would receive notifications and alerts of unsafe situations, such as someone about to run a red light as they're nearing an intersection or an oncoming car, out of sight beyond a curve, swerving into their lane to avoid an object on the road.

Over 30,000 motor fatalities occurred every year throughout the United States and connected vehicles could dramatically reduce the number of fatalities and serious injuries caused by accidents on our roads and highways. While the number of people surviving crashes has increased significantly due to new vehicle technologies such as airbags, anti-lock brakes, and other vehicle-technologies, the USDOT is shifting its focus from helping people survive crashes to preventing crashes from happening in the first place.

A widespread deployment of connected vehicle technology is anticipated to provide numerous additional benefits beyond safety. Dedicated short-range communications (DSRC) allow rapid communications (up to 10 times per second) between elements of a connected vehicle network, in particular for safety critical applications. Cellular phone technology is also anticipated to facilitate the use of many connected vehicle concepts. With safety as a primary goal, connected vehicle technology is

anticipated to aid motorists in actively avoiding crashes and other incidents. DSRC technology will enable innovative mobility deployments such cooperative cruise control and vehicle platooning, increasing roadway throughput and reducing congestion and delay. Coordination between vehicles and infrastructure will mitigate unnecessary breaking and stopping at intersections, resulting in reduced fuel consumption and lowered emissions. Road weather information gathered from the various nodes of the system will be gathered and analyzed by transportation management centers, allowing for advanced warnings and more efficient deployment of maintenace staff and improved operations of their roadway systems. A system of connected vehicles has the potential to transform the way we travel through the creation of a safe, interoperable wireless communications network. Various connected vehicles applications are planned to offer a wide range of safety, mobility and environmental benefits, as shown on **Figure 3.2**.

Figure 3.2. Connected Vehicle Applications

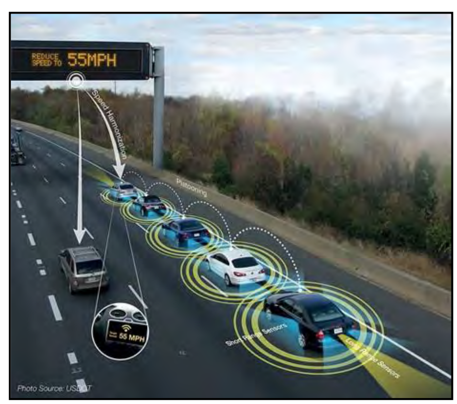


3.5.2 Connected Vehicle Infrastructure

Vehicle-to-Everything (V2X) communications is the passing of information from a vehicle to any entity that may affect the vehicle. Through its instant communication V2X allows multiple road safety applications, such as:

- Forward Collision Warning
- Queue Warning
- Do Not Pass Warning (DNPW)
- Blind Intersection Warning
- Emergency Vehicle Approaching
- Road Works Warning
- Curve Speed Warning
- Red Light Violation Warning
- Cooperative Cruise Control & Platooning
- Vulnerable Road User (VRU) alerts

Vehicle-to-Vehicle (V2V) communications is the wireless exchange of data among vehicles (including cars, trucks, transit vehicles, and motorcycles) traveling in the same vicinity. V2V communication is based on WLAN technology and works directly between vehicles or the infrastructure, which form a vehicular ad-hoc network, as two V2X senders come within each other's range. Direct communications build upon proximity direct communication (300+ feet typically). This latency-sensitive communication is a vital component for V2V safety.



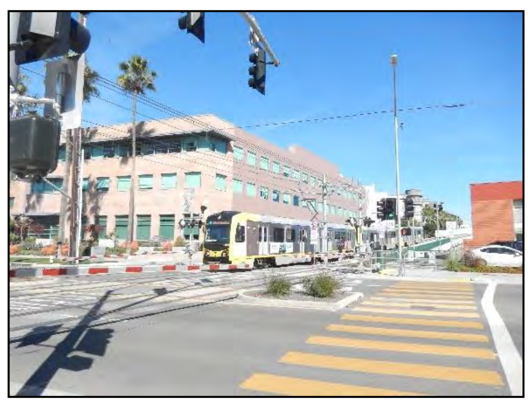
Vehicle-to-Infrastructure (V2I) communications is the wireless exchange of critical safety and operational data between vehicles and roadway infrastructure. This type of network communication utilizes LTE broadcast messages from a V2X server to other vehicles and beyond. This type of communication is more latency tolerant, as it typically involves V2I situational awareness. This includes cellular, Wi-Fi or satellite applications. V2I is the next generation of ITS. Agencies are likely to install V2I infrastructure alongside or integrated with existing or proposed ITS equipment. It is anticipated that the majority of V2I deployments may qualify for similar federal-aid programs as ITS deployments, if the deploying agency meets certain eligibility requirements.

Deploying agencies may use the funds for equipment procurement, installation, preventive maintenance, and operational costs of V2I technologies, provided that the equipment and systems are compatible with the basic connected vehicle standards for interoperability and security standards.

Vehicle-to-Pedestrian(V2P) communications is the wireless exchange of critical safety and operational data between road users including people walking, people using wheel chairs or other mobility devices, passengers embarking and disembarking buses and trains, and people riding bicycles. Pedestrian detection can be implemented in vehicles, infrastructure, or with pedestrians themselves to provide warnings to drivers and pedestrians. Some of the V2P applications in development include:

- **Mobile Accessible Pedestrian Signal System (PED-SIG)** - An application that allows for an automated call from the smart phone of a pedestrian who is blind or has low-vision to the traffic signal. In addition, drivers attempting to make a turn are alerted to the presence of a pedestrian at the crosswalk.
- **Pedestrian in Signalized Crosswalk Warning (Transit)** - An application that warns transit bus operators when pedestrians, within the crosswalk of a signalized intersection, are in the intended path of the bus.

Applications related to connected vehicles could also improve public transportation services. Examples include:



- **Transit Signal Priority (TSP) -** An application that provides signal priority to transit at intersections and along arterial corridors.
- **Connection Protection (T-CONNECT) -** An application that enables coordination among public transportation providers and travelers to improve the probability of successful transit transfers.
- **Dynamic Transit Operations (T-DISP) -** An application that links available transportation service resources with travelers through dynamic transit vehicle scheduling, dispatching, and routing capabilities.

Connected Vehicle communication are accomplished through Wi-Fi based technology, Dedicated Short Range Communication (DSRC) in the ITS band of 5.9 GHz (5.85-5.925 GHz). A dedicated IEEE standard, 802.11p, has been established for the foundation of V2X Communications and the exchange of data between high-speed vehicles with other vehicles and pedestrians and roadside elements. Various V2X technologies include:

- Advanced MIMO
- 256QAM
- Enhanced broadcast
- Low latency
- Unlicensed spectrum
- Dual connectivity, 5G

The roadmap to new OFDM-based 5G cellular coverage will bring new capabilities for the Connected Vehicle beyond existing 4G LTE coverage. The benefits include extreme throughput of 1 Gbps with wider bandwidths, edgeless connectivity i.e. multi-hop coverage, 1 ms end-to-end latency that is faster and more reliable, high reliability through multiplexing and high availability to provide multiple fault tolerant links.

Connected Vehicle Reference Implementation Architecture (CVRIA)

The Connected Vehicle Reference Implementation Architecture (CVRIA) has listed the following roles in implemeting a connected vehicle program:

- ***Enterprise*** - Describes the relationships between organizations and the roles those organizations play within the connected vehicle environment.
- ***Functional*** - Describes abstract functional elements (processes) and their logical interactions (data flows) that satisfy the system requirements.
- ***Physical*** - Describes physical objects (systems and devices) and their application objects as well as the high-level interfaces between those physical objects.
- ***Communications*** - Describes the layered sets of communications protocols that are required to support communications among the physical objects that participate in the connected vehicle environment.

The vision for connected vehicle technologies is to transform surface transportation systems to create a future where:

- Highway crashes and their tragic consequences are significantly reduced.
- Traffic managers have data to accurately assess transportation system performance and actively manage the system in real time, for optimal performance.
- Travelers have continual access to accurate travel time information about mode choice and route options, and the potential environmental impacts of their choices.
- Vehicles can talk to traffic signals to improve mobility and reduce delay, and help drivers operate vehicles for optimal fuel efficiency.

Connected vehicle safety applications will enable drivers to have 360-degree awareness of potential hazards and crash situations—even those they cannot see. In-car warnings will alert drivers of imminent crash situations, such as merging trucks, cars on the driver's blind side, or when a vehicle ahead brakes suddenly. Connected vehicle technologies will generate real-time data that drivers and transportation managers can use to make green transportation choices. For instance, informed travelers may decide to avoid congested routes, take alternate routes, use public transit, or reschedule their trip—all of which can make their trip more fuel efficient and eco-friendly.

Potential benefits of a Connected Vehicle Program Include:

- Increases in safety, mobility, system efficiency, and access to resources for disadvantaged groups, and decreases in negative environmental impacts such as vehicle emissions, the need for physical expansion, and noise.
- Decreases in undesirable transportation impacts to the environment and society.
- Increased opportunities to partner with non-government groups, such as private industry and universities.
- Real-time and real-world data to help with transportation planning and transportation system operations.
- Demonstrations of CV environments that fit into real-world environments of today.
- Reduction of fatalities through weather-related, safety, infrastructure-based, and other applications.

Additionally, connected vehicle road weather applications will assess, forecast, and address the impacts that weather has on roads, vehicles, and travelers. Data from connected vehicles provide the opportunity to pinpoint where and how weather is affecting the roadways, thus leading to greater understanding of the scope of road treatments and mitigation strategies during inclement weather, greater quality of the information provided to drivers and travelers, and greater details for producing more targeted traffic management strategies.

A Connected Vehicle platform has many parts that need to be in place for it to be working on the street successfully. Whether these solutions are provided by the Original Equipment Manufacturer (OEM) or 3rd party integrators, generally there are four (4) different areas of CV technology that need to be implemented for a working deployment. These areas are:

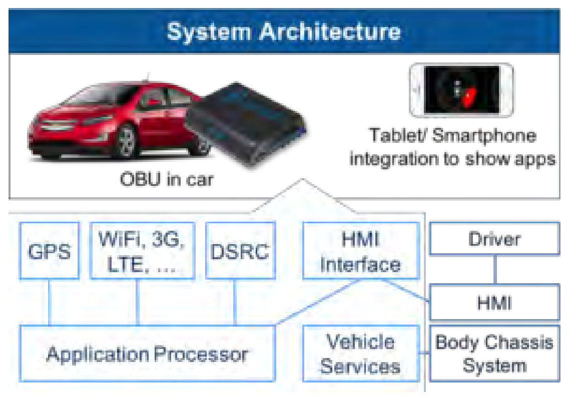
- **On-board Unit** (OBU) – Vehicle/Pedestrian/Bicyclist
- **Road-side Unit** (RSU) - Traffic Signal/Lighting Standard
- **V2X Middleware** - Data Services/Background Processes
- **V2X Applications** (Apps) - Human Interface/Message Format

The **On-board Unit** (OBU) is typically a ruggedized DSRC radio unit located inside a vehicle that is capable of interfacing to either the road-side unit (RSU), adjacent

OBU or to the cloud for V2I broadcast messages. These units shall support multiple connectivity options, such as Bluetooth, Wi-Fi, GPS, and cellular. Security is also a main focus of this product and has built-in security measures.

The **Road-side Unit** (RSU) is typically a ruggedized Wi-Fi hoptspot radio unit located on a signal mast-pole at a signalized intersection. These units and tied into the traffic signal controller cabinet and interface to approaching OBU's within 300 feet of the intersection and to other adjacent RSU units along the corridor. These units support multiple connectivity options, such as DSRC, Wi-Fi, and GPS. Configuration of these units are specialized and require an in-depth knowledge and background of applied processes.

V2X middleware is the entire background database functionality of the connected vehicle architecture that runs services between all OBU's, RSU's and V2X applications. These important processes interpret all messages and flags and determine how the traffic data gets routed. Typically a Linux or C standard platform, this allows the V2X middelware architecture to run on several different hardware platforms.



V2X applications (Apps) are various software applications that are accessed via in-car infortainment system, by tablet or smartphone. Currently, there is a large range of V2X apps that will to continue to grow as the technology emerges. Some of these Apps include: Forward Collision Warning (FCW), Emergency Brake Light (EEBL), Blindspot Warning (BSW), Do Not Pass Warning (DNPW), Left Turn Assist (LTS) among others like Blind Curve Warning and Reduced Speed Warning. Most applications are typically Apple iOS and Android compatible.

