CITY OF SAN DIEGO

TRAFFIC SIGNAL COMMUNICATIONS MASTER PLAN

PREPARED BY:

STACK TRAFFIC CONSULTING, Inc.

PREPARED FOR:

THE CITY OF SAN DIEGO

TRANSPORTATION & STORM WATER

DECEMBER 2014

SAN DIEGO TRAFFIC SIGNAL COMMUNICATIONS MASTER PLAN

December 2, 2014

Version	Date	Status
1	07/14/2014	Issued for City Review
2	10/24/2014	Issued for City Review
3	11/06/2014	Submitted Final Draft
4	12/02/2014	Submitted Final Report

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

REFERENCES

- Executive Summary
  - Reference 1: City of San Diego Climate Action Plan DRAFT, City of San Diego, September 2014
  - Reference 2: City of San Diego Fire Services Standards of Response Coverage Deployment Study, City of San Diego Fire Rescue Department, February 2011
  - Reference 3: California Strategic Highway Safety Plan, Office of Traffic Safety, 2013
  - Reference 4: California Local Roadway Safety Manual, U.S Department of Transportation Federal Highway Administration, April 2013
  - Reference 5: San Diego Regional Intelligent Transportation Systems Strategic Plan, San Diego Association of Governments, August 2011
  - Reference 6: SANDAG 2050 Regional Transportation Plan, San Diego Association of Governments, October 2011
  - Reference 7: City of San Diego, City of San Diego Economic Department, March 2011
  - Reference 8: City of San Diego, City of San Diego Transportation & Storm Water Department, January 2014
- Chapter 1- Introduction
  - Reference 1: City of San Diego, City of San Diego Economic Department, March 2011
  - Reference 2: Southern California Coastal Ocean Observing System, Federal Funding Opportunity, Fiscal Year 2011
  - Reference 3: "Number of Border Crossing Stabilizes," *San Diego Union Tribune*, July 2011
  - Reference 4: "The Facts: Why Tourism Matters to San Diego," San Diego Tourism Authority, January 2014
  - Reference 5: San Diego's Road to Economic Recovery, San Diego Regional Chamber of Commerce, June 2012
  - Reference 6: City of San Diego, City of San Diego Transportation & Storm Water Department, January 2014
  - Reference 7: City of San Diego Climate Action Plan Draft, City of San Diego, September 2014
  - Reference 8: City of San Diego Fire Services Standards of Response Coverage Deployment Study, City of San Diego, February 2011
  - Reference 9: California Strategic Highway Safety Plan, Office of Traffic Safety, 2013
  - Reference 10: California Local Roadway Safety Manual, U.S Department of Transportation Federal Highway Administration, April 2013
  - Reference 11: San Diego Regional Intelligent Transportation Systems Strategic Plan, San Diego Association of Governments, August 2011
  - Reference 12: SANDAG 2050 Regional Transportation Plan, San Diego Association of Governments, October 2011
- Chapter 2- Existing Conditions
  - Reference 1: City of San Diego Records, City of San Diego Transportation & Storm Water Department, February 2014
  - Reference 2: City of San Diego Records, City of San Diego Transportation & Storm Water Department, January 2014
  - Reference 3: SanGIS GIS Data Warehouse, SANDAG, February 2014

  - Reference 4: QuicNet Traffic Management System, City of San Diego, January 2014
  - Reference 5: City of San Diego Records, City of San Diego Transportation & Storm Water Department, January 2014
  - Reference 6: City of San Diego Records, City of San Diego Transportation & Storm Water Department, January 2014
  - Reference 7: City of San Diego Records, City of San Diego Transportation & Storm Water Department, February 2014
  - Reference 8: City of San Diego Maintenance Staff, City of San Diego Transportation & Storm Water Department, January 2014
  - Reference 9: Fieldwork Verification, January 2014
  - Reference 10: Google Earth Verification, January 2014
  - Reference 11: City of San Diego Records, City of San Diego Transportation & Storm Water Department, February 2014
  - Reference 12: Public Facilities Financing Plans Research, City of San Diego Facilities Financing Section of the Planning Department, June 2014
  - Reference 13: Detection Range of Optical Emergency Vehicle Preemption System under Typical System Maintenance Conditions Study, Institute of Transportation Engineers (ITE) Journal, June 2013
  - Reference 14: SuperLoop Project , SANDAG, September 2014
  - Reference 15: “New Stoplights Fight Gridlock: San Diego embracing new ‘adaptive’ signals as neighborhoods get more dense”, *San Diego Union Tribune*, October 2014
  - Reference 16: Integrated Corridor Management (ICM) Fact Sheet, SANDAG, 2013
  - Reference 17: City of San Diego, City of San Diego Transportation & Storm Water Department, June 2014
- Chapter 3- System Deficiencies and Resolution
  - Reference 1: City of San Diego Traffic Signal Maintenance Staff, City of San Diego, June 2014
- Chapter 6-ITS Element Recommendations
  - Reference 1: NTCIP 9001 version v04, American Association of State Highway and Transportation Officials (AASHTO), Institute of Transportation Engineers (ITE), and National Electrical Manufacturers Association (NEMA), July 2009
  - Reference 2: Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems, United States Department of Transportation Federal Highway Administration, August 2012
  - Reference 3: An Approach to Communications Security for a Communications Data Delivery System for V2V/V2I Safety: Technical Description and Identification of Policy and Institutional Issues, United States Department of Transportation Research and Innovative Technology Administration (RITA), November 2011
  -
- Chapter 7- Implementation Phasing Plan
  - Reference 1: Traffic Signal Operations and Maintenance Staffing Guidelines, United States Department of Transportation Federal Highway Administration, March 2009
  - Reference 2: Traffic Signal Operations and Maintenance Staffing Guidelines, United States Department of Transportation Federal Highway Administration, March 2009

- Reference 3: Approved Public Facilities Financing Plans, City of San Diego Facilities Financing Section of the Planning Department, June 2014
- Reference 4: Typical Public Facilities Financing Plan 15 Month Timeline, City of San Diego Facilities Financing Section of the Planning Department, June 2014
- Reference 5: Impact Fees, City of San Diego Facilities Financing Section of the Planning Department, June 2014
- Reference 6: Impact Fees, City of San Diego Facilities Financing Section of the Planning Department, June 2014
- Reference 7: TransNet Fact Sheet, SANDAG, October 2014
- Reference 8: City of San Diego Fiscal Year 2015 Adopted Budget, City of San Diego, April 2014
- Reference 9: Transportation & Stormwater, City of San Diego Fiscal Year 2015 Adopted Budget, City of San Diego, April 2014
- Reference 10: MAP-21 Highway Safety Improvement Program (HSIP) Fact Sheet, United States Department of Transportation Federal Highway Administration, September 2013
- Reference 11: "Bill Aims to Change Red Lights to Green," *San Diego Union Tribune*, September 2014
- Reference 12: Best Value Analysis Program, City of Carlsbad
- Reference 13: Local Agencies and Design-Build Contracting: A Brief Paper for Legislators and Their Staff, September 2009
- Reference 14: Construction Contracts: Law and Management, John Murdoch and Will Hughes, 2007
- Reference 15: Systems Manager, United States Department of Transportation Bureau of Transportation Statistics,

- Chapter 9- Master Plan Costs and Benefits
  - Reference 1: 2012 Urban Mobility Report Powered by INRIX Traffic Data, Texas A&M Transportation Institute, December 2012
  - Reference 2: California State Assembly Bill 1447, Assembly woman Marie Waldron, August 2014
  - Reference 2: National Transportation Operations Coalition and Traffic Signal Library

ES Executive Summary

The City of San Diego has initiated the most significant investment in its history, in state-of-the-art traffic signal systems technology and Intelligent Transportation Systems (ITS), through the development of the Traffic Signal Communications Master Plan (TSCMP). The benefits of the plan are drastic, great, and wide ranging. Through modernization of the traffic signal system in San Diego, traffic signals throughout the community will be coordinated and this will increase public safety, shorten commutes, reduce greenhouse gasses, and increase mobility at intersections for all modes of travel including motorists, bicyclists, pedestrians, transit, and emergency vehicles.

The Plan's purpose is to guide the City on implementing traffic signal communications and ITS technology improvements and includes resource allocation related to improvement prioritization, funding sources, and staff levels.

The plan is ground-breaking in many ways: the breadth of technology proposed includes every critical element of the traffic signal system, the technology is state-of-the-art, the area of deployment covers the entire City and all 1531 traffic signals, and the plan is scheduled for complete implementation in three phases by 2025.

E1 Advancing Initiatives

The Traffic Signal Communication Master Plan (TSCMP) advances several Local, Regional, and State transportation initiatives. These include:

The **City of San Diego Climate Action Plan (CAP)**[1] initiative (Draft, September 2014) identifies measures to meet greenhouse gas (GHG) reduction targets for 2020 and 2035. Action 3.4 calls to reduce vehicle fuel consumption through implementation of the City's Traffic Signal Communications Master Plan.

The **City of San Diego Fire Services Standards of Response Coverage Deployment Study**[2] is a comprehensive study of the level of fire service staffing, response times, and outcomes. The City's set standard for emergency response times is 7 minutes and 30 seconds. The TSCMP provides a complete upgrade for all of the existing emergency vehicle preemption system components throughout the City and will help the City achieve response time goals.