The signal phase and timing information or SPaT from the signal controller will need to be shared or provided to the automobile industry using a roadside unit. Agencies will need to agree via a resolution or agreement to share this information to the auto industry via a secured 3rd party application. The SPaT messages will allow drivers to see the traffic signal information as they approach the intersection at the posted speed. Typical signalized intersection V2I communication network and signal controller cabinet and roadside V2I equipment are shown on **Figures 3.3 and 3.4**.

Figure 3.3. Signalized Intersection Typical V2I Communication Architecture

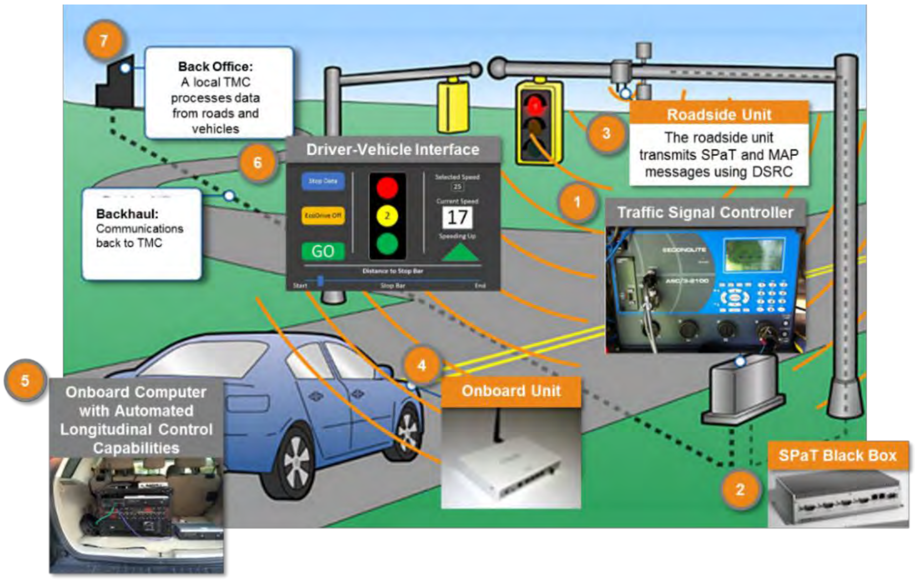
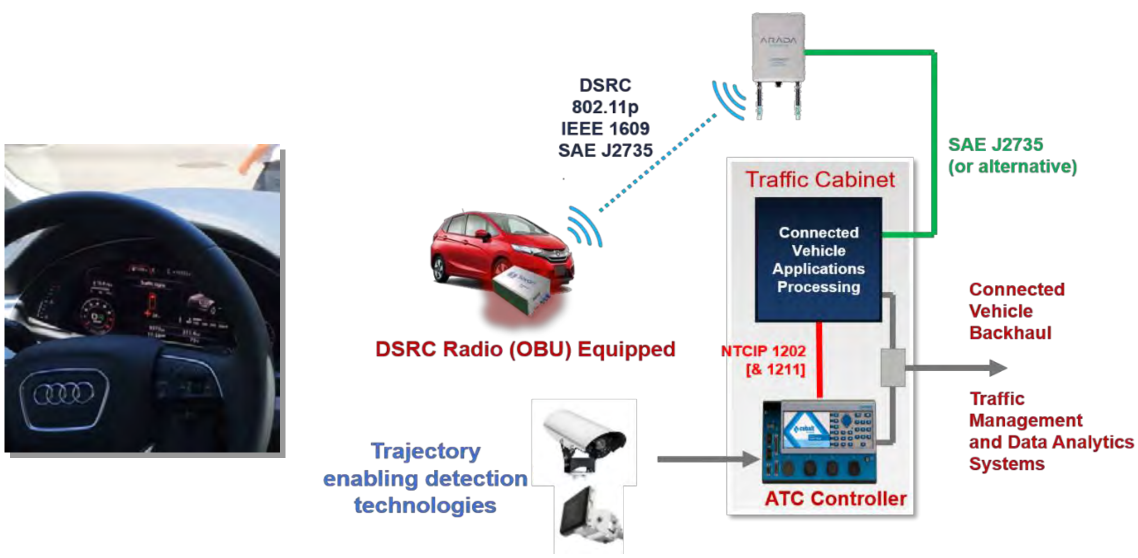
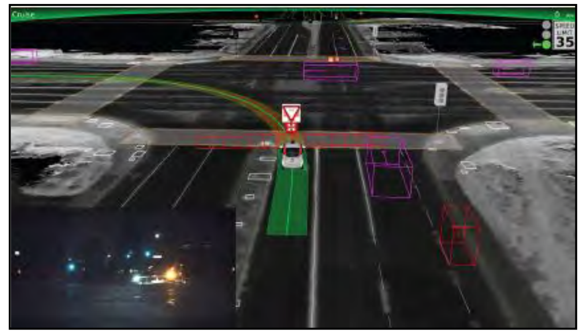


Figure 3.4. Signalized Intersection Typical V2I Communication Network



For a successful deployment of a CV Program, stakeholders must establish standards and policies to use new technologies and support tools for real-time needs and to meet long-term public policy objectives. Development of a cost/benefit analysis should be performed and lessons learned through implementation on high priority CV applications. Lastly, it shall support all State, local and all transit agency functions in the valley; and meet the latest State and National ITS and CV architectures.

3.5.3 Autonomous Vehicles / Automation



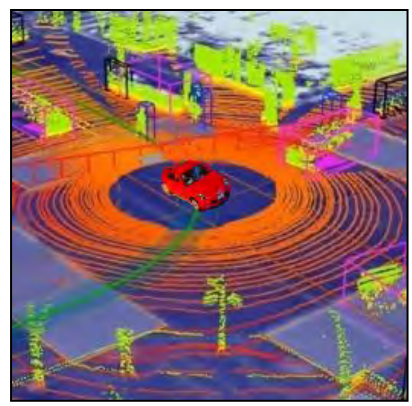
The National Highway Traffic Safety Administration (NHTSA) defines vehicle automation as having five levels:

Level 0: No Automation - Driver is in complete and sole control of brakes. Steering, throttle, and motor power at all times.

Level 1: Function-Specfic Automation – Automation of one or more functions; electronic stability control or pre-charged brakes.

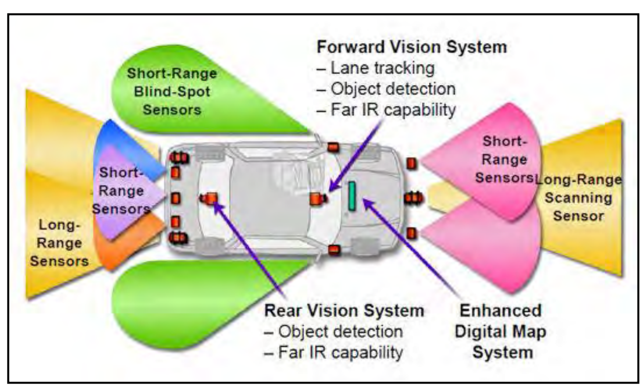
Level 2: Combine Function Automation – Automation of at least two functions (e.g. adaptive cruise control and lane centering steering).

Level 3: Limited Self-driving Automation – Automation that takes over all safety-critical fucntions under certain traffic conditions. Driver is available for ocacasional control.



Level 4: Full Self-driving Automation – Vehicle can perform all safety-critical driving functions for an entire trip. Driver is not expected to be available for control during the trip.

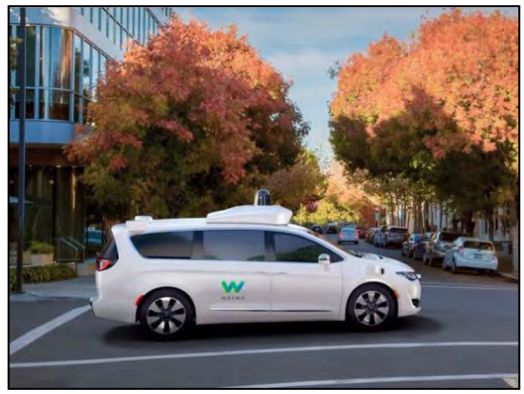
Different levels of automation may have a significant impact on driving safety, personal mobility, energy consumption, operating efficiency, environmental impact, and land use. While research into automated vehicles and other aspects of automation are in the early stages, it is fast gaining attention around the world in all sectors of the economy. Potential benefits of automation programs Include:



- Reducing the number and severity of crashes caused by drivers or by other conditions (e.g., weather, pedestrians, roadway conditions).
- Reduction of aggressive driving.
- Expanding the reach of transportation modes to disabled and older users, as well as providing "last mile" connectivity service for

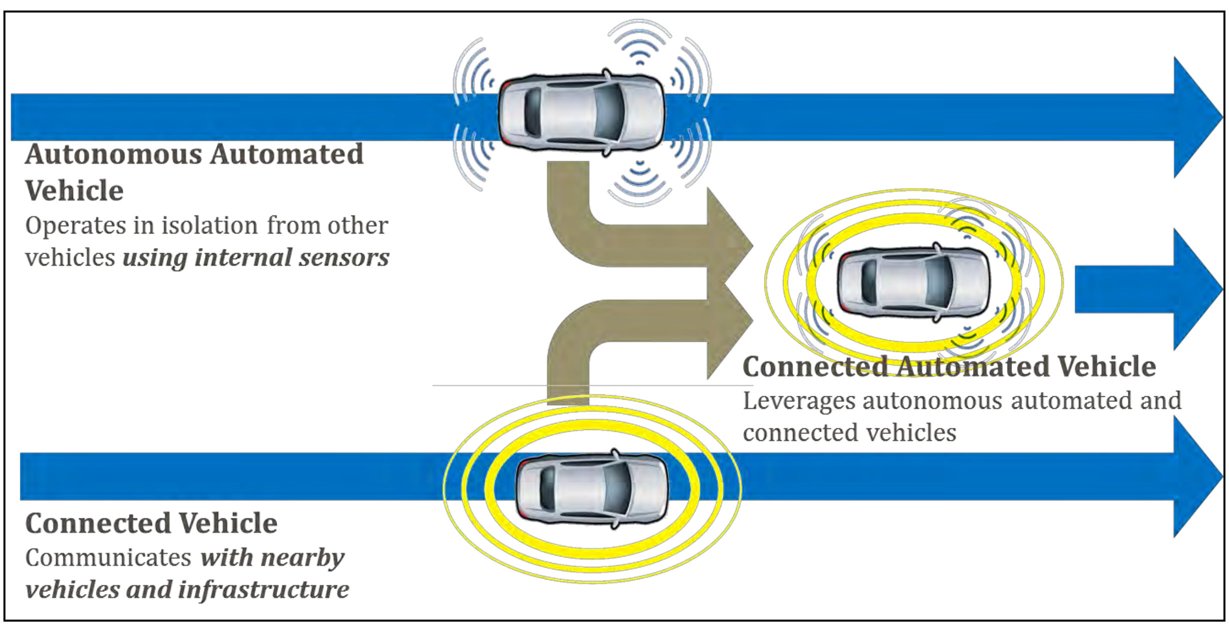
all users.

- Increasing the efficiency and effectiveness of existing transportation systems.
- Providing guidance to State and local agencies to help them understand the impacts of automated vehicles on the assets that they manage (i.e., roads, bridges, land, etc.).



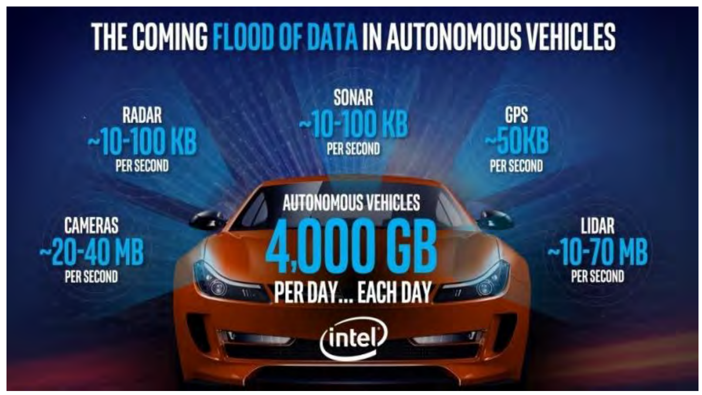
An autonomous vehicle (driverless, self-driving car) is a vehicle that is capable of sensing its environment and navigating without human input. Autonomous cars can detect surroundings using a variety of techniques such as radar, sensor technologies (LiDAR), GPS, odometry, and computer vision. Advanced control systems interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage, traffic signals, etc. Autonomous cars have control systems that are capable of analyzing sensory data to distinguish between different cars on the road, which is very useful in planning a path to the desired destination. Some autonomous vehicles update their maps based on sensory input, allowing the vehicles to keep track of their position even when conditions change or when they enter uncharted environments. Although, autonomous vehicle technology is different from the connected vehicle technology, both platforms will be merged in the near future to form a connected automated vehicle as highlighted on **Figure 3.5**.

Figure 3.5. Connected Automated Vehicle



Also, autonomous vehicles technology will also be applicable for transit, freight and other transportation modes. Manufacturers are already developing and testing driverless transit pods to serve as transit shuttles for downtown areas, business parks, universities, and airports. They are also promoting the use of these vehicles for “First and Last Mile” to promote transit, increase transit ridership, and reduce the number of vehicles in their roadway system.

According to Intel, the flow of data coming from each autonomous vehicle will reach over 4,000 gigabytes per vehicle per day. Also, vehicle manufacturers are changing their business model to a more functional and lifestyle models where consumers employ automobiles-as-a-service. This is one reason why Uber and GM/Lyft, among others, are investing heavily in autonomous technology.

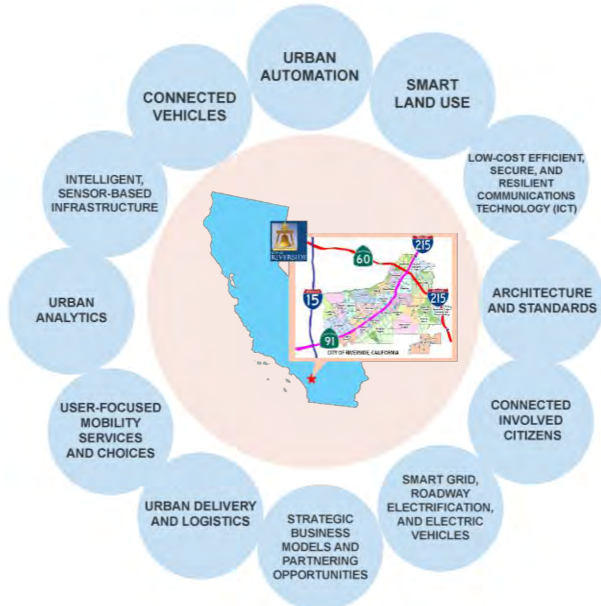


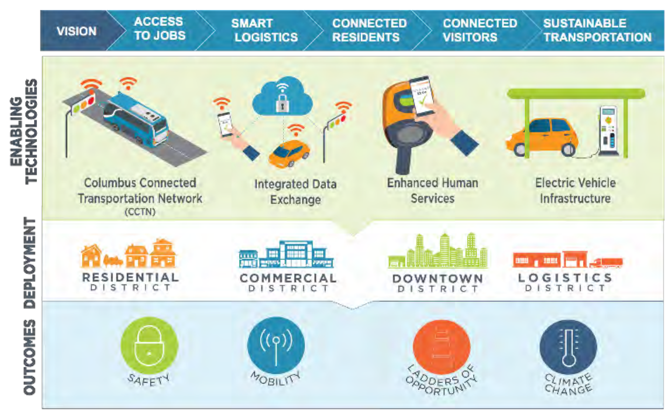
So over the next few years, vehicles will come with more autonomous features. Adaptive cruise control will be a feature that will drive autonomously in traffic jams. Lane keeping alerts will turn into real lane keeping while driving down the highway, and assisted parking will turn into fully autonomous parking.

3.5.4 Smart Cities - Transportation Elements

Smart City is an urban development vision to integrate multiple Information and Communication Technology (ICT) and Internet of Things (IoT) solutions in a secure fashion to manage a city's assets – the city's assets include, but are not limited to, local departments' information systems, schools, libraries, ***transportation systems***, hospitals, power plants, water supply networks, waste management, law enforcement, and other community services. The goal of building a smart city is to improve quality of life by using urban informatics and technology to improve the efficiency of services and meet residents' needs. ICT allows city officials to interact directly with the community and the city infrastructure and to monitor what is happening in the city, how the city is evolving, and how to enable a better quality of life. Through the use of sensors integrated with real-time monitoring systems, data are collected from citizens and devices – then processed and analyzed.

In 2016, the USDOT Smart City Challenge encouraged cities to put forward their best and most creative ideas for innovatively addressing the challenges they are facing with their transportation system. The vision of the Smart City Challenge was to demonstrate and evaluate a holistic, integrated approach to improving surface transportation performance within a city and integrating this approach with other smart city domains such as public safety, public services, and energy. The intent of this challenge was to address how emerging transportation data, technologies, and applications can be integrated with existing systems in a city to address transportation challenges. The USDOT was looking for bold and innovative ideas for proposed demonstrations to effectively test, evaluate, and demonstrate the significant benefits of smart city concepts. The USDOT Smart City Challenge was a $40 million grant award for one mid-sized city that can demonstrate how advanced data and Intelligent Transportation Systems (ITS) technologies and applications can be used to reduce congestion, keep travelers safe, protect the environment, respond to climate change, connect underserved communities, and support economic vitality. To assist cities, the USDOT identified twelve (12) vision elements that provided a framework for applicants to consider in the development of a city's proposed demonstration. The USDOT received applications from 78 cities in the United States, including eleven (11) from California. The City of Columbus, Ohio was awarded with the grant.





Smart City transportation system elements include smart ITS technologies, connected vehicles/autonomous vehicles, smart city fleet, smart parking systems, smart roadway lighting systems, vehicle electrification, and smart universal payment system.

3.5.5 Shared-Mobility and Mobility-as-a-Service (MaaS)

Shared-use mobility are transportation services that are shared among users, including public transit; taxis and limos; bikesharing; carsharing (round-trip, one-way, and personal vehicle sharing); ridesharing (car-pooling, van-pooling); ridesourcing/ride-splitting; scooter sharing; shuttle services; and commercial delivery vehicles providing flexible goods movement.

Mobility-as-a-Service (MaaS), describes a shift away from personally owned modes of transportation and towards mobility solutions that are consumed as a service. This is enabled by combining transportation services from public and private transportation providers through a unified gateway that creates and manages the trip, which users can pay for with a single account. Users can pay per trip or a monthly fee for a limited distance. The key concept behind MaaS is to offer both the travelers and goods mobility solutions based on the travel needs. MaaS is not limited to individual mobility; the approach can be applied to movement of goods, particularly in urban areas.

This shift is fueled by a myriad of innovative new mobility service providers such as ride-sharing, bike-sharing programs, and car-sharing services as well as on-demand bus services. On the other hand, the trend is motivated by the anticipation of self-driving cars, which put in question the economic benefit of owning a personal car over using on-demand car services, which are widely expected to become significantly more affordable when cars can drive autonomously. This shift is further enabled by improvements in the integration of multiple modes of transportation into seamless trip chains, with bookings and payments managed collectively for all legs of the trip. MaaS may cause a decline in car ownership, which would reduce overall emissions. It could also significantly increase the efficiency and utilization of transit providers that contribute to the overall transit network in the region.

3.5.6 Internet of Things (IoT)

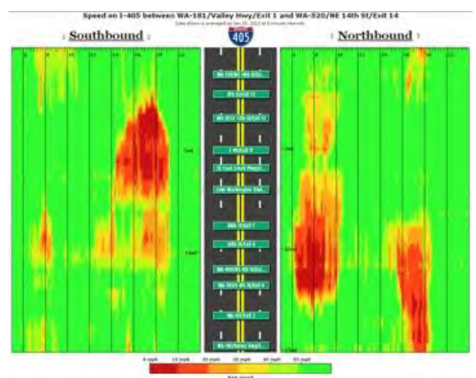
The Internet of Things (IoT) is the internetworking of physical devices, vehicles (also referred to as "connected devices" and "smart devices"), buildings and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. In 2013, the Global Standards Initiative on Internet of Things (IoT-GSI) defined the IoT as "the infrastructure of the information society". The IoT allows objects to be sensed and/or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit.

The IoT can assist in integration of communications, control, and information processing across various transportation systems. Application of the IoT extends to all aspects of transportation systems (i.e. the vehicle, the infrastructure, and the driver or user). Dynamic interaction between these components of a transport system enables inter- and intra- vehicular communication, smart traffic control, smart parking, electronic toll collection systems, logistic and fleet management, vehicle control, and safety and road assistance.

3.5.7 Mobile Applications (Apps)

Dynamic Mobility Applications (DMA) are the next generation of applications that will support further transformations in mobility. These applications focus on innovative methods for operating existing transportation systems and on greater integration across modes (e.g. light vehicles, transit vehicles, and trucks).

After successfully delivering Connected Vehicle applications in Palo Alto and other San Francisco Bay area cities, mobile applications (Apps) allows transportation agencies to selectively publish traffic intersection data to any 3rd party for the growing number of Connected Vehicle applications like "Talking Intersections," which provide valuable intersection data to the driver, improving safety, reducing emissions, and more.



Data provided by signal controllers, sensors, and central management software are used to predict and time-calibrate the state of the traffic signal, so auto manufacturers can incorporate it into their telematics and in-vehicle information systems. A growing number of communities are exploring these applications since early results were favorable and auto manufacturers are launching Connected Vehicle systems in 2017 and later model cars.

3.5.8 Large Traffic Data

Data Capture and Management (DCM) is the creation and sharing of high-quality, real-time, multimodal transportation data, captured from connected vehicles, mobile devices, and infrastructure. The DCM vision is to improve the operation and management of each agency's transportation system as well as available traveler information by providing integrated data from connected vehicles to researchers, application developers, and system operators.

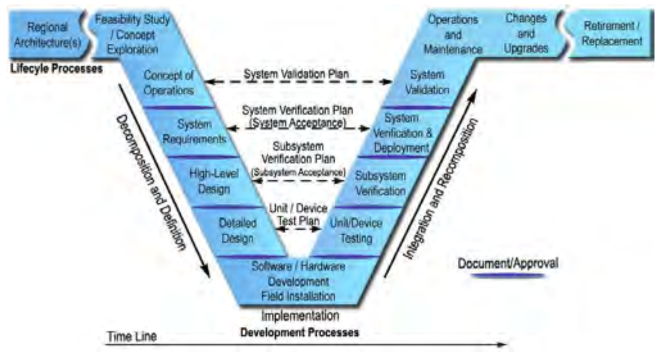
With the popularity of the application of large-scale traffic sensors and surveillance cameras in traffic network analysis and resources allocation, local cities and agencies have begun collecting a large amount of structured/unstructured traffic data. This large amount of data provide a good platform to develop new paradigms and strategies in system design, system development, information processing, and performance evaluation in Intelligent Transportation Systems.

Large data providers structure this data to system-wide information that analyzes data from traditional road sensor networks with up-to-the-minute data from consumer and fleet vehicles, mobile devices, and incidents. With millions of additional GPS points, large data offers public agencies access to the most comprehensive coverage and analysis available.

Ultimately, large traffic data or metadata will focus on the most recent technical progresses on the big data driven applications for ITS, e.g., data processing methods, data-driven computing techniques, and application-oriented system models. The primary objective of this model is to build an intelligent system that dynamically visualizes the statistics of the large-scale traffic data. Enterprise data will also have to:

- Integrate new data sets inline with legacy data management systems
- Identify a role for data management and ownership
- Enable business relationships between public and private sector for data privacy protection

4. CONCEPT OF OPERATIONS



This Concept of Operations (ConOps) is a necessary step in the systems engineering process and a key component leading to the development of system requirements and preliminary engineering/ design in the next phase. This document provides a high-level description of what the upgraded ATMS and TMC major capabilities will be, how the future system will be operated. Specifically, the Concept of Operations (ConOps) will provide detailed communication requirements for all field devices, field communication HUB locations, Traffic Management Centers (TMC), and will identify the recommended technologies for each application.

Recommendations for deployments of Advanced Traffic Management Systems (ATMS), Advanced Transportation Controllers (ATC), High Definition (HD) Internet Protocol (IP) Close Circuit Television (CCTV) camera systems, Video Management Systems (VMS), Arterial Management Systems (AMS), Dynamic Message Sign (DMS) systems, Changeable Message Sign (CMS) systems, Ethernet/IP-based communications, and other ITS field elements will be included. System architecture exhibits are also provided to illustrate the connectivity between the recommended improvements and ITS elements from the field to the TMC, center-to-center (C2C) communications (e.g. links from TMC to LA IEN).