The TSCMP is expected to reduce intersection crashes in San Diego. The **California Strategic Highway Safety Plan (SHSP)**[3] identifies signal timing and ITS tools as appropriate safety countermeasures for intersection crashes. The **California Local Roadway Safety Manual**[4] also identifies improved signal timing, coordination, and operation as a safety benefit to address locations that have a crash history at multiple signalized intersections.

The **San Diego Region Intelligent Transportation Systems (ITS) Strategic Plan**[5] outlines a unified vision for the regional ITS investment strategies that regional transportation agencies have prioritized for funding and implementation. Arterial Management is one of the six investment areas identified by the ITS Strategic Plan and consistent with the Transportation Systems Management chapter of the **SANDAG 2050 Regional Transportation Plan (RTP)**[6]. The TSCMP advances the 2050 RTP and ITS Strategic Plan arterial management investment area to the next level by identifying the specific ITS technologies, deployment strategies, and resources required for the overwhelming majority of arterials in the Region.

E2 Need

San Diego is the eighth-largest city in the United States and second-largest in California[7] and is one of the fastest growing cities in the nation. San Diego has a population of over 1.3 million people and covers an area over 370 square miles. San Diego has traditionally built roadways, adding capacity to meet the growing traffic demand. This approach becomes less practical as San Diego's roadway network becomes built-out due to right-of-way constraints, environmental impacts, and high costs of building new and/or expanded roadways. The City cannot build its way out of traffic congestion and should augment traditional investments in roadway construction by investing in Intelligent Transportation Systems (ITS) solutions to optimize the use of existing roadway capacity through improved traffic signal synchronization and operations management.

E3 Deficiency Identification

The City operates and maintains over 1,500 traffic signals which provide safe movement at intersections for vehicles, pedestrians, bicyclists, emergency vehicles, and transit/rail[8]. The signals must also operate efficiently and reliably to provide progression through a series of signals to minimize congestion and maintain a higher level of safety. The communications and control technology operating the signals was developed approximately 30 or more years ago. These include dial up modems connected through an extensive network of fiber optic multiplexors and twisted pair copper communications. The existing communications system is functionally obsolete and in some instances in a state of disrepair due to the outdated equipment. Replacement parts are difficult or impossible to obtain and staff is devoting an excessive amount of time trying to keep the equipment serviceable. This system is incapable of providing efficient traffic management and operations for the City in the modern traffic environment.

Table E-1 contains a summary of the existing communications repair and gap issues.

Table ES-1 Traffic Signal Conditions Summary

Traffic Signal Type	Quantity
City of San Diego Total	1531
Existing Communication Infrastructure Present	1046
No Communication Due to Repair	178
No Communication Due to Gap	307

E4 Key Recommendations

The following list summarizes key communications system and ITS element recommendations identified in this master plan.

E4.1 Communications System

The future City of San Diego traffic signal communications network shall meet the following goals.

- Compatible with current and future industry standards,
- Eliminate single vendor dependency,
- Increase equipment availability,
- Increase system capacity,
- Reduce system cost,
- Redundant, self-healing,
- Provide more bandwidth for current and future applications.

The future City of San Diego traffic signal communication network will be based on the Ethernet protocol. All existing proprietary time division multiplexers (both the OTNs and ADCs) will be discarded and replaced with layer 3 Ethernet routers. These new routers will serve as the hubs of the new backbone. The existing fiber plant will be utilized with layer 3 routers in ring based redundant and self-healing backbone network architecture. The network shall be designed as a two-tiered network. Tier 1 will utilize the layer 3 node equipment connected to each other in a ring network using 10 Gbps or higher link speeds. Tier 2 will utilize layer 2 field Ethernet devices connected to each other also in a ring network at various link speeds, depending on the equipment on that link.

The existing copper wire infrastructure investment that is already in place throughout the City of San Diego shall be preserved, thus saving money on infrastructure costs. All existing analog modems shall be replaced with VDSL based Field Ethernet Switches (FES).

The existing signal communication system accessed via the dial-up lines throughout the City will be converted into wireless access via either:

- 4G Wireless routers, communicating to the TMC over the Internet of Things (IoT) Network.
- Dedicated, City owned wireless radios connecting to the nearest layer 3 router.

Intersections currently connecting to the network via existing 900 MHZ serial (EIA-232) digital, low bandwidth, wireless radios will be converted into high bandwidth wireless Ethernet links.

All of the Digiboards at the TMC will be removed and discarded and replaced with “Virtual Com Port” software. All of the existing 170E controllers currently communicating over their serial ports will be upgraded with a serial to Ethernet converter card plugged-in the existing modem slot of the 170E controller chassis making them capable of communicating over the new Ethernet network.

E4.2 ITS Elements

The goal of the ITS element recommendations is to gain operational efficiency by having real time 24/7 access to every ITS device in the network and dynamically monitoring each and every one of the devices from the Traffic Management Center (TMC). ITS element recommendations are summarized below:

A modern Traffic Management Center providing a dedicated workspace for operations staff, and communications and management systems, should be implemented as part of future system expansion. A video wall of a minimum 3 rows of 4 LCD displays per row should be installed for continuous real-time monitoring of the traffic conditions for timely remedial action. The central system software requires the support of the National Transportation Communications for ITS Protocol (NTCIP). Rugged laptops with 4G/LTE communication capabilities should be assigned to each operator to allow for programming and troubleshooting of field devices and remote connection to the TMC servers/devices.

All future backbone communications medium should use a minimum of 96 strands single mode fiber optic cable where there is an existing conduit and where there will be new conduit installed.

- Traffic Operations fiber strands are not to be shared.
- No other VLANs on Transportation & Storm Water Department fiber.
- Traffic Operations network must be totally independent from other departments' networks.
- No sharing of the layer 3 routers,
- No sharing of the layer 2 FESs.
- Owned communications wherever and whenever possible.
- The ultimate goal is a wired network.
- Use city owned point to point or point to multipoint line of sight broadband Ethernet radio links to shoot shorter gaps where no agency connections exist.
- Use cellular to shoot wider gaps where no agency connections exist.
- Utilize other City department communications when advantageous to shoot a gap.
- If available and not planned for future use, other fiber buffer tubes may be shared.

ITS/ATC communication hub cabinets and fiber vaults are recommended. Field cabinets that will house the layer 3 equipment should be air conditioned and UPS protected.

Additional ITS element recommendations include the following:

- ITS Traffic Signal Cabinet
- ATC Controllers
- Conflict Monitors
- Detection Systems
- Emergency Vehicle Preemption System
- Battery Backup Systems
- CCTV Cameras

- Adaptive Signal Control Systems
- Changeable Message Signs
- Web Portal

E5 Implementation Phasing

Transforming the existing network, composed of thousands of field devices spread over 370 square miles, requires a phased approach where critical deficiencies are addressed first, followed by a strategic conversion of the remaining communication infrastructure.

The objective is to complete the TSCMP in 10 years, by year 2025. This plan revolves around technological advances that necessitate change in a timely manner, in order to keep as relevant as possible. It is also recognized that the recommendations of the TSCMP are largely unfunded and it will take time to build the proper funding into the City's Capital Improvement Program (CIP). The technology identified by the TSCMP is critical for the operation and maintenance of the City's traffic signal network which provides for safe and efficient mobility for all modes of travel. Implementing this plan expeditiously will provide the greatest return on investment through reduced traffic congestion, fewer crashes, greater productivity, lower transportation costs, and lower greenhouse gas emissions.

Phase 1: Critical Deficiencies (Year 1-3) – This includes repairing and/or establishing communications to the 500 plus communication deficiencies identified throughout the City. The Traffic Management Center will also be implemented in Phase 1.

Phase 2: Central Business District (Year 3-6) – As a best practice, the transformation of the legacy network shall begin centrally and expand outward into peripheral networks. Phase 2 constitutes Ethernet upgrades of nearly 500 intersections contained by the Central Business District (i.e. Downtown).

Phase 3: Peripheral Networks (Year 6 -10) –The final phase of the communications overhaul will call for the replacement of existing hubs and extending Ethernet communication to each intersection serviced by the hub. The implementation of phase 3 focuses on the remaining 500 or so intersections with the advantage of new Ethernet networks to connect to in the interior of the City.

E6 Staffing Recommendations

The operations and maintenance (O&M) staff for traffic signals have overlapping areas of responsibility and staff skills are complimentary. The most well managed systems occur when operations engineers and maintenance technicians work side by side. The following are recommendations for O&M staffing:

- The traffic signal/ITS staffing should be a combination of traffic operations engineers and maintenance technicians.

- The traffic signal/ITS O&M staff should be exclusively dedicated to traffic signal system related activities.
- Duties include managing the TMC, implementing new operations and systems, troubleshooting and maintaining the communications lines, equipment, and ITS elements in the field and TMC.
- The traffic signal/ITS O&M staff should comprise of 5 operations engineers and 3 technicians. This is in the order of double the existing staff dedicated to traffic signal/ITS related duties and equates to roughly 200 signals per staff.
- The traffic signal/ITS O&M staff should have expertise in traffic operations, communications systems, Ethernet networking, and ITS devices.
- If necessary, existing personnel will be trained on Ethernet based communication architectures and protocols.
- There should be regular training and classes set up to learn new systems and how to troubleshoot and repair.
- The TMC should be manned 24/7 with 3-4 staff working 8 hours during the day and one of them during the night.
- The City should contract the services of an on-call ITS and traffic signal operations engineering firm to provide highly technical services. This would provide much needed staff support during the TSCMP implementation. This would also provide flexibility in staffing levels as needed as in-house staffing levels are met.