4.1 Stakeholders

Identification of participating agencies and stakeholders is one of the required components of a regional ITS architecture. The success of the transportation interconnect master plan depends on participation by a diverse set of stakeholders. In this step, the stakeholders in the transportation system are identified, and the process of encouraging their participation in the regional ITS architecture development process has been initiated.

Table 4.12 - Project Stakeholders

ID	Stakeholder	Key Contacts	Title	Role/ Responsibilities
1	City of Lancaster - Public Works Staff	Mr. Troelis Niebla	City Engineer	Owns entire traffic signal network infrastructure. Administer the Master Plan and ITS Expansion/ Traffic Modernization Projects
2	City IT Staff			Provide coordination/ integration efforts for ATMS system

ID	Stakeholder	Key Contacts	Title	Role/ Responsibilities
3	City Traffic Signal Staff	Mr. Alan Perkins	Principal Traffic Engineering Technician	Operate and maintain ITS system deployments within City of Lancaster
4	ADVANTEC Consulting Engineers, Inc.	Mr. Carlos Ortiz Mr. Jose Guedes Mr. Tracy Moriya Mr. John Cox	Project Director Project Manager Deputy Project Manager Systems Engineer	Assisting City stakeholders with the Master Plan and ITS Expansion/ Traffic Modernization Projects

4.2 Needs Assessment

4.2.1 Description of Current System

The City currently utilizes a centralized Traffic Management Systems (TMS) for remote command and control of their traffic signal network. This typically involves City/Agency staff to monitor and maintain the system within City Hall/TMC location, while traffic signal technicians respond to trouble calls and perform preventative maintenance on the traffic signal hardware on a routine basis. This is the preferred method of traffic signal operations as it provides a complete oversight and operation view of each traffic signal system tied to the central TMS system, and gives the signal operator the ability to make changes to signal timing/coordination functions and provide override control from a remote TMC location.

The existing centralized TMS system is an outdated legacy system and does not have the functionality and benefits of newer centralized TMS, called Advanced Traffic Management Systems (ATMS). Advanced Traffic Management Systems provide many advantages over existing legacy TMS systems, such as Ethernet IP capability, ATC controller functionality including high resolution data and peer-to-peer communications, and integration of other ITS elements such as HD IP CCTV, CMS, Arterial Management Systems and capability for C2C communications to surrounding agencies like the LA County IEN.

4.2.2 Justification for Nature of Changes

While the City of Lancaster has a large portion of their traffic signal system interconnected, most utilize antiquated copper interconnect cable or wireless communications that connect to legacy traffic signal controllers and interface to legacy traffic management systems that may no longer be supported. Additionally, there is no video surveillance deployed for real-time traffic monitoring and surveillance citywide. Although the City have made an effort to update their traffic signal infrastructure and have begun replacing aging equipment as part of their previous ITS master plan, intersection widening/street improvements projects, or as a one-to-one direct replacement, these legacy systems are at their end of life and a concerted effort should be taken to advance the replacement of these systems.

To overcome the limitations of the existing legacy systems, and to address the stakeholders current and future needs, implementation of the latest ATMS, ATC, TMC, and Intelligent Transportation Systems (ITS) will be required to achieve these goals, which include the following:

- Ability to manage traffic control systems remotely (via TMC, remote workstation, laptop, etc.)
- Ability to allow TMC staff to create a library of signal timing plans (AM/MD/PM, events, etc.)
- Ability to maintain consolidated traffic signal history including database changes, controller timing changes, maintenance history, and malfunction history. Information should be able to be retrieved by date, time and intersection ID, malfunction type, maintenance type
- Ability to allow TMC staff and authorized users (consultant and/or traffic signal maintenance contractor) to connect to the traffic system via a mobile device to make modifications (i.e., signal timing)
- Ability to automatically integrate traffic signal timing data from a traffic signal simulation software (or include simulation software as part of the traffic system / application)
- Ability to view and manipulate CCTV/video detection cameras and modify camera detection zones at the traffic control center and from a remote / mobile location
- Allow staff remote access to traffic signal information for trouble shooting purposes (such as communication failures, whether signal is working / online, timing, etc.)
- Integrate Arterial Management Software for retrieval and export of free-flow traffic detection data. This also includes high-resolution data and measurements of effectiveness (MOE) outputs
- Integrate ITS hardware and Asset Management Software
- Ability to integrate Changeable Message Signs and CMS sign programming within the new traffic system
- Ability to share traffic information and cameras with the Emergency Operations Center (EOC) as well as remote operation
- The upgraded system should be secure via multiple communication channels (i.e., wireless and wired connectivity)
- The upgraded system should maintain a log of changes and the user that made the change
- The upgraded system must include a Video Wall Map
- Ability to integrate other ITS initiatives such as Transit Signal Priority (TSP) in order to enhance operations and reliability for valley's transit agency
- Prepare the City for existing or upcoming transportation initiatives and/or strategies; including connected vehicles/autonomous vehicles, big data, and smart cities transportation elements

4.3 Integration of Ethernet/IP-based Communications

One of the primary objectives of the Transportation Communications Master Plan is to provide recommended systems, and to layout a migration path to integrate from existing equipment to the latest communications and ITS technologies. This includes upgrades to Ethernet/Internet Protocol (IP) based communications systems, ITS field elements (e.g. traffic signal controllers/equipment, video detection cameras, CCTV cameras, arterial management systems, CMS, etc.) and TMC upgrades.

To provide Ethernet/IP-based communications, the existing traffic signal controllers must be compatible or have the ability to be upgraded. If not, traffic signal controllers must be replaced or modified to allow communications over an Ethernet/IP-based network including network equipment in the field (e.g. hardened managed Ethernet switches). Core central systems servers/network equipment must also be able to communicate via Ethernet/IP and be configured for TCP/IP transmission. Legacy systems generally do not have the ability to be upgraded; therefore, these systems shall be replaced by the latest ATMS along with the latest traffic signal controllers (ATCs) and ITS elements.

As the City continues to build out their new ITS infrastructure, it should look for opportunities to implement these recommended ITS elements on a phased implementation plan.

4.4 Integration of ITS Components

Understanding the integration of ITS components is a key factor for decision makers, stakeholders, and local support staff. Typically, the migration from existing to new ITS components, elements and communication systems occurs in phases. The overall system architecture plan illustrates the links between all traffic signals, ITS field elements, communication hub locations, TMC, IT server room, City Hall and other City owned building locations. Once this is established, a phase implementation plan can be developed – beginning with the first phase of improvements – by possibly implementing an updated core central and communications systems. As the work occurs, an interim plan should be established that maintains the existing legacy systems while implementing the new advanced systems. Depending on the phase of the project, it should be expected that two operating systems (legacy systems and new advanced systems) will be operational side-by-side until the replacement of all legacy systems are complete. For the City of Lancaster, it is envisioning that the primary improvements consist of the following:

- Upgrade existing legacy traffic management system to an Advanced Traffic Management System (ATMS)
- Upgrade existing legacy communications to Ethernet/Internet Protocol (IP) based communications
- Upgrade existing legacy traffic signal controllers to an Advanced Transportation Controllers (ATC)
- Other ITS elements: Hybrid Video/Radar detection cameras, HD IP CCTV cameras

4.5 System Architecture

The purpose of having a system architecture plan is to understand the agencies vision regarding their traffic signal, ITS elements, and communications systems under build-out conditions. It provides a high-level understanding of the overall network including the communication topology, links, and typical connections between field communication hubs, traffic signal controllers, ITS elements, and TMCs. Depending on the level of detail, system architecture plans may also include the typical hardware required at each communication hub, traffic signal cabinet, and at the TMC including links to other offices (workstations) and buildings (Maintenance Yard).

The following sections provide detailed descriptions, high-level system level design, and system architectures for the recommended ITS technology improvements. To understand how these improvements are linked we provided a breakdown, which includes a three-tiered system overview/approach:

- Fiber Optic Communications Backbone System Architecture
- Advanced Traffic Management System (ATMS) Architecture
- Local intersection level ITS elements System Architecture

By using a tiered system approach, we can determine interface requirements and sub-system interfaces from high-level Backbone inter-connectivity, to the centralized Advanced Transportation Management Systems (ATMS), and down to the local roadside units/ITS elements such as traffic signal controllers or detection units.

The system architecture and high-level preliminary design identifies each systems' requirements and subsystem interfaces. System architecture diagrams presented in **Figures 4.5, 4.6 and 4.7** show the links between ITS field elements including communication systems, traffic signal systems, video detection systems, Closed Circuit Television (CCTV) systems, arterial management systems (future), and, also to the City's IT server room and TMC or TOC. The system architecture diagrams also show communication links between workstations located at the City Hall and the City's communication network. During the design phase of the project, these system architectures will be further developed into detailed drawing diagrams for more detailed interconnection requirements between all components.

Figure 4.6 depicts the Communications Backbone System Architecture.

Figure 4.7 depicts the Advanced Traffic Management System (ATMS) Communications System Architecture.

Figure 4.8 illustrates an example of intersection level system architecture and ITS elements.