If combining operations engineers and technicians in one group does not work due to policy limitations, then pursuing a dialog and agreement between Transportation Engineering Operations Division and Street Division for Streets to assign 3 technicians dedicated to TMC and ITS maintenance is strongly recommended.

E7 Order of Magnitude Cost Estimate

The overall deployment cost for the San Diego Traffic Signal Communication Master Plan communication systems, ITS elements, and staffing needs for each implementation phase is presented in **Table ES-2**.

Table E-2 Citywide TSCMP Deployment Cost Estimate(1)

Subarea / Item #	Subarea	Phase 1	Phase 2	Phase 3	Total
1	Kearny Mesa/Clairemont Mesa	$1,693,500	$0	$1,137,000	$2,830,500
2	Pacific Beach/Mission Bay	$1,462,500	$0	$90,750	$1,553,250
3	Mid City	$2,512,500	$3,099,750	$0	$5,612,250
4	Mission Gorge/Navajo	$767,250	$0	$0	$767,250
5	Tierrasanta/Murphy Canyon	$441,750	$0	$0	$441,750
6	Carmel Valley	$525,750	$0	$66,000	$591,750
7	Southeast San Diego	$1,074,000	$432,000	$0	$1,506,000
8	Logan Heights/Barrio Logan	$564,000	$780,750	$0	$1,344,750
9	Del Mar Heights	$627,750	$0	$478,500	$1,106,250
10	San Ysidro	$678,000	$0	$2,300,250	$2,978,250
11	Otay Mesa	$426,000	$0	$115,500	$541,500
12	Mission Valley/Linda Vista	$1,877,250	$0	$1,781,250	$3,658,500
13	Rancho Bernardo	$650,250	$0	$990,750	$1,641,000
14	Mira Mesa	$723,750	$0	$884,250	$1,608,000
15	Sorrento Valley	$461,250	$0	$763,500	$1,224,750
16	La Jolla	$515,250	$0	$1,155,750	$1,671,000
17	Airport/Point Loma	$969,000	$2,112,000	$0	$3,081,000
18	Scripps Poway	$484,500	$0	$1,087,500	$1,572,000
19	Central Business District	$1,058,250	$2,887,500	$0	$3,945,750
	Sub Total Communications	**$17,512,500**	**$9,312,000**	**$10,851,000**	**$37,675,500**
20	TMC	$780,000	-	-	$780,000
21	ITS O&M Staff	$180,000	$270,000	$270,000	$720,000
22	ITS Elements	-	$62,302,500	$62,296,000	$125,378,500
	Grand Total	**$18,472,500**	**$71,884,500**	**$73,417,000**	**$163,774,000**

(1) Each phase will be implemented in stages (based on subarea priority) as funding becomes available.

The order of magnitude cost estimate is $163.8 million. This includes soft costs such as engineering and management. This projection includes eight additional staff positions at build-out.

E8 Funding Sources

The existing funding for traffic systems and ITS projects through the FY 2015 approved budget and Capital Improvement Program (CIP) is insufficient to meet the City's needs. Historically the funding allocations were in the order of $1 million; however current annual allocation is $100 thousand. In order to provide a reasonable level of funding to implement the most critical elements of the TSCMP communications systems, a significant increase of CIP budget allocated for ITS is needed along with challenging alternative funding opportunities.

There are several potential alternative funding sources for the Traffic Signal Communications Master Plan implementation. These include the City's Public Facility Financing Plans, Development Impact Fees, Regional Transportation Congestion Improvement Program, Transnet, and grant opportunities (HSIP and Assembly Bill 1447). Each funding source similarly requires lead time and preparation to program money for improvements. Staff resources will be necessary to prepare needed documentation and administer funds per the specific source requirements. Preparation in advance is critical to meet strict deadlines and prevent lost funding opportunities.

E9 Delivery Methods Recommendations

It's critical for the City to maintain as much flexibility in contracting/procurement as possible. Specific components of the TSCMP lend themselves to a particular delivery method. Packaging the various implementations into component projects that best match a delivery method will provide the highest degree of success. The following are delivery method recommendations.

- Advertise for an on-call/as-needed contract for professional services of an ITS System Manager-Integrator (SM-I) consulting firm. The contract should include provision of engineering services for design-bid-build projects. This provides the City with the specialized expertise necessary to ensure successful project implementation, a high degree of flexibility in use of services, qualifications based selection, and the most significant level of control over the most critical aspects of project deployment.

- Utilize the design-bid-build method for traditional construction oriented work including: underground installations, installations requiring machinery, and labor intensive installations. This will simplify the contractors work and increase the likelihood of more competitive bids.

- The best value bid package method should be used in instances where an off the shelf solution is desired for wide deployment. Examples of the systems to procure via best value are: controllers, conflict monitors, CCTV cameras, etc. The contract can be set for multiple years with no minimum purchase requirement and other special provisions. A separate contract would be utilized for installation; or installation by City forces and/or the SM-I service contract.

E10 Next Steps

The next step is realizing the recommendations of the Master Plan through immediate action on a series of items that are necessary to quickly move the TSCMP into the implementation phase. The primary focus is on the short-term strategies and priorities that will build success over the course of deployment. The City will ultimately decide the most effective and beneficial approach to continue the process of implementing the Master Plan. Possible next steps for consideration by the City given the TSCMP recommendations include:

Project Prioritization – Establishing communications to all traffic signals in the City as recommended by the master plan is the most critical and highest priority. The subareas identified in Figure 3-1 are prioritized in order of highest to lowest number of traffic signals affected. Project delivery in this order will provide the widest communications coverage possible and the highest potential for visibly improved traffic operations in the near term for the surrounding community.

Staffing – The City traffic signal operations and maintenance groups are understaffed and creating new staff positions is a difficult and lengthy process. The staff resource needs become especially acute considering the expertise needed and workload associated with TSCMP implementation. It is recommended that the City advertise for an on-call/as-needed contract for professional services of an ITS Systems Manager-Integrator-Engineering consulting firm in order to bridge the gap between existing staff resources and immediate Master Plan deployment needs.

Develop a Priority Project PS&E and Build – Select one subarea for immediate implementation of TSCMP architecture and equipment recommendations. This will provide a benchmark and check for costs, resource needs, scheduling, and related project delivery metrics for future Master Plan deployments.

Opportunities – There is much opportunity available to the City, both internally and externally, to implement the recommendations of the Master Plan by partnering on infrastructure projects through other departments or agencies and seeking out potential funding sources. The following immediate actions are recommended to ensure opportunities are achieved.

- With the services of a qualified ITS SM-I/Engineering firm the City will have the resources to apply for and administer grant opportunities to fund ITS improvements. The return on investment is significant.
- Seek to reassign funds in the current fiscal year's budget to prioritize TSCMP phase 1 recommendations.
- Assess open development projects and include TSCMP recommendations as a mitigation measure and/or community benefit.
- Assess current and planned CIP projects and opportunities for conduit installation along deficient routes.
- Assess all existing funding earmarked for traffic signal communications improvements and allocate to TSCMP phase 1 implementation.

Master Plan Monitoring – On a semi-annual basis update the master plan GIS maps and network architecture to reflect implementation progress. This item will track master plan implementation and is intended to sustain a high level of interest and participation amongst staff and management. A full TSCMP update should be conducted every five years.

E11 Cost Effectiveness

The cost-effectiveness analysis shows that the operational benefits achieved by implementing the phase 1 TSCMP recommendations provide a benefit-cost ratio of more than 50:1, meaning that benefits from these programs save more than $50 for every dollar spent. This cost savings is consistent with State and National benefit-cost ratio reporting of approximately 40 to 60:1 return on investment. The savings achieved in phase 1 alone exceed the cost of the complete 10 year TSCMP implementation. The TSCMP recommendations provide significant benefit per dollar spent and this is economically advantageous for San Diego businesses and residents.

1 INTRODUCTION

The City of San Diego Traffic Signal Communication Master Plan (Plan) establishes the planning framework to implement state-of-the-art communications technology and Intelligent Transportation Systems elements to meet the immediate and long term needs of the City's transportation network. This Plan presents: a comprehensive view of the existing and future systems architectures, detailed GIS mapping of the City's existing and future communications infrastructure and traffic signal locations (including state of repair), GIS mapping of other City departments and agencies communications infrastructure, and guidelines for the system technology and ITS elements to deploy. Most importantly, the plan includes strategic phasing for plan implementation considering critical needs, costs, and available resources.

This document is designed to be used actively by both management and staff as the City embarks on the task of implementation. This Plan will greatly improve the City's ability to provide excellent service through much needed systems to all users of the transportation network.

1.1 Need

San Diego is the eighth-largest city in the United States and second-largest in California and is one of the fastest growing cities in the nation. San Diego has a population of over 1.3 million people and covers an area over 370 square miles[1]. Some notables; San Diego is: home to the largest naval fleet in the World[2], shares the busiest international border in the World with Mexico[3], has a significant tourism industry[4], and is a hub for technology[5], manufacturing, and research industry hosting major producers of wireless technology, software, pharmaceutical and biotech. San Diego is also one of the most desirable places to live -anywhere.

All of this activity places significant demand on the City's transportation infrastructure. San Diego has traditionally built roadways, adding capacity to meet the demand. This approach becomes less practical as San Diego's roadway network becomes built-out due to right-of-way constraints, environmental impacts, and high costs of building new and/or expanded roadways. The City cannot build its way out of traffic congestion and should augment traditional investments in roadway construction by investing in Intelligent Transportation Systems (ITS) solutions to optimize the use of existing roadway capacity through improved traffic signal synchronization and operations management.

The City operates and maintains over 1,500[6] traffic signals which provide safe movement at intersections for vehicles, pedestrians, bicyclists, emergency vehicles, and transit/rail. The signals must also operate efficiently and reliably to provide progression through a series of signals to minimize congestion and maintain a higher level of safety. The communications and control technology operating the signals was developed approximately 30 or more years ago. These include dial up modems connected through an extensive network of fiber optic multiplexors and twisted pair copper communications. The existing communications system is functionally obsolete and in some instances in a state of disrepair due to the outdated equipment. Replacement parts are difficult or impossible to obtain and staff is devoting an excessive amount of time trying to keep the equipment serviceable. This system is incapable of providing efficient traffic management and operations for the City in the modern traffic environment.

1.2 Purpose

The Traffic Signal Communications Master Plan represents the first master plan of its kind for the City of San Diego. The Plan's purpose is to guide the City on future traffic signal communications and ITS technology improvements. This includes resource allocation related to improvement prioritization, funding sources, and staff levels. This Master Plan represents a significant opportunity for the City of San Diego to move the traffic communications system and supporting elements to the technological forefront of traffic signal systems. The TSCMP ultimately represents benefits to travelers in the form of better traffic signal operation which improves mobility for all modes including motorists, bicyclists, pedestrians, transit, and emergency vehicles.

1.3 Consistency with Initiatives

The Traffic Signal Communication Master Plan (TSCMP) is consistent with several documents that build a framework for Local, Regional, and State transportation related initiatives. The documents include:

The **City of San Diego Climate Action Plan (CAP)** initiative (Draft, September 2014) identifies measures to meet greenhouse gas (GHG) reduction targets for 2020 and 2035[7]. The Implementation and Monitoring phase of the CAP sets forth several actions to ensure success. Action 3.4 calls to reduce vehicle fuel consumption through implementation of the City’s Traffic Signal Communications Master Plan. The target is to retime either 200 traffic signals or 13 coordinated traffic signal systems per year.

The **City of San Diego Fire Services Standards of Response Coverage Deployment Study** is a comprehensive study of the level of fire service staffing, response times, and outcomes[8]. The City’s set standard for emergency response times is 7 minutes and 30 seconds and the City has encountered difficulty meeting this goal. The Emergency Vehicle Preemption system throughout much of San Diego is first generation technology (over 20 years old) and technically obsolete. The TSCMP provides a complete upgrade for all of the existing emergency vehicle preemption system components throughout the City. This will improve emergency response times and help the City achieve response time goals.

The TSCMP is expected to reduce intersection crashes in San Diego. The **California Strategic Highway Safety Plan (SHSP)** identifies signal timing and ITS tools as appropriate safety countermeasures for intersection crashes[9]. The **California Local Roadway Safety Manual** also identifies improved signal timing, coordination, and operation as a safety benefit to address locations that have a crash history at multiple signalized intersections[10]. The TSCMP recommends systems that are primary to implement traffic signal control strategies including coordinated traffic signal operations. The goals of these strategies are to maximize throughput and minimize stops on the coordinated roadway. The reduction in delay and stops results in fewer intersection red-light violations, less aggressive driver behavior, and fewer intersection crashes.

The **San Diego Region Intelligent Transportation Systems (ITS) Strategic Plan** outlines a unified vision for the regional ITS investment strategies that regional transportation agencies have prioritized for funding and implementation[11]. The purpose of the document is to provide policy guidance and articulate common vision of what ITS applications should be employed in the region to improve mobility, safety, efficiency, and reliability. Arterial Management is one of the six investment areas identified by the ITS Strategic Plan and consistent with the Transportation Systems Management chapter of the **SANDAG 2050 Regional Transportation Plan (RTP)**. The goal of the arterial management investment area is to expand regional deployment and integration of arterial management systems, signal coordination and management, seamless arterial operations across jurisdictions, and support the related goal of improving the competitiveness of transit and reducing travel times on the regions roadway network. The TSCMP advances the 2050 RTP and ITS Strategic Plan arterial management investment area to the next level by identifying the specific ITS technologies, deployment strategies, and resources required for the overwhelming majority of arterials in the Region[12].

1.4 Document Organization

The remainder of this document is divided into six sections as described below:

2. Existing Conditions: contains the results of extensive research and a comprehensive inventory of the existing traffic signal communications infrastructure in-place throughout the City of San Diego.

3. Systems Deficiencies and Resolutions: presents the areas and locations where there is a gap in traffic signal communication or repair issues. Also presented is an order of magnitude estimate of the technical solution necessary to resolve the communications.

4. Future Road Network Communication Infrastructure: presents a roadmap of planned roadways and recommend communications infrastructure to accommodate new development based on Community and Facility Financing Plans.

5. Communications Equipment Upgrade Recommendations: contains recommendations on upgrades to communications equipment to reflect current industry standards with the goal of increasing equipment availability, increasing system capacity, reducing maintenance needs and system down time.

6. ITS Element Recommendations: The goal of these recommendations is to gain operational efficiency by integrating all ITS devices into the proposed communications network.

7. Implementation Phasing Plan: presents a strategic staged approach for the prioritized deployment of the Master Plan including schedule, resource requirements, and funding mechanisms.

8. Next Steps: These include immediate action on a series of items that are necessary to quickly move the TSCMP recommendations into the implementation phase.

9. Cost Benefit Analysis: Compares the cost and benefits associated with TSCMP recommendations and the cost effectiveness.

2 EXISTING CONDITIONS

The Existing Conditions section forms the basis for planning and designing the system architecture necessary to build the future traffic signal communication system and related ITS elements. Contained are the results of extensive research and a comprehensive inventory of the existing traffic signal communications infrastructure in-place throughout the City of San Diego. The infrastructure includes: traffic signal locations, the City Traffic Management Center (TMC), and various Intelligent Transportation System (ITS) and communications media, devices, and facilities. This section also identifies communications facilities located within the City that are owned by other City departments and agencies. A Geographical Information System (GIS) database and map of the existing systems infrastructure research and inventory was created and presents all elements identified. This section also identifies the existing maintenance and operations staffing levels dedicated to traffic signal communications infrastructure. This section is divided into the following subsections:

- Traffic Signals
- Traffic Signal Communications System
- ITS Elements
- Operations and Maintenance Staff
- Other Public Communication Infrastructure
- GIS Database Attributes and Layers

2.1 Traffic Signals

Several sources were referenced to determine the number and locations of all traffic signals in the City of San Diego. City records were researched and all available traffic signal "as-built" plans obtained[1]. The traffic signal plans were used to verify location information and the plans typically show pertinent information related to the traffic signal build including: interconnect links (to and from), type of interconnect, controller and cabinet type, and other connected equipment. A total of 1,677 traffic signal plans were researched and all of the plans were scanned and a digital library created[2].

A map of traffic signal locations was obtained from San Diego Geographic Information Source (SanGIS)[3]. The SanGIS map was used as a baseline for base map layers including roads and boundaries. The City QuicNet Traffic Management System (TMS) database was also researched and City staff provided a separate list of traffic signal locations[4]. All of the various sources were compared and verified against City records and Google Earth. This process has provided an accurate map of existing traffic signals citywide.

At the time of this report, there are 1,531 City owned and operated traffic signals in the City of San Diego[5].

2.2 Existing Traffic Signal Communications System

The City of San Diego has an extensive traffic signal communication system. The system has been installed over the past several decades and is comprised of various media and network devices. Approximately 1,000 of the 1,677 traffic signal plans previously referenced contained traffic signal interconnect information[6]. Additionally, 56 interconnect specific plans were researched[7]. The existing traffic signal communications system in San Diego is comprised of:

- A fiber optic lines based digital backbone network (multimode and singlemode),
- A copper wire based analog multi-drop network,
- Dial-up field master based multi-drop network (9 discrete locations),
- 900 MHz serial digital, low bandwidth, wireless radios,
- Traffic Management Center[8].

The following subsections describe the existing traffic signal communication system elements and architecture.

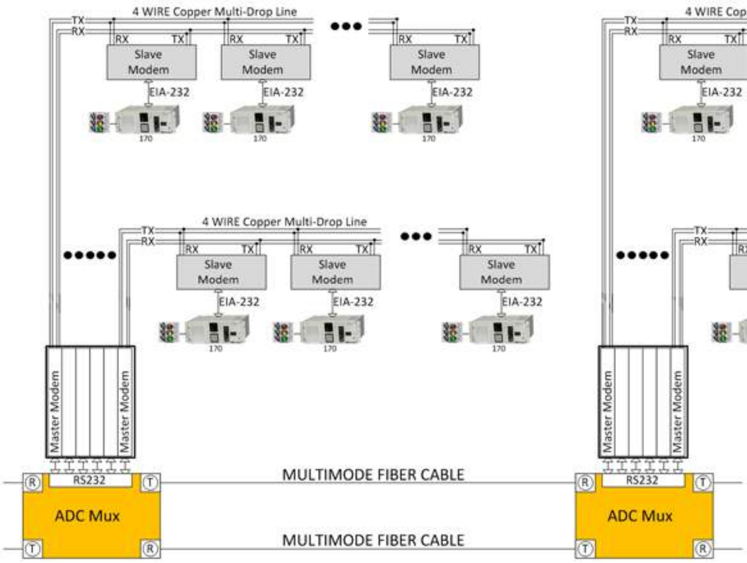
2.2.1 Existing Multimode Fiber Optic Network

The multimode fiber optic lines based digital backbone network utilizes the older generation ADC Magnum 100 multiplexers connecting to each other on the older generation multimode fiber plant. The areas connected include: El Cajon Blvd, Market Street, Hillcrest, College, and the Mid-City area. Fiber strand counts on the multimode network include:

- TMC to 54th and El Cajon route has an 8 strand multimode fiber cable,
- The 32nd St and Market to 47th St and Market route is a hybrid cable and carries 8 strands of multimode fiber, 4 strands of singlemode fiber, and two 19 gauge copper wires.