Figure 4.6. Communications Backbone System Architecture

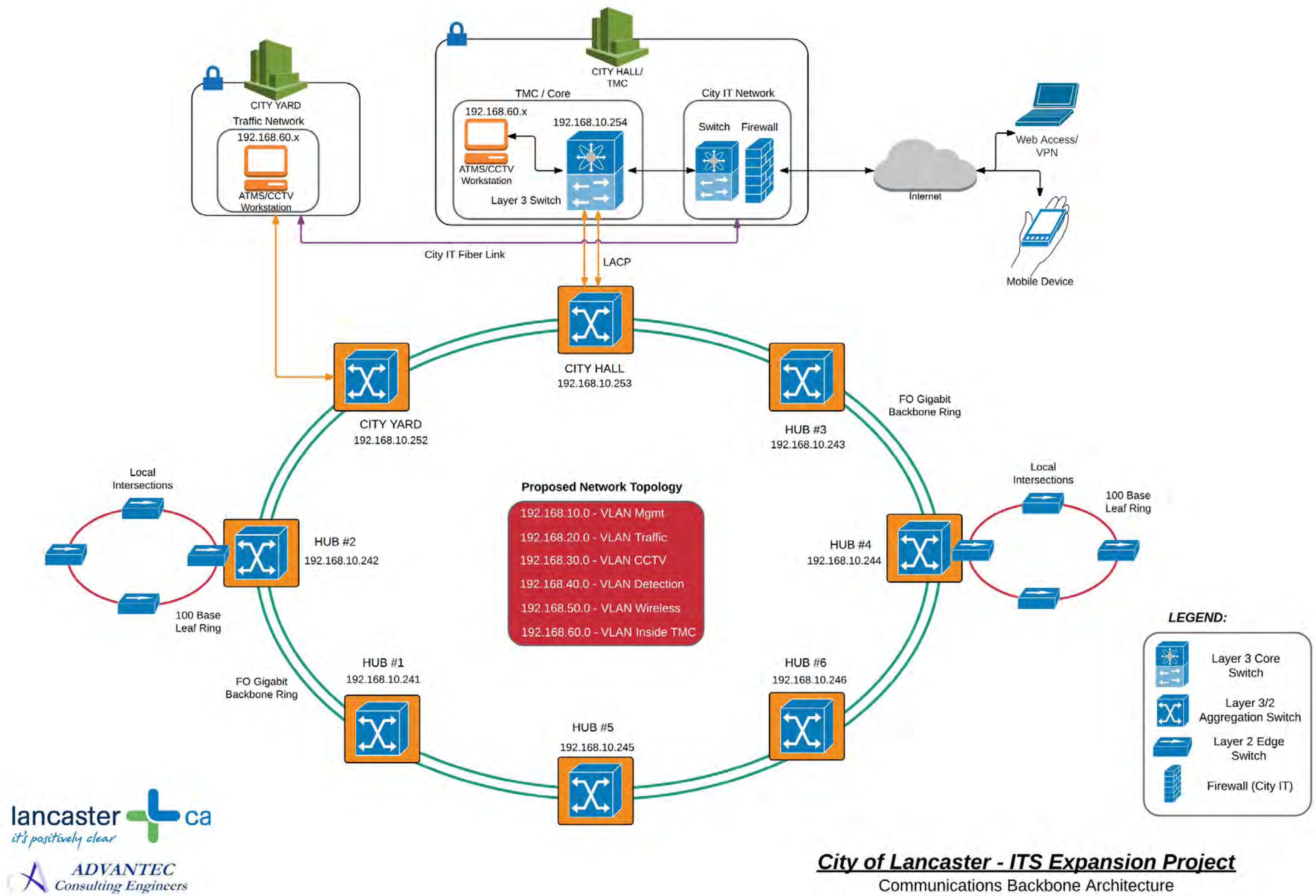


Figure 4.7. ATMS Communications System Architecture and ITS Elements

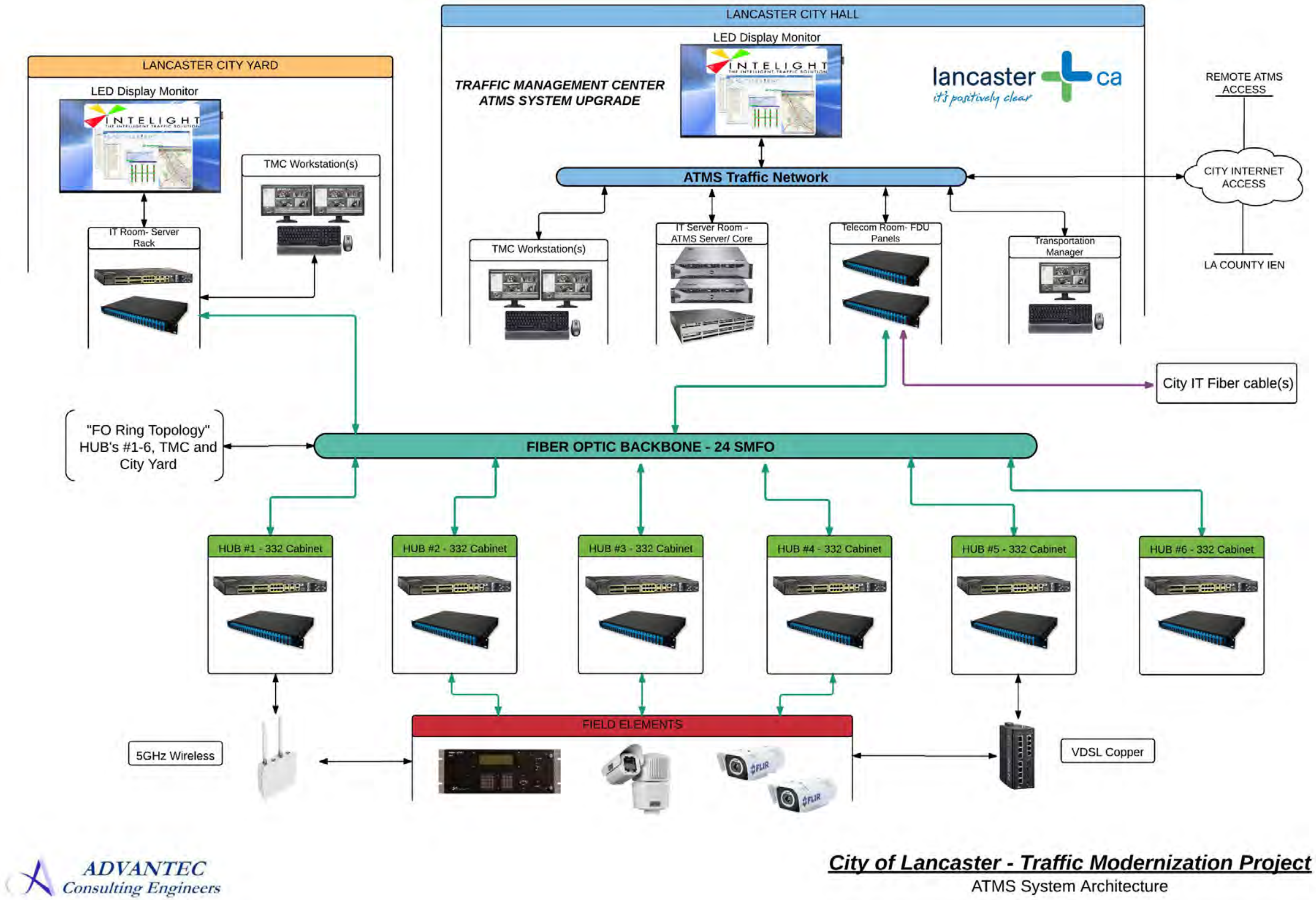
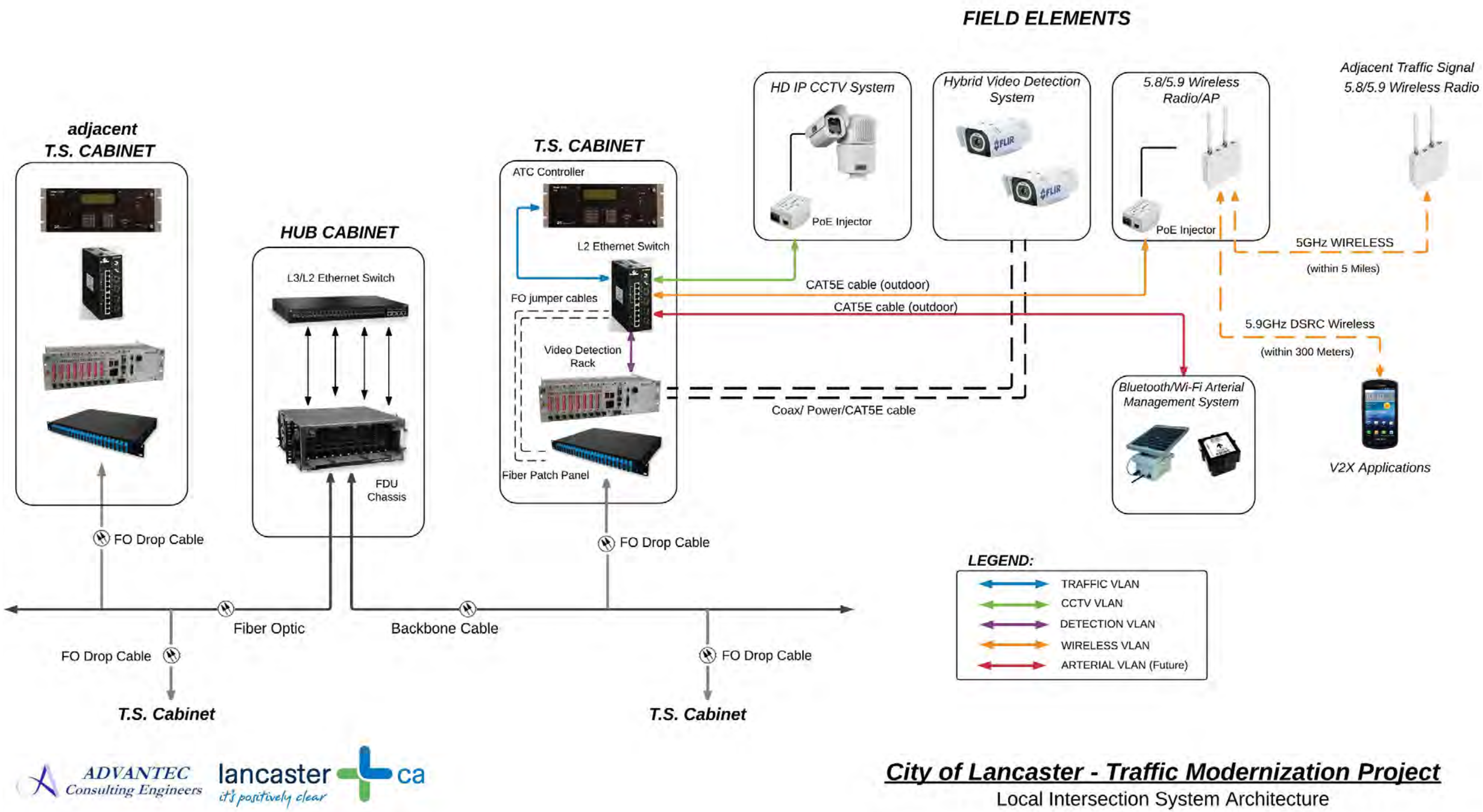


Figure 4.8. Intersection System Architecture and ITS Elements



5. SYSTEM REQUIREMENTS

A System Integrator (SI) will be procured by the City for the deployment of the various ITS recommendations as identified in the system architecture and as part of the **ITS Expansion** and **Traffic Signal Modernization** improvement projects. The sequence of activities that will integrate software components into sub-systems, and sub-systems into entire systems will be defined. Integration and verification are closely linked processes in which one follows the other until the entire system is ready for operational deployment. The following summarizes the system level design guidelines for the Transportation Communications Master Plan.

5.1.1 Traffic Controller

The need for installation of latest ATC model traffic signal controllers have been identified at various areas of the valley. For agency's that require monitoring of ASPTM's or propose to run Adaptive Traffic Signal Control (ATSC), new ATC controllers will be required. City and agency staff should be aware that removal and replacement of legacy controllers with new ATC models typically require new local timing data/sheets. Additionally, each controller replacement will require a "4-way" flash operation while the new ATC controller is installed.

Typically, the process for implementing a new ATC controller or other ITS device into a network system includes the following:

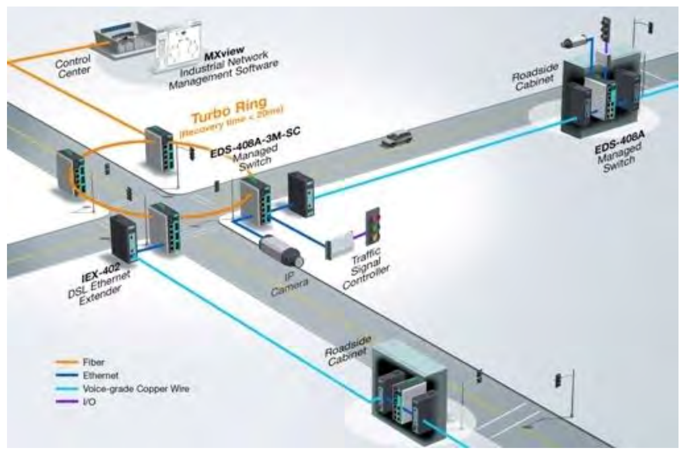
- Configure/set IP Address & VLAN Assignment(s) within the ITS Device/field equipment (e.g., controller, VIDs, IP switch, etc.)
- Add ITS Device’s IP Address & VLAN Assignment to Master spreadsheet (for documentation purposes)
- Add ITS Devices to ATMS System through user interface (e.g., database, Map display, etc.)

Integration of the proposed ATC controller will be required at the central ATMS. Please note that the type of network modification needed when a user or field device is added to the system is to establish/configure the appropriate IP Address and port number and verify proper communications to central.

5.1.2 Provide Ethernet/IP-based Communications

The communication systems guideline consists of different design elements connected together including fiber optic cable, wireless Ethernet broadband, Ethernet-over-copper (VDSL), Ethernet switches, patch cords and other various equipment. The design criteria for the City improvement project is an Ethernet based private and secured Wide-Area Network (WAN). Essentially the data transmission medium for the proposed ATC/CCTV/ATMS system (and other future Arterial Management/DMS/CMS/ traffic based network systems), a strong Ethernet-based WAN is critical for viewing ITS elements at the Traffic Management Center in real-time. Using existing/proposed fiber optic backbone cables wireless Ethernet back-haul links, we are able to design a robust WAN topology with proposed field communication HUB locations. Similar to an enterprise campus LAN model, this network layout provides the local agencies with a foundation to build upon for future expansion. The typical proposed network layout includes:

- Core Layer - City Hall IT Data Server Room (Layer 3)
- Aggregate Layer - Field HUB Locations (Layer 2)
- Access Layer - All connected field devices (Traffic Signal, CCTV, Bluetooth/Wi-Fi, Video Detection, etc.)



Based on a network ring topology, existing field communication HUB locations will be utilized to connect to all local field devices in a leaf ring format. Local Traffic/CCTV field data will be sent over 100base fiber/wireless/VDSL connection to each field communication hub location. All traffic data will be gathered at this point and sent to the core layer over a separate Gigabit fiber uplink connection. Uplink connections will be made from each separate field communication hub location to City Hall/TMC core location.

As part of the City upgrade network design, bandwidth calculation needs to be performed to account for adequate network performance. **Table 5.13** summarizes the typical network bandwidth calculations.