The basic network architecture is shown below in **Figure 2-1**.

Figure 2-1 Multimode Basic Network Architecture



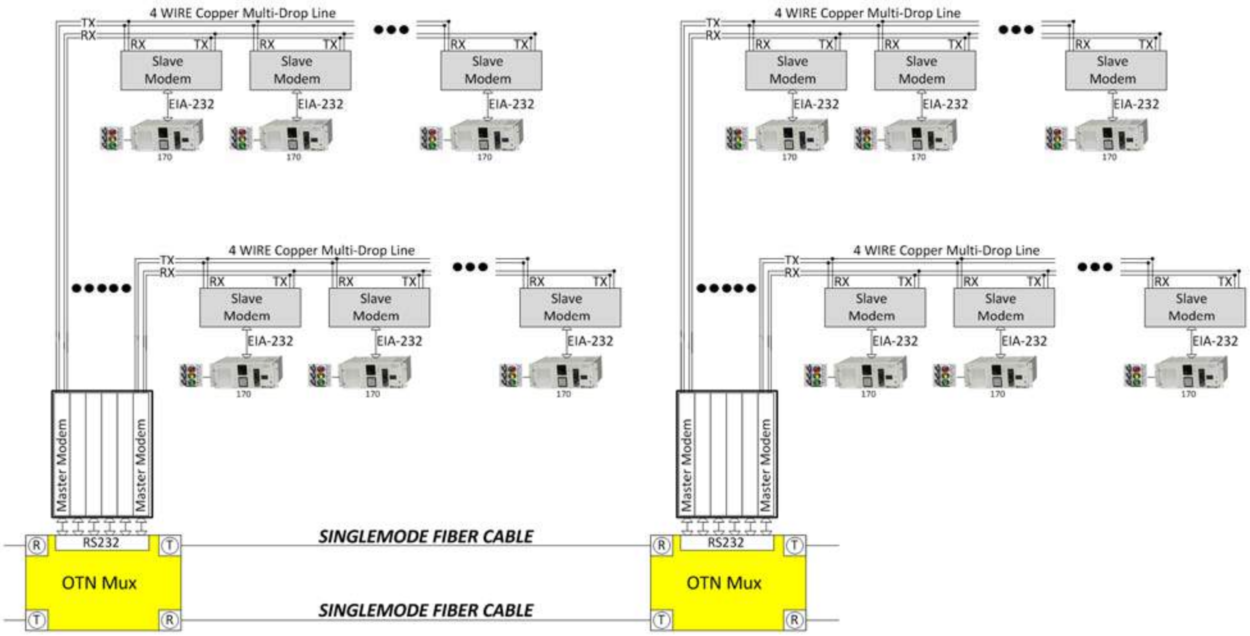
The multimode fiber optic cable from the TMC, to 32nd St and Market St was damaged several years ago. This communication link was replaced with a singlemode fiber cable. Since the ADC multiplexers use multimode fiber optic ports, multimode to singlemode media converters were used between the fiber and the ADC multiplexer.

2.2.2 Existing Singlemode Fiber Optic Network

The singlemode fiber optic lines based digital backbone network utilizes the newer generation Siemens OTN multiplexers connecting to each other on the newer singlemode fiber plant in the South Bay, Linda Vista, Golden Triangle, Mira Mesa, Rancho Penasquitos, and Rancho Bernardo areas. Fiber strand counts on the singlemode network include:

- TMC to 1st and Hawthorne route has a 24 strand singlemode fiber cable,
- 1st and Hawthorne to 8th and Washington route has a 24 strand singlemode fiber cable,
- 8th and Washington to Texas and El Cajon has a 24 strand singlemode fiber cable,
- TMC to Main St and Woden St route has a 24 strand singlemode fiber cable,
- Main St and Woden St to Beyer route has a 24 strand singlemode fiber cable (this fiber optic cable run goes through the cities of Chula Vista and National City),
- 1st and Hawthorne to Washington and Pac Hwy route has a 24 strand singlemode fiber cable.
- There is a singlemode fiber cable starting from a hub at Morena St. that runs up Linda Vista Rd to Genesee. From Genesee the fiber connects to La Jolla Village Dr.
- La Jolla Village Dr. / Miramar Rd. have a singlemode cable running down it that goes to Camino Ruiz then to Black Mountain. From Black Mt. the singlemode fiber runs up Carmel Mt. to Rancho Bernardo.
- Most of the newer singlemode fiber cables carry 24 or more strands arranged in multiple buffers of 12 strands each in standard color configurations. The basic network architecture is shown below in **Figure 2-2.**

Figure 2-2 Singlemode Basic Network Architecture



2.2.3 *Copper Wire Analog Multi-drop Network*

As depicted on Figures 2-1 and 2-2, both multiplexer systems utilize EIA-232 channel ports connecting to the master modems of the copper wire based analog multi-drop network. All analog multi-drop modems, configured as either master or remote, are the GDI 404 model running at 2,400 bits per second.

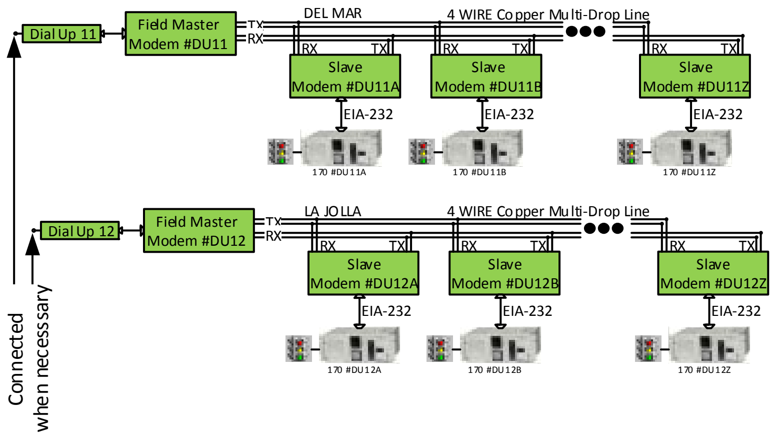
The original copper interconnect was 19 gauge in the Central Business District (CBD) and most intersections in the downtown area have 3 pairs of copper wire. Termination cabinets are fed with #19 gauge wires and are 100, 50, 25, 18, 12, and 6, pair cables. Interconnect cable for new intersections in the CBD or replacement cable is 22 gauge copper, 3 pair or 6 pair. Most of the rest of the City's interconnect is 6 pair 22 gauge with some 6 pair 19 gauge.

2.2.4 *Dial-Up Field Master Based Multi-Drop Network*

At the TMC there is one dial-up modem that can dial into any one of the nine dial-up field master based multi-drop corridors only one corridor at a time. Dial-up communications are not ideal as 24-hour access is not achievable thus making the system very limited. This has a detrimental impact on traffic signal operations; especially real time monitoring, data logging, manual control, and central based control operations.

As an example of the dial-up field master network, the existing signal communication system in the Del Mar Heights area operates via a 2,400 bits per second dial-up modem connected to 3 field master modems of each multi-drop line[9]. The dial-up field master based multi-drop network is shown below in **Figure 2-3**.

Figure 2-3 Dial-Up Field Master Based Multi-Drop Network



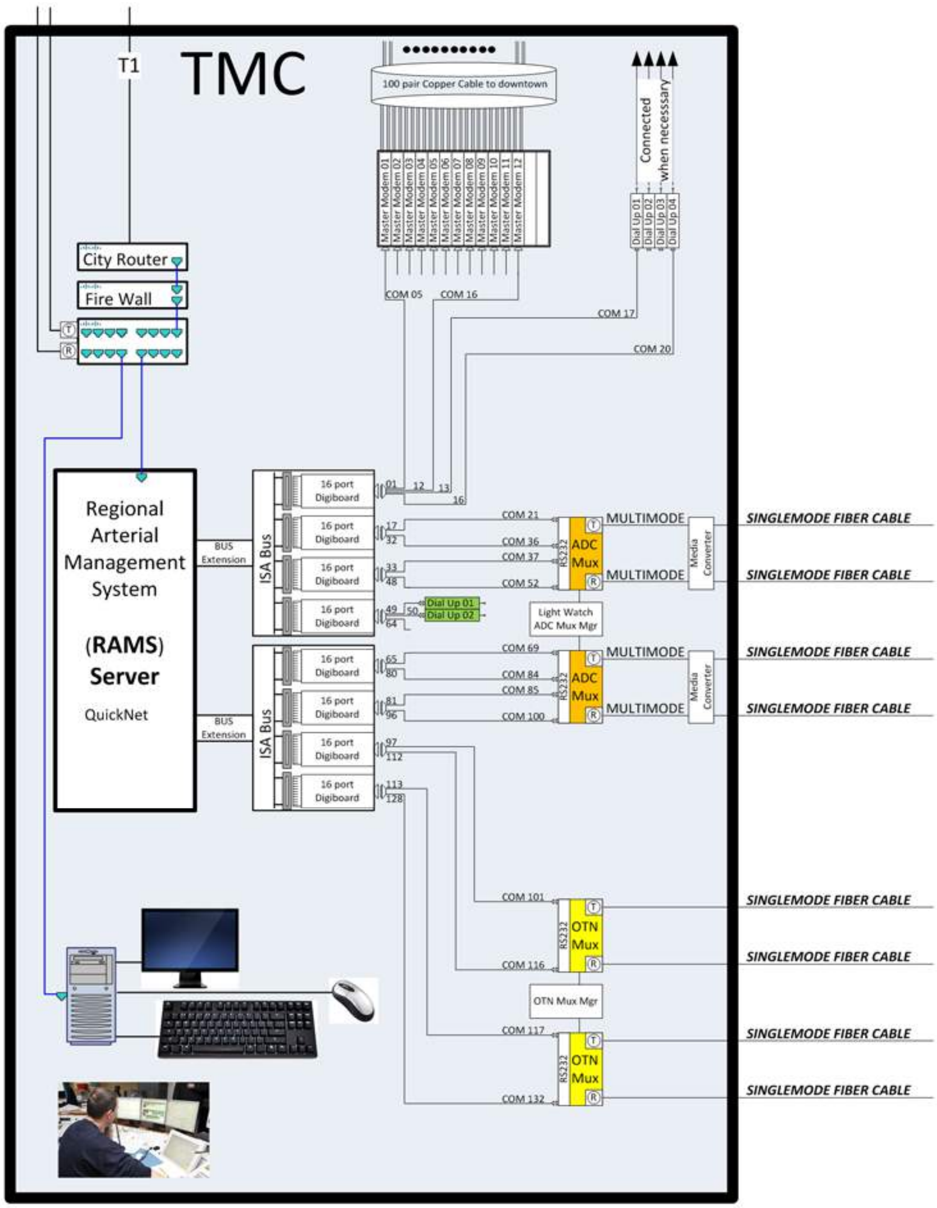
2.2.5 900 MHz Serial Digital Wireless Interconnect.

Several locations in the City utilize wireless radios for interconnect where there are no copper wire or fiber mux to directly connect to the network. The wireless radio communication is 900 MHZ serial (EIA-232) digital, low bandwidth.

2.2.6 Traffic Management Center

The TMC is located in the basement of the City Operations Building (COB). Existing TMC equipment is serial EIA-232 communications based. There are two groups of four, rack mounted Digi C/CON-16 Concentrators. Each Digi has 16 EIA-232 ports connecting directly to multiplexer channels or analog modems. Since the Personal Computer's (PC's) DOS or Windows operating system uses the first four COM ports for the Operating System (OS), the Digi ports start at COM 5. The existing TMC configuration is shown below in **Figure 2-4.**

Figure 2-4 Existing TMC Configuration



2.2.7 *Existing Traffic Signal Communications Architecture*

The complete existing traffic signal communications architecture is shown schematically in **Appendix B** of this document. This is a full size 24x36 schematic fold out plan.

2.3 ITS Elements

The existing ITS elements are traffic signal system devices and applications that are currently deployed in the City of San Diego. The following subsections provide a description and brief discussion.

2.3.1 Cabinets and Controllers

The City of San Diego has a variety of traffic signal cabinets located throughout the city, including Type 332, Type 336, and Type 337. The Type 336 and 337 cabinets are typically found in the CBD area where many signals are two or four phase. The Type 332 is the most common signal cabinet used in the City and is the current standard installation.

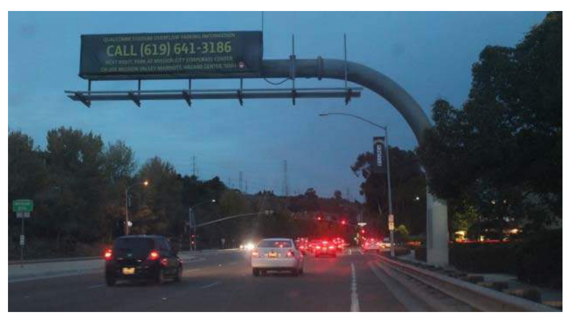
The majority of controllers in the field are Type 170 or Type 170E controllers. The 170E is found in builds following year 1990, approximately. There are a handful of locations that have Coldfire 750 controllers. All traffic signals run either 223 or 233 programs with the 223 program being used for the majority of traffic signals. In addition, 2070 ATC controllers with Omni eX software are expected to be deployed in the very near future along El Cajon Boulevard and N. Harbor Drive.

Figure 2-5 Typical Type 332 Cabinet

Typical plug-ins in the standard 332 cabinet configuration in the City include: model 222 loop detectors, various generations of EVP discriminators, 210 conflict monitor unit, 242 isolator cards, 200 load switches, and 204 flashers. The Power Distribution Assembly (PDA) is Type 1 or Type 2 depending on the date of installation. PDA Type 2 is found in builds following year 2000, approximately. **Figure 2-5** shows a typical Type 332 signal cabinet with a 170E controller and standard plug-ins.

2.3.2 Changeable Message Signs

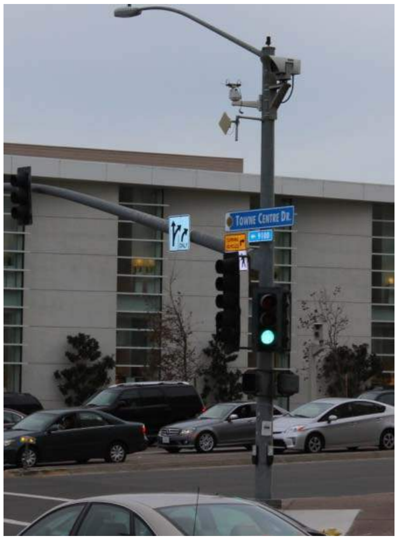
The existing communication system also supports nine Changeable Message Signs (CMS). Five CMS are located in the CBD and the other four locations are on Friars Road near Qualcomm Stadium. Two of the signs on Friars Road (shown right) are owned and operated by the City's Transportation & Storm Water (TSW) Department and the other two are owned and operated by Qualcomm Stadium. The CMS are the old flip disc type or lamp type and this technology is obsolete. Manufacturers that built these CMS are either out of business or not supporting the product. Two of the signs continue to work and the other signs have been cannibalized for parts to maintain the operational signs. In the CBD communications for the CMS is EIA-232. Signs are connected to a dedicated twisted 2-pair copper interconnect with a GDI 404 stand-alone modem at each end; one at the TMC and one at each CMS to handle the conversion from FSK to EIA-232. The two TSW CMS on Friars Road are also EIA-232 and a dedicated 2-pair copper interconnect runs from the CMS to a Termination/Hub cabinet. A GDI 404 stand-alone modem is located at the sign end and at the Hub end. The modem at the Hub is connected to a fiber optic multiplexer which



transports the data back to the TMC. Message creation and scheduling can be done remotely by using a software program running on a server at the TMC. Local messages can be programed at each sign using a laptop. The two Qualcomm Stadium CMS on Friars Road are also EIA-232 and a dedicated 2-pair copper interconnect runs from the CMS to a Termination cabinet located at Mission Village Drive and Friars Road. These signs have pre-programmed messages that Special Event staff may select from and schedule using a sign controller.

2.3.3 CCTV

The existing communications infrastructure at one time supported several analog CCTV cameras. Camera video was viewed in the TMC on a video wall which is comprised of a large center screen and six small monitors (three on each side), and a Vicon video switcher distributed the video to the screens. Cameras are installed on Friars Road near Qualcomm Stadium and also in the Golden Triangle area near University Town Center (UTC). Analog Video from the Friars Road cameras are fed into an IFS video to multimode fiber optic media converter and a single dedicated multimode fiber was used to bring the video back to the TMC. Repeaters were used along the path to assure proper transmission levels. Camera pan/tilt/zoom (PTZ) was controlled by a COHU camera control unit (CCR), and control could be performed at the TMC using a software program or manually at the camera location using the COHU CCR. An improvement project upgraded the Friars Road fiber from multimode to singlemode, rendering the cameras non-functional as all the existing interface equipment was multimode.



Two PTZ cameras were installed in the Golden Triangle area at the intersections of Towne Centre Drive and La Jolla Village Drive, and North Torrey Pines and Genesee[10]. Analog video and PTZ EIA-232 data control were brought back to the Termination/Hub cabinet at La Jolla Village Drive and Genesee which transported the video and data back to the TMC via the Siemens multiplexer on singlemode fiber. The intersections of La Jolla Village Drive and Genesee and Villa La Jolla and La Jolla Village Drive have video detection, and this video was also brought back to the TMC. The original design for the Golden Triangle cameras called for ISDN as the transport carrier of data and video to the TMC. Prior to completion of the ISDN design, fiber was installed and made available. Unfortunately, the Golden Triangle cameras were not activated due to equipment issues and cost constraints.

2.3.4 Central Traffic Management System

The City of San Diego utilizes the QuicNet 4+ Regional Arterial Management System (RAMS) central control software to manage its traffic signals. The RAMS system provides a common software application and link between local agencies in San Diego County for coordinated traffic operations between crossing and adjacent jurisdictions. The link between the agencies is accomplished over a T1 leased line as shown on **Figure 2-4**. The RAMS system was developed roughly between 1998 and 2005, and implemented in 2006[11].