Table 5.13 - Traffic Data Network Calculations - Typical Agency Use Case

Type of Device	Expected Network Traffic
ATC Traffic Signal Controller	0.5 Mbps
HD IP CCTV Camera with PTZ Control (each camera, dual streaming)	4.0 Mbps
Video Detection Network Streaming	3.0 Mbps
Bluetooth/Wi-Fi Arterial Management System	0.5 Mbps
Future ITS/ ATMS Traffic Data (including adaptive control)	0.5 Mbps
Network Management - monitoring	5.0 Mbps

Backhaul	Assumption	Actual	Capacity
2.5 Gbps Backbone Connection	• All proposed ATC traffic signal controllers (140 X 0.5 Mbps) • All proposed HD IP CCTV cameras communicating (15 X 4.0 Mbps) • Video Detection network streaming (70 X 3.0 Mbps) • Future Bluetooth/Wi-Fi detection stations (20 X 0.5 Mbps) • Other future ITS / ATMS Traffic Elements (50 X 0.5 Mbps) • Network management monitoring network devices (2.0 Mbps)	70.0 Mbps 60.0 Mbps 210.0 Mbps 10.0 Mbps 25.0 Mbps 2.0 Mbps **Total 377 Mbps**	**2,500 Mbps (a 15% load)**

As indicated in the calculations above, an entire citywide Traffic Data network system can operate over 2.5 gigabit uplink connection at 15% load (typical) at total build-out conditions. Additionally, each gigabit uplink connection will be shared by (2) HUB switches sharing the network traffic for even less load as part of the improvement project. The design criteria will include implementation of advanced routing technology such as Layer 3 transport to accommodate Traffic/CCTV/Detection/Wireless and future VLAN's. This type of inter-VLAN communication also makes it possible to integrate other proposed ITS traffic applications, such as Adaptive Traffic Control Systems (ATCS), CMS/Parking etc. Therefore, communications network design shall provide enough capacity (bandwidth) for the proposed ITS traffic improvements and future ITS traffic data to be implemented when necessary.

5.1.3 Advanced Traffic Management System (ATMS)

The new ATMS systems provide the functionality of full Ethernet/IP-based communication, integration of ATC controllers and upgraded capabilities such as high-resolution data and peer to peer communication. Additionally, they also support expanded functions such as ATCS control, CCTV view and control, and 3rd party integration of isolated sub-systems like Arterial Management Systems, CMS software and ASPTM's. Legacy Traffic Management Systems (TMS) do not have this capability. Therefore, agencies should consider upgrading concurrently with other late model ITS technologies to provide the total visibility and control of these systems.

5.1.4 HD IP CCTV Cameras

The need for High Definition IP CCTV Cameras have been proposed at selected high-volume intersections. The intersections have been strategically chosen for intersections tilt/zoom capabilities that will allow city/agency staff to monitor traffic conditions at intersections and roadway segments, troubleshoot, and fine-tune intersection operations in real-time.

The surveillance images can be shared with other stakeholders including other City departments, other agencies, and the public via City/agency's websites and/or mobile applications. Careful placement at the intersection should be considered to ensure proper line of sight so that the city/agency staff can manage and operate the intersections efficiently. Integration of the proposed IP CCTV cameras will be required at the central VMS system.

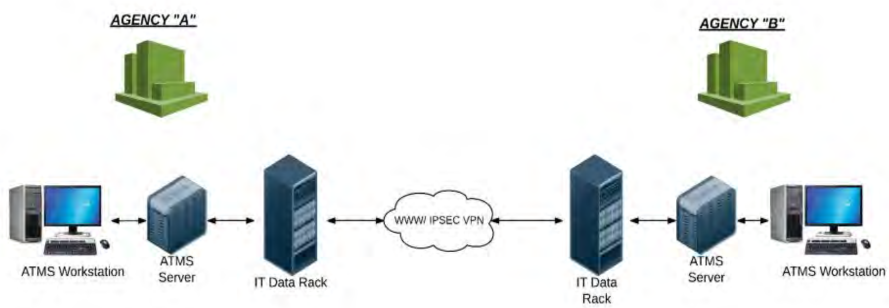
5.1.5 Video Management System (VMS)

A dedicated video management system is a complex management system that administers the IP CCTV video camera deployment of any given agency. Typically, these systems require dedicated hardware servers, additional equipment and licensing fees to filter and decode the video streams. A cost analysis evaluation should be performed for each agency to determine whether a dedicated VMS system should be deployed. In lieu of a dedicated VMS system, alternate "web viewer" based software programs provide similar CCTV control and can be used for sharing of video images. Web viewer systems must first be evaluated based on CCTV camera type/model, as some CCTV system required dedicated hardware servers.

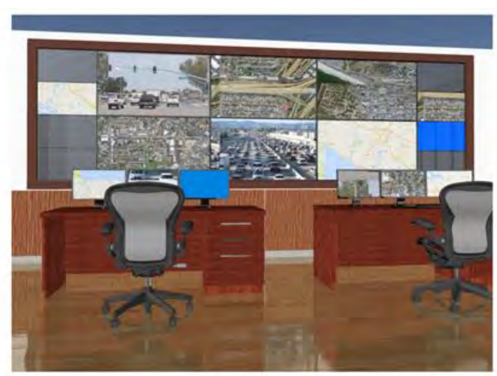
5.1.6 Inter-Agency Communications (IEN)

Inter-Agency communications is an important objective of regional traffic signal synchronization projects. The goal is to provide shared two-way traffic data and/or CCTV video feeds across jurisdictional boundaries. The first step in establishing C2C communications is identifying center-to-center intertie points. For instance, locations along city boundaries with shared fiber optics can provide for a high-bandwidth connection to each TMC center for shared traffic data and video images using a dedicated fiber optic backbone. A fiber sharing plan should be established, with dedicated fiber strands physically connecting to each TMC. This shall be implemented through the planning process and agreements shall be established to maintain the physical connection including the use of traffic data and video feeds. For agencies that are not physically able to connect to a shared fiber optic backbone network, other connections may be established such as a IPSec VPN link through the world-wide web. In addition, a third party or Consultant can be connected to the system via a IPSec VPN link to assist agencies on the operations and maintenance of the traffic signal system.

After physical hardware links are established, further hardware and software integration will be required to perform seamless inter-agency communication. A key factor in sharing information between ATMS systems if the background processes of the manufacturers themselves. Key efforts must be made on both ends to establish data sharing based on industry standards/protocols.



5.1.7 Traffic Management Center



A centralized Traffic Management Center (TMC) is a key goal for providing advanced traffic management and monitoring at the local agency level throughout the City of Lancaster and providing a potential links to LA County and the City of Palmdale. The centralized TMC would be able access and/or view and monitor the traffic control, video, and ITS elements from all local roadside elements.

A complex set of varying interfaces must be established for a successful working deployment. Trained staff must monitor and maintain the traffic signal network, demarcation of hardwired/fiber optic/wireless signal communications will need to be brought into the building, and designated space/IT space is required for each system. Overall, the goal is to view, operate, and manage the city/region's arterial traffic, maintain and monitor traffic signal timing and synchronization; and as a result, to reduce traveler commuter times and maximize roadway capacity from a centralized location.

Standard equipment that is required for basic TMC operations include the following:

- ***Video Wall/Controller:*** A new overhead video wall and controller allows seamless viewing across multiple monitors and windows. It can provide multiple maps, videos, and data displays.
- ***Control Room IT Server/Data Equipment and Racks:*** It is recommended dedicated rack space are provided for traffic management servers, network switches, fiber distribution unit, UPS/battery backup units for the rack, and other equipment as required by the traffic management center.
- ***Dedicated Electrical Service/HVAC:*** It is recommended to provide the proper lighting requirements to minimize glare and lighting control issues. A dedicated HVAC will facilitate the temperature control inside the TMC and Control Room.
- ***Cables and Raceways:*** Power cables should be run separately from communication cables in order to maintain organization in the TMC space. All cables should be plenum rated. Overhead cable raceways should be used to assist in cable organization above equipment racks.
- ***ATMS Servers:*** Multiple traffic servers will be required for separate communication and database functions. CCTV/CMS/Arterial Management Systems require additional servers. The central ATMS software will have the ability to monitor and control the local/regional traffic signal system. The Traffic Engineers/Operators will also be able to control signal timing remotely and set time-of-day and special event timing parameters.
- ***Work Station(s):*** The work station is the console from which the TMC operators will be conducting major TMC duties. The work stations can be a computer and monitor that staff is already working at that has access to the TMC server though direct connection or through the City LAN and or displayed onto an overhead LED display monitor/video wall.

6. RECOMMENDATIONS

The City's existing TMS system and legacy analog fiber optic/copper communications system has been in place for many years and are no longer the industry standard protocol for ITS communications. The current technology implemented within the City is antiquated. Future network expansion shall be built upon evolving and matured technologies. As the City grows and technologies advance, future communications should provide for ease of maintenance and expansion.

In developing a Citywide wide area network, and having the capability share data and video across jurisdictional boundaries, it is important to understand what technologies are available, how they work together, and which can be used in our toolbox when performing upgrades. Therefore, the initial upgrades should start with the central ATMS, ATC specification traffic signal controllers, Ethernet/IP-based communications network, and closing communication gaps. In addition, other ITS improvements should also be considered such as HD IP CCTV camera systems, hybrid video/radar detection, arterial management system technologies, etc. to facilitate the operations of the signalized intersections and corridors; and to provide performance measurement tools to pro-actively manage the transportation system.

Newer Advanced Traffic Management Systems (ATMS) have the capabilities to provide newer technologies such as; peer to peer communications, high resolution data, ATCS functionality, C2C communications and Connected Vehicle integration. Once a new ATMS is deployed then other upgrades should follow such as: new Advanced Transportation Controllers (ATC), upgrading communications networks to be Ethernet/IP-based – the combination of these improvements allows the ease integrating these systems and helps provide integration of other ITS sub-systems such as video management systems or arterial management systems.

Table 6.14 summarizes recommended technologies to maximize the City's infrastructure. These future recommendations are based on needs for increased bandwidth, redundant communications, and ease of maintenance.

Table 6.14 - Phase I Project Improvements

System Component	Limits	Improvements
Network backbone	Sierra Highway, 10th Street West	72 SMFO cable, HUB Improvements: FDU's, Aggregate Ethernet Switch equipment
Network Distribution	Avenue I, Avenue J, Avenue K, Avenue L, Avenue M (East-West)	72 SMFO cable, ATC Controllers, Edge Ethernet Switch, Video Detection Equipment, HD IP CCTV cameras

System Component	Limits	Improvements
Wireless Distribution	Existing north-south Copper SIC limits. Last mile locations, locations with no underground conduit	5GHz Wireless Ethernet Broadband Radios (MIMO), Edge Ethernet Switch, Video Detection Equipment
ATMS Core	City Hall	ATMS System, Video Management System, La County IEN platform, TMC Workstation(s), LED Video Display Monitor
ATMS Remote	Maintenance Yard	TOC Workstation(s), LED Video Display Monitor

6.1 Near Term and Future Improvements by Others

The City of Lancaster shall look to incorporate the latest ITS technologies and infrastructure with public works and private development improvements along their existing and proposed signalized intersections and roadway systems. At a minimum, the City of Lancaster should include the following improvements:

- 3” conduit with 72 SMFO distribution cable
- Splice vaults with 12 SMFO drop cable
- 2070 ATC controllers
- HD IP CCTV Cameras
- Vehicle/Bicycle Detection Systems per lane
- If migrating to video/radar detection systems, it shall be link to the City’s TMC and video images shall be provided
- Consider Bluetooth/Wi-Fi Arterial Management Systems

Overall, the evaluation of the Citys existing and future traffic management systems, communication systems, ITS elements, and TMCs, identify opportunities that exist for inter-agency and regional communication in the form of sharing traffic data/video between the local cities/agencies and provide a framework for other forms of shared data, or cloud-based connectivity. This can be accomplished by establishing key connection points between agency boundaries and dedicating a percentage of available networking resources for future use.

Existing infrastructure such as fiber optic backbone communications; and near-term citywide fiber optic high-bandwidth improvements, provide the Ethernet/IP-based communications needed to establish connectivity between agencies for data and video sharing, which can be expandable and scalable for new ITS and ATMS deployments. Once these systems are deployed, they can provide: the infrastructure and greater opportunity to maintain sychronized corridors; and the communication backbone necessary to implement and manage bus service priority (BSP), traveler information systems, arterial freeway management systems, and integrated corridor management systems on a regional level.

7. PROJECT PHASING and DEPLOYMENT

The successful implementation of a multi-phase citywide project requires the development of priorities prior to deployment. The need for a systematic approach and defined priorities help determine the near term and long-term projects for ITS technologies deployment in the City of Lancaster. Key considerations include:

- Development and installation prerequisites. Identify what systems/sub-systems need to be deployed before other systems/sub-systems can function
- Deployment of interfacing systems that must precede deployment of other system features
- Create a viable operational capacity at each stage. This determines how much of the system must be deployed for it to operate effectively at each stage

In addition, a phasing and deployment strategy has been developed that identifies near term deployments (first phase) and long-term deployments (future subsequent phases) of the project improvements. This includes project prioritization and recommended improvements. The project prioritization is based on preliminary cost estimates, agency needs, and local and regional benefits.

7.1 Project Priority

Near term and long-term priorities were developed and are separated into several subsequent phases. Near term phasing includes the "Phase I" infrastructure deployments under the **ITS Expansion** and **Traffic Signal Modernization** projects. Phase I build-out conditions include replacement of existing copper signal interconnect (SIC) cable to new fiber optic cable and installation of new wireless Ethernet broadband where no underground conduit exists. Ultimate build-out conditions include new fiber optic cable and closing communication gaps.

The long-term phases assume the construction of remainder priority corridors, future traffic signals, additional communication infrastructure and ultimately fiber optic build-out to city limits. From an agencies perspective, any design of future traffic signals should include equipment required to meet near term and long term ITS needs described in this master plan. Long term needs include future traffic signals, added fiber optic cable, additional CCTV cameras, additional Arterial Management System detection, installation of Changeable Message Signs (CMS) hardware/software and Connected Vehicle (C2X) infrastructure.

7.1.1 Phase I (ITS Expansion and Traffic Modernization Projects)

The objective of phase I implementation is to provide a new fiber optic network, Ethernet IP communications, a new central ATMS software system and new ATC controllers citywide. Phase I improvements are broken down into 2 distinct projects below:

- **ITS Expansion Project** includes the upgrade of the City's fiber optic backbone. Dark / proposed fiber optic cable will close any communications gaps. HUB locations will provide aggregation of local traffic communications and transmit via the proposed Gigabit backbone ring. Installation of new ATC traffic signal controllers and core ATMS central system will provide the interface to all existing/ future traffic signals and connection to the LA County Information Exchange Network (IEN).

- **Traffic Signal System Modernization Project** will upgrade major east-west corridors with fiber optic cable in existing conduit, install Ethernet Edge switches, install Video Detection streaming equipment, install HD IP CCTV equipment, and provide high-bandwidth 5GHz wireless communications to remote traffic signals.

Core central ATMS improvements at City Hall and the Maintenance Yard will provide remote real-time surveillance of traffic operations. A proposed Video Management System will interface and manage the video feeds of all streaming Video Detection/ CCTV cameras. Essentially, these improvements provide a foundation to connect all existing/future traffic signals and ITS elements, such as future Phase II and Smart Cities applications.

Figure 7.9 illustrates the Core Communications Architecture under the Phase I project.

Figure 7.10 illustrates the Proposed ITS Improvements under the Phase I project.

Figure 7.9. Phase I – Core Communication Architecture

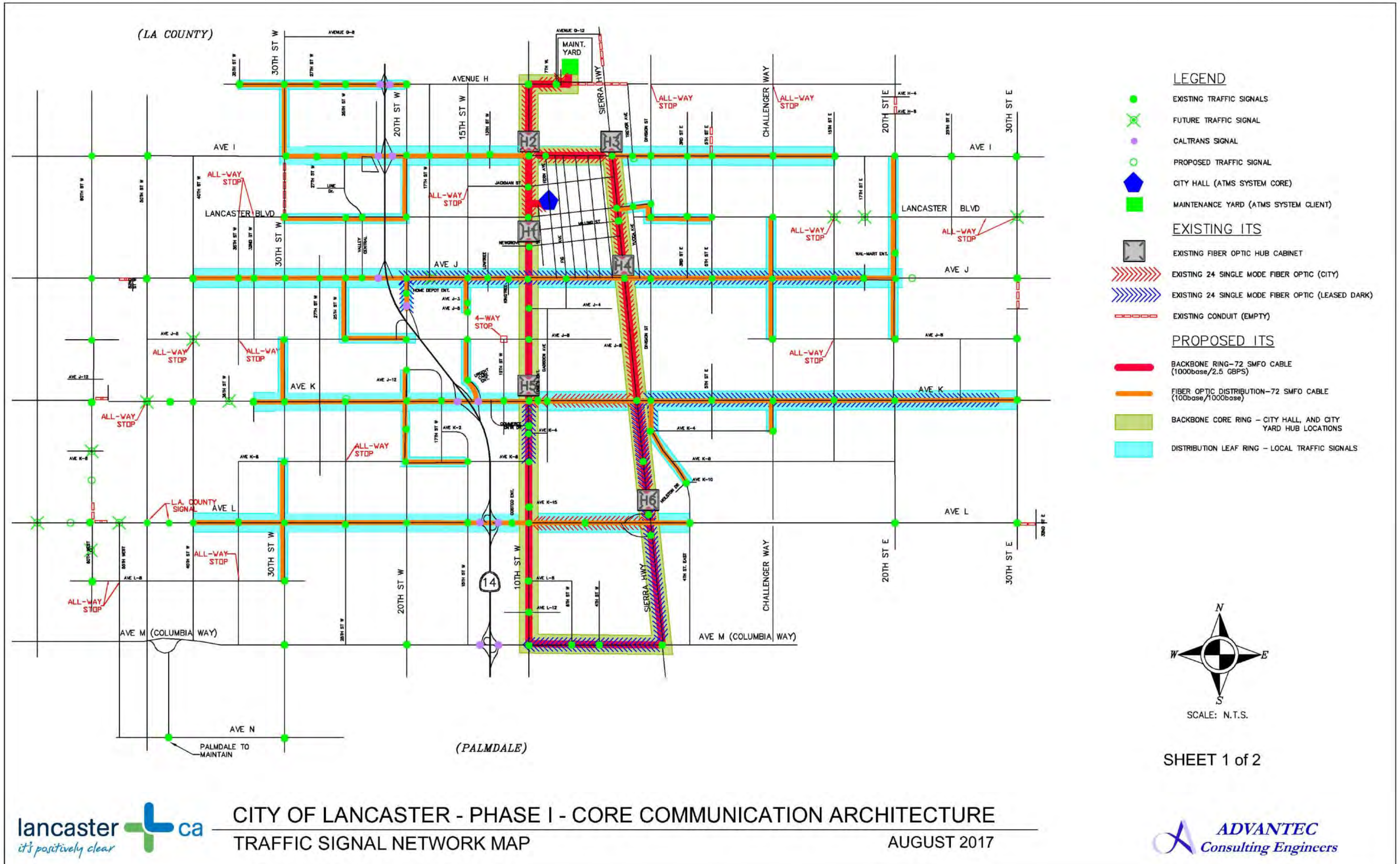
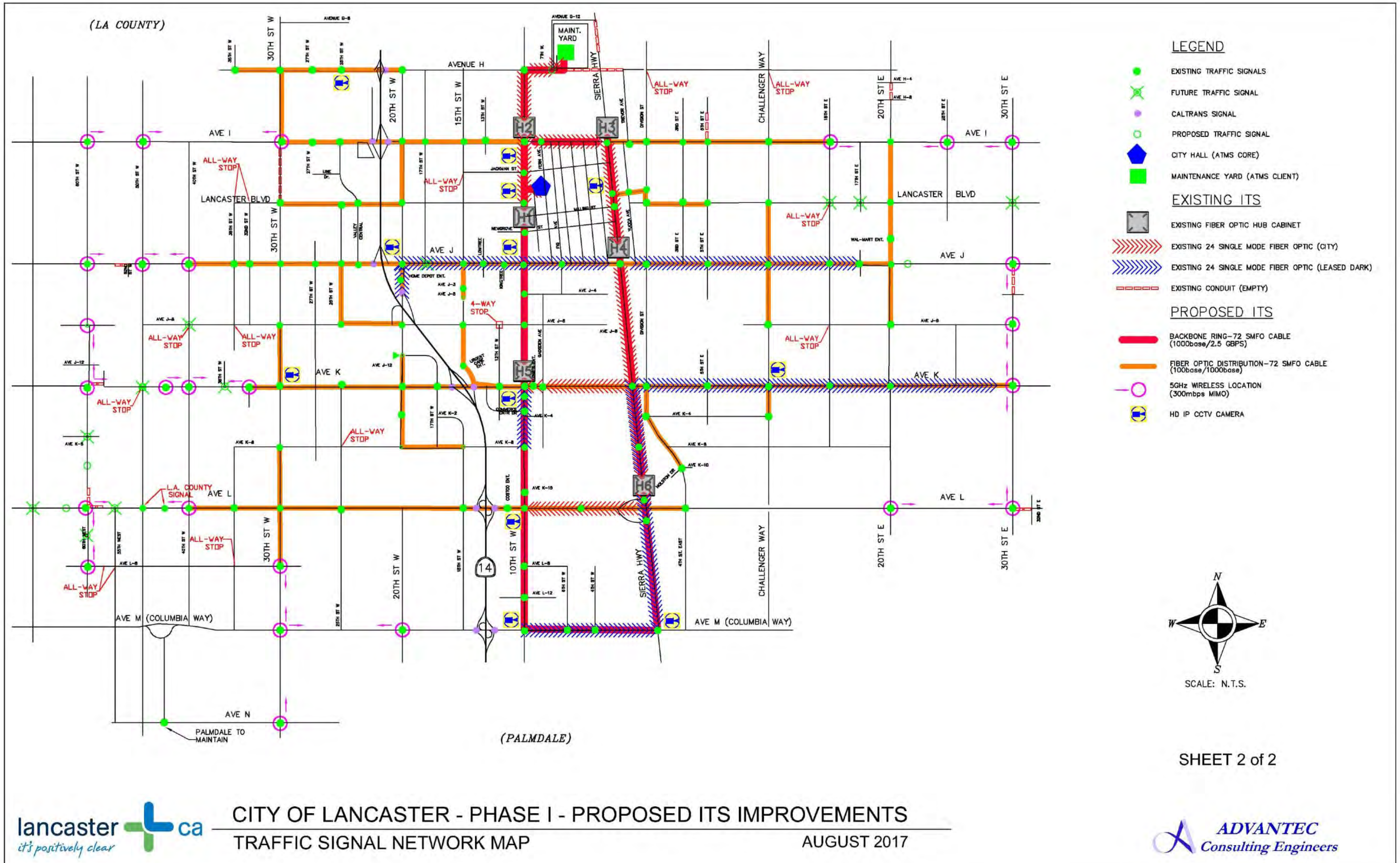


Figure 7.10. Phase I – Proposed ITS Improvements



7.1.2 Phase II - Additional Fiber Optic/ ITS Upgrades

The objective of Phase II implementation is to expand the City's fiber backbone network and provide additional ITS elements such as HD IP CCTV's at additional locations and implement new Arterial Managements Systems (Bluetooth/Wi-Fi) for real-time travel time information. Other elements such as Adaptive Traffic Signal Control (ATCS) shall also be considered during this phase.

- **Fiber Optic Upgrades**

  The citywide fiber optic network will be expanded and new fiber optic HUB cabinets will be installed at select locations. Between new/ existing HUB locations, further Sub-Rings can be established which will provide for additional redundancy of the fiber optic backbone.

- **HD IP CCTV Upgrades**

  The need for High Definition IP CCTV Cameras have been proposed at selected high-volume intersections. The intersections have been strategically chosen for intersections tilt/zoom capabilities that will allow city/agency staff to monitor traffic conditions at intersections and roadway segments, troubleshoot, and fine-tune intersection operations in real-time.

  The surveillance images can be shared with other stakeholders including other City departments, other agencies, and the public via City/agency's websites and/or mobile applications. Careful placement at the intersection should be considered to ensure proper line of sight so that the city/agency staff can manage and operate the intersections efficiently. Integration of the proposed IP CCTV cameras will be required at the central VMS system.

- **Arterial Management System Upgrades**

  The need for monitoring floating car data along key arterial segments in the City of Lancaster is a priority. Bluetooth and Wi-Fi detection sensors and processing units should be place at specific locations along key project corridors to transmit unique MAC address data to the central TMC location. Backend software has the ability to host a server at the TMC or subscription based in the Cloud. Unique algorithms have the capability to calculate travel times, speeds, volumes and origin-destination along a corridor.