At the time of this report, 1,224 City traffic signals were contained in the City's QuicNet 4+/RAMS database with down communications for several hundred at any given time. Existing communication infrastructure traffic signal information was obtained from the City's QuicNet system. This information included: location, status, COMM Channel/Field Master, type, and drop number. In order to create a comprehensive view, Caltrans traffic signals and anticipated future traffic signals within the City of San Diego were also documented[12].

2.3.4.1 Existing Operations

Achieving optimal and sustainable mobility for different modes of transportation requires a comprehensive traffic signal system that utilizes a variety of operations and ITS technologies. A modern communication system is absolutely necessary to facilitate the use of these ITS elements. All operations need regular maintenance and monitoring and ITS device communication is paramount to the operational effectiveness of each application. Beyond maintenance, stakeholders of ITS projects and operations now require regular performance metrics which are produced by the collection of data stored by ITS field devices. The existing operations and applications that require communications infrastructure include:

2.3.4.1.1 Traffic Signal Timing & Coordination

The sheer size of the signal system in San Diego requires a communication network to efficiently and effectively manage signal timing parameters. Without remote access, an operator/engineer needs to physically enter timing parameters at the intersection. If the timing modification is designed to address a reported issue or inefficiency, verification of the intended fix will require a site visit during the time of the reported incident. These efforts equate to hours of wasted time and narrow the chances of properly maintaining the performance of an isolated intersection without the remote accessibility offered by a communication network.

The communication network is crucial for proper coordination of signal timing between intersections of both major and minor arterials. Traffic signal coordination requires the exact synchronization and maintenance of traffic controller clocks; that each plan is implemented at the same time-of-day; the ability to view and compare the coordination details of each intersection along the arterial; and regular fine-tuning of newly implemented coordination strategies. While many factors can contribute to arterial congestion, a common source is the loss of communication between intersections and central system software.

2.3.4.1.2 Advanced Signal Operation

The City has several areas of advanced traffic signal operations that require support of reliable communications systems. These include preemption systems, priority operations, the RAMS network, and Integrated Corridor Management system.

2.3.4.1.2.1 Grade crossing preemption

The signal operations at intersections with railroad crossings are critical as public safety is of the upmost importance. New requirements involve complex signal timing that enhances safety while accommodating non-conflicting movements of traffic. Traffic operations at railroad crossings require advanced control systems to achieve complex operations and ensure safe and optimal signal performance during grade crossing preemption events.

2.3.4.1.2.2 Emergency Vehicle Preemption (EVP)

Specific Emergency Vehicle Preemption technology is utilized to override signal operations and provide priority to approaching emergency responders. The phase selectors of modern EVP systems report the status of all critical components and permit the incorporation of technological advancements such as GPS (which has proven to improve safety and emergency response times)[13]. While many of the existing preemption devices within San Diego are antiquated, all modern phase selectors utilize Ethernet interfaces to communicate with central software for remote monitoring and maintenance of this vital system.

2.3.4.1.2.3 Transit signal priority (TSP)

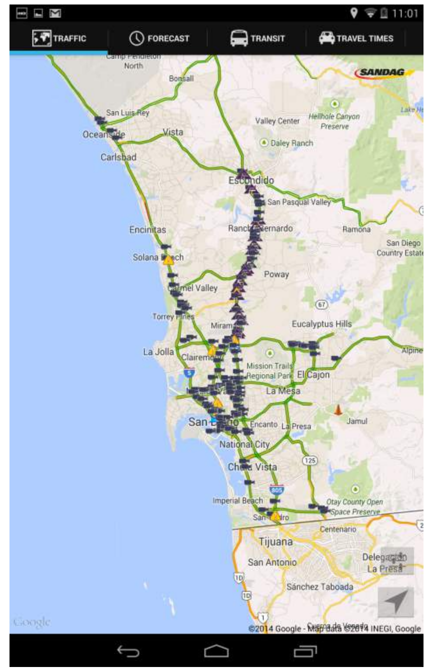
Recent TSP projects in the City of San Diego quintessentially exemplify the pressing need for an Ethernet communication infrastructure[14]. The stakeholders of TSP projects have been tormented by the inability to properly collect performance measures from devices capable of producing the needed metrics. Reliable communications are also imperative for evaluating the effect of TSP events on traffic signal timing.

2.3.4.1.2.4 Adaptive Signal Control

Adaptive is emerging as a viable solution for unpredictable traffic patterns of arterials within the City of San Diego. The City's first modern adaptive system (Rhythm Engineering - InSync) was recently deployed along Lusk Blvd and demonstrated reliable capabilities. System performance was monitored remotely and Ethernet communication was a system requirement. Moving forward, the City of San Diego is interested in further deployments of Adaptive Signal Control technology[15]. While Adaptive offers advancements over traditional traffic signal timing operations, it shares the need for a modern Ethernet communication infrastructure.

2.3.4.1.2.5 *Regional Arterial Management System (R.A.M.S)*

The Regional Arterial Management System allows operators to monitor the status of traffic controllers maintained by other agencies. The regional operations include the ability to establish a common time source for all traffic controllers in the County in addition to eliciting regional events which can override the normal operations of traffic signals across jurisdictions. This system extends the responsibility to maintain stability of center-to-field communications as other agencies depend on the local communication network.



2.3.4.1.2.6 *Integrated Corridor Management (ICM)*

One of the newest regional operations, Integrated Corridor Management combines the functionality of several ITS elements in order to synchronize a calculated event-driven response to live traffic conditions. While the totality of ICM involves multiple agencies, the system utilizes center-to-center as well as center-to-field communication. This advanced operational strategy is critically hamstrung if the center-to-field communications are unsound[16].

2.4 Existing Operations and Maintenance Staff

The City of San Diego employs staff with primary responsibility for the operation and maintenance of the traffic signal system.

2.4.1 *Traffic Signal Operations Staff*

The Traffic Signal Operations Group for the City of San Diego is part of the Transportation Engineering and Operations Division of the Transportation and Storm Water Department. The operations group staff consists of:

- 1 Senior Engineer,
- 3 Associate Engineers,
- 6 Assistant Engineers, and
- 1 Junior Engineer.

The Traffic Operations Group is primarily responsible for traffic signal operations and is also involved with the general responsibilities of the Transportation Engineering Operations Division responsibilities including:

- coordinate traffic investigations for signs, markings, traffic control devices, speeding concerns and parking issues
- accident data collection and analysis

- traffic volume data collection
- establishment of speed zones
- traffic signal management (signal timing, installation and modification)
- conducting mobility studies
- investigating and responding to the need for street lights, pedestrian safety improvements, traffic calming and school safety improvements

The Traffic Operations Group is also involved with the Pedicab Program, Bicycle Program, Transportation Alternatives Program, and coordination with regional agencies including SANDAG, MTS, and Caltrans.

2.4.2 Traffic Signal Maintenance Staff

Traffic signal maintenance in the city of San Diego is the responsibility of the Electrical Section which is part of the Street Division of the Transportation and Storm Water Department. The Electrical Section staff consists of a manager and 14 technicians. The responsibility of the Electrical Section is to ensure that the traffic signals are functioning properly. All traffic signals are on a quarterly maintenance schedule and the technicians respond to emergencies around the clock.

2.5 Other Public Communication Infrastructure

Documentation of other departments and outside public agencies fiber optic communications routes were obtained through meetings with the City of San Diego Communications Division, Department of Information Technology. The City Communications Division has obtained and kept records of various department and agencies communications facilities through participation in the City of San Diego Fiber Working Group (FWG). City participants include: Wastewater, Water, Traffic, and Communications. Regional agencies include: SANDAG, MTS, and the Unified Port District. Other agencies and departments that were researched include: Caltrans, Police, SafetyNet, and San Diego Data Processing[17].

The information provided was extensive and hundreds of records were researched. Several of these entities have utilized traffic signal conduit to expand their communications networks. Each entities fiber optic communications were assigned unique layers and the fiber optic routes mapped.

2.6 Existing Conditions GIS Map and Database

A Geographic Information System (GIS) database and map of the existing systems infrastructure research and inventory was created and presents all information researched and identified as appropriate for inclusion. ESRI software ArcMap 10.2.2 was utilized. A dynamic layer set and attribute tables were created of all existing traffic signals, fiber optic cable, copper signal interconnect cable (SIC), wireless links, and fiber optic communication nodes. The layers include:

Table 2-1 Summary of Inventory Information for Dynamic Layer Set

Dynamic Layer	Inventory Information
Dial Up Field Masters	Location, Maintenance Date
Local Field Masters	Location, Maintenance Date, Communication Channel, Digi Number
Traffic Signal Comm Repair issue	Location, QN COMM/Field Master, Status, Type, Device ID, Drop Number
Traffic Signal Communication Gap	Location, QN COMM/Field Master, Status, Type, Device ID, Drop Number
Traffic Signal	Location, QN COMM/Field Master, Status, Type, Device ID, Drop Number
Fiber Termination Cabinet	Location, Equipment, Maintenance Date
Copper Termination Cabinet	Location, Equipment, Maintenance Date
Caltrans Traffic Signal	Location, QN COMM/Field Master, Status, Type, Device ID, Drop Number
Existing Hub	Location, Node/Ring Number, Multiplex, Communication Channel, Digi Number
Existing Wireless Links	Starting Intersection, Ending Intersection, Interconnect Type, Online/Offline
Existing Fiber Optic Cable	Conduit Size, Interconnect Type, Single or Multimode, Maintenance Date
Existing Copper Interconnect	Conduit Size, Interconnect Type, Maintenance Date
Metropolitan Wastewater Fiber	Conduit Size, Interconnect Type, Maintenance Date
Police Department Fiber	Conduit Size, Interconnect Type, Maintenance Date
SafetyNet	Conduit Size, Interconnect Type, Maintenance Date
MTS Fiber	Conduit Size, Interconnect Type, Maintenance Date
Caltrans Fiber	Conduit Size, Interconnect Type, Maintenance Date

Attribute tables were created based on the inventory data inputs and correspond with the layers shown on **Table 2-1**. **Figures 2-6** through **2-8** below provide examples of three existing conditions attribute tables and information contained.

Figure 2-6 Traffic Signal Attribute Table

Table

Traffic Signal

FID	Shape	Device_ID	LOCATION	QN_COMM	Drop	STATUS	TYPE
0	Point	966	Camino Santa Fe & Carroll Road	59	20	OFFLINE	SERIAL
1	Point	952	Carmel Mountain Road & Conference Way	64	16	OFFLINE	SERIAL
2	Point	1188	El Camino Real & Carmel Mountain Road		4	OFFLINE	SERIAL
3	Point	938	Carmel Mountain Road & Penasquitos Drive	62	28	OFFLINE	SERIAL
4	Point	1189	Carmel Mountain Road & Vista Sorrento Parkway		5	OFFLINE	SERIAL
5	Point	936	Carmel Mountain Road & Stoney Creek Road	62	19	OFFLINE	SERIAL
6	Point	950	Highland Ranch Road & Carmel Ridge Road	64	17	OFFLINE	SERIAL
7	Point	189	Market Street & 25th Avenue	16	13	OFFLINE	SERIAL
8	Point	782	Scripps Ranch Boulevard & Carroll Canyon Road	56	10	OFFLINE	SERIAL
9	Point	1181	Poway Road & Creekview Drive	63	13	OFFLINE	SERIAL
10	Point	775	Scripps Ranch Boulevard & Erma Road	56	3	OFFLINE	SERIAL
11	Point	381	Miramar Road & Miramar Place	53	4	OFFLINE	SERIAL
12	Point	780	Scripps Ranch Boulevard & Scripps Lake Drive	56	8	OFFLINE	SERIAL
13	Point	690	Imperial Avenue & 25th Avenue	108	1	OFFLINE	SERIAL
14	Point	990	47th Street & Federal Boulevard	106	4	OFFLINE	SERIAL
15	Point	397	Camino Ruiz & Miralani	54	11	OFFLINE	SERIAL

1 (0 out of 1046 Selected)

Traffic Signal

Figure 2-7 Existing Copper Interconnect Cable Attribute Table

Table

Existing Traffic Copper Interconnect

FID	Id	Shape *	Conduit_1 Size	Interconnect Type	C_1_Maint	Conduit_2 Size	Interconnect Type 2	C2_Maint
0	0	Polyline	2"	COPPER SIC - 6PR22	4-24-1991			
1	0	Polyline	2"	COPPER SIC - 6PR22	4-24-1991			
2	0	Polyline	2"	COPPER SIC - 6PR22	4-24-1991			
3	0	Polyline	2"	COPPER SIC - 6PR22	4-24-1991			
4	0	Polyline	2"	COPPER SIC - 6PR22	4-24-1991			
5	0	Polyline	2"	COPPER SIC - 6PR22	4-24-1991			
6	0	Polyline	2"	COPPER SIC - 6PR22	4-24-1991			
7	0	Polyline	2"	COPPER SIC - 6PR22	4-24-1991			
8	0	Polyline	2"	COPPER SIC - 6PR22		1.25	COPPER SIC	
9	0	Polyline	2"	COPPER SIC - 6PR22		1.25	COPPER SIC	
10	0	Polyline	1.25"	COPPER SIC - 6PR22				
11	0	Polyline	2"	COPPER SIC - 6PR22		2"	COPPER SIC-3PR19	
12	0	Polyline	2"	COPPER SIC - 6PR22		2"	COPPER SIC-3PR19	
13	0	Polyline	2"	COPPER SIC - 6PR22		2"	COPPER SIC-3PR19	
14	0	Polyline	2"	COPPER SIC - 6PR22		2"	COPPER SIC-3PR19	
15	0	Polyline	2"	COPPER SIC - 6PR22		2"	COPPER SIC-3PR19	

1 (0 out of 2084 Selected)

Existing Traffic Copper Interconnect

Figure 2-8 Existing Fiber Optic Cable Attribute Table

Table

Existing Traffic Fiber Interconnect

FID	Shape *	Id	C1_Size	Inter_Type	C_1_Mainta	C2_Size	Inter2_Typ	C_2_Maint	C3_Size
0	Polyline	0	2"	FIBER	01-07-2000				
1	Polyline	0	2"	FIBER	01-07-2000				
2	Polyline	0	2"	FIBER	01-07-2000				
3	Polyline	0	2"	FIBER	01-07-2000				
4	Polyline	0	2"	FIBER	01-07-2000				
5	Polyline	0	2"	FIBER	01-07-2000				
6	Polyline	0	2"	FIBER	01-07-2000				
7	Polyline	0	2"	FIBER	01-07-2000				
8	Polyline	0	2"	FIBER	01-07-2000				
9	Polyline	0	2"	FIBER	01-07-2000				
10	Polyline	0	2"	FIBER	01-07-2000				
11	Polyline	0	2"	FIBER	01-07-2000				
12	Polyline	0	2"	FIBER	01-07-2000				
13	Polyline	0	2"	FIBER	01-07-2000				
14	Polyline	0	2"	FIBER	01-07-2000				
15	Polyline	0	2"	FIBER	01-07-2000				

1 (0 out of 285 Selected)

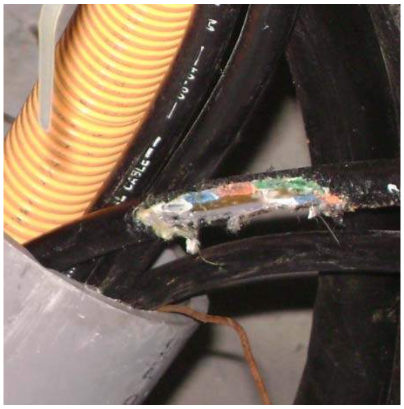
Existing Traffic Fiber Interconnect

All existing conditions are mapped on the Traffic Signal Communications Master Plan map which is contained in **Appendix A**.

3 SYSTEM DEFICIENCIES AND RESOLUTION

The System Deficiencies and Resolution phase of the Master Plan flows from the Existing Conditions section and presents the areas and locations where there is a gap in traffic signal communication or repair issues. Also presented is an order of magnitude estimate of the technical solutions necessary to resolve the communications.

3.1 Deficiency Identification



There are two main reasons that the existing traffic signals have deficient communications:

- Gaps – signals that have no existing communication line (central and/or local) to connect with.
- Repair – existing signals not communicating due to disrepair or faults on the system.

The following two subsections describe the deficiency identification process, either gap or repair, and lists the affected locations.

3.1.1 Gap Identification

There are a couple of considerations in the communication gap identification process: gaps between individual intersections, and gaps between a group of intersections and a communication link to the TMC. The individual or group gap considerations become important in the resolution process. Most communication gaps were readily identified by inspection of the existing conditions information presented on the GIS map. There are a total of 308 intersections in the City of San Diego with a physical communication gap and approximately 18 gaps between groups of intersections and the TMC.

3.1.2 Repair Identification

A meeting was held with the City's Traffic Signal Maintenance staff to identify locations of physical traffic signal communication disrepair. Additionally, key issues that affect the status of maintaining the City's traffic signal communication system were surveyed. A questionnaire was developed to achieve insight into the existing issues encountered by maintenance staff and also obtain suggestions that will help develop the recommended communication paths. Questions provided to maintenance staff are as follows:

1. What are the communications issues encountered (i.e., down communications, intermittent communications, major repair, unserviceable equipment, etc.)?
2. Where are the most problematic locations or communication lines?
3. Is documentation an issue and are there specific areas lacking current documentation?
4. Are there areas in the City where communications can be simplified?
5. How many designated staff members perform communication maintenance? Any system champions?

6. What is the priority for solving communication issues (i.e., low, moderate, high)?
7. How much time is typically spent troubleshooting communication issues?
8. Suggestions on what would help the shop to make communication maintenance more efficient (i.e., training, tools, system access, designated staff)?

Based on the meeting with the maintenance staff, detailed interconnect repair problems were identified at several locations throughout the City. The most common problem included known damaged or broken conduits and/or interconnect cable at identified locations. A summary of the repair locations is contained in **Table 3-1** below.

Table 3-1 Summary of Maintenance Issues

No	LOCATION	PROBLEM DESCRIPTION	AFFECTED AREA	PROPOSED RESOLUTION
1	Genesee / Manitou	Conduit damage west side	3 I/S	Repair conduit.
2	Commercial / National	I/C damage	1 I/S	Repair I/C.
3	Dennery, Red Coral to Black Coral	Damaged conduit	3 I/S	Repair conduit.
4	Federal, 47th and 50th	Damaged