- **Adaptive Traffic Signal Contol (ATCS)**

  For intersections that have high volume mainline traffic or specific locations adjacent to schools/airports/special event centers that require high volume green times for only specific times of day, an Adaptive Traffic Signal Control system may be warranted. There are two important requirements for a successful ATCS deployment: reliable communications and upgraded vehicle detection. Typically, communications will be provided by the Ethernet/IP-based connections, from controller to controller, from controller to field communication hub, and all communications back to the TMC. Most adaptive systems require that vehicle detection be provided for each lane, for all approaches. Both advance detection and presence (or limit line) detection should be separated by lane.

Figure 7.11 illustrates the Core Communications Architecture under the Phase II project.

Figure 7.12 illustrates the Proposed ITS Improvements under the Phase II project.

Figure 7.11. Phase II – Core Communication Architecture

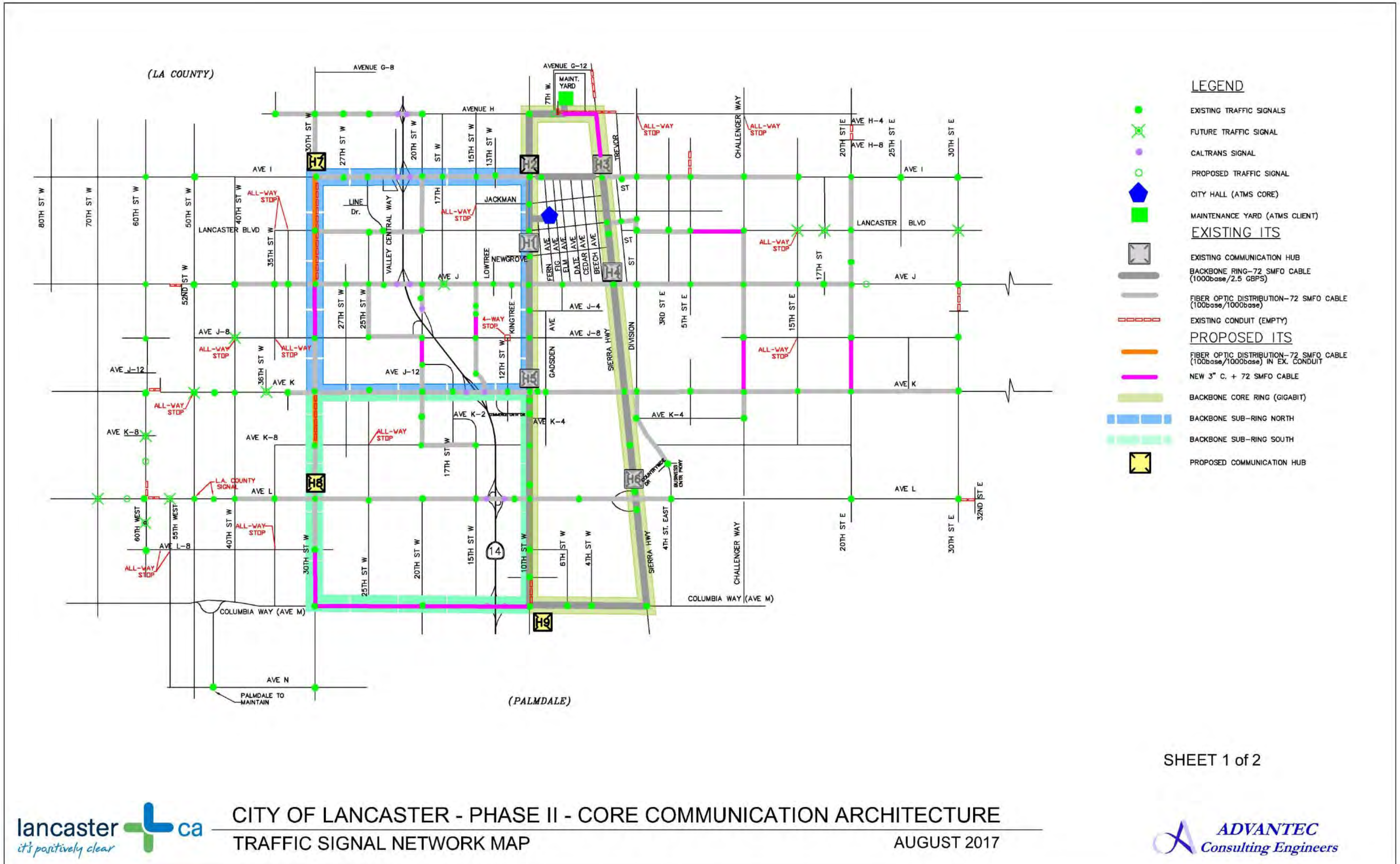
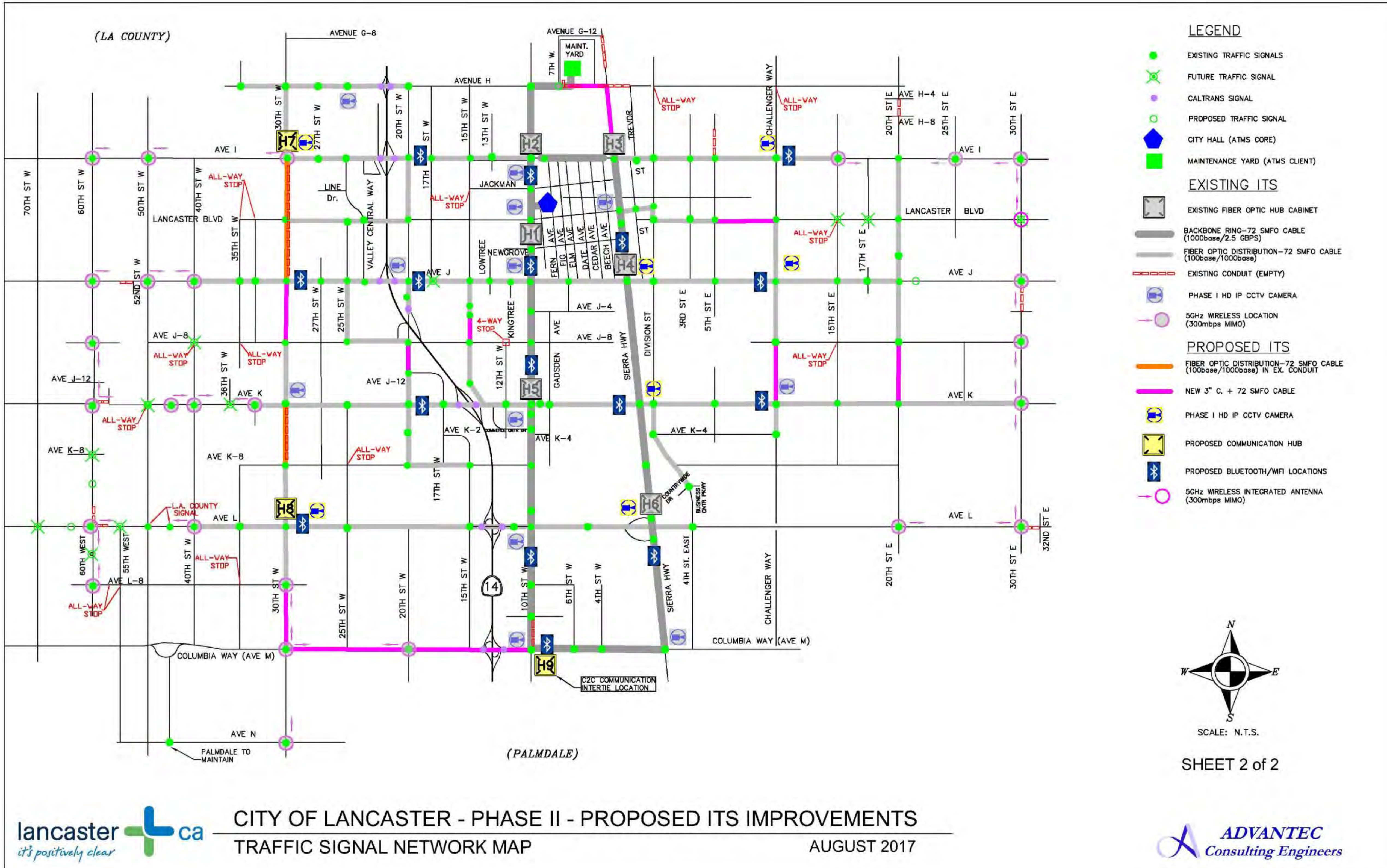


Figure 7.12. Phase II – Proposed ITS Improvements



7.1.3 Phase III - Smart Cities Elements and Expansion

A Smart City is an urban development vision to integrate multiple Information and Communication Technology (ICT) and Internet of Things (IoT) solutions in a secure fashion to manage a city's assets – the city's assets include, but are not limited to, local departments' information systems, schools, libraries, **transportation systems,** hospitals, power plants, water supply networks, waste management, law enforcement, and other community services.

The goal of building a Smart City is to improve quality of life by using urban informatics and technology to improve the efficiency of services and meet residents' needs. ICT allows city officials to interact directly with the community and the city infrastructure and to monitor what is happening in the city, how the city is evolving, and how to enable a better quality of life. Using sensors integrated with real-time monitoring systems, data are collected from citizens and devices – then processed and analyzed.

- **Smart Lighting Systems**

  Smart Lighting Systems are a key element in the Smart Cities applications. The need for Smart Lighting Systems are important for the local agencies and the region by using less energy, reducing energy costs, providing safer environments, and reducing environment impacts.

  Smart Lighting Systems brighten lighting when there is activity detected, and dim down lighting to reduce costs when streets and parking facilities are empty. Smart Lighting Systems have the capability to be adjusted to several predefined factors such as weather, pedestrian movement, vehicle movement and monitoring sensitive areas. As a result, it can save energy while maintaining the same or increased level of safety.

- **Smart Parking Systems**

  Smart Parking Systems are a key element in the Smart Cities applications. The need for Smart Parking Systems are important for the local agencies and to the region, which can improve a parking revenue and reduce traffic volumes and emissions due to reduction in driving time to find open parking spots. The latest generation of these systems combines low cost, in-street sensors with payment stations, back-end management and enforcement software, and smart phone customer access portals. This includes:

  - New conveniences for visitors and residents – created by available parking spot locations, flexible payments, fees, and parking spot reservations – all through smart phone applications
  - Increased revenues are created from the introduction of new services and fees, such as: time of use charging, premiums for reservation services, and less meter downtime
    - Although fees for public parking within parking lots and structures are not currently established within the Coachella Valley, this illustrates the benefit if the local cities/agencies were to consider this option
  - More efficient directed parking enforcement, achievable through real time violation notifications sent to patrolling enforcement officers

- Significant reduction in city-wide traffic volumes and emissions due to reduction in driving time to find open parking spots
- Links to on-street dynamic message signs with messages displaying occupancy and directions to alternate parking facilities when other parking facilities are full

- **Connected Vehicles (CV)**

Connected Vehicle technology is present and fast approaching deployments in many surrounding areas. Wireless design guidelines must be established with a strategic deployment plan within a given project area. If designated, a new wireless communication installation would be able to transmit adjacent point-to-point traffic data in addition to localized DSRC radio communications. If this cannot be established from point-to-point, additional or stand-alone 5.9 GHz DSRC radio units must be strategically placed/powered at mid-block locations. Ideally unrestricted line of sight must be established from one radio to the next, providing overlap within a 300-meter range. This provides complete coverage within a connected vehicle network.

A Connected Vehicle platform has many parts that need to be in place for it to be working on the street successfully. Whether these solutions are provided by the Original Equipment Manufacturer (OEM) or 3rd party integrators, generally there are four (4) different areas of CV technology that need to be implemented for a working deployment. These areas are:

- **On-board Unit** (OBU) – Vehicle/Pedestrian/Bicyclist
- **Road-side Unit** (RSU) - Traffic Signal/Lighting Standard
- **V2X Middleware** - Data Services/Background Processes
- **V2X Applications** (Apps) - Human Interface/Message Format

For a successful deployment of a CV Program in the Antelope Valley, stakeholders must establish standards and policies to use new technologies and support tools for real-time needs and to meet long-term public policy objectives. Development of a cost/benefit analysis should be performed and lessons learned through implementation on high priority CV applications.

8. REFERENCES

- FHWA, ITS Architecture Implementation Program, US Department of Transportation
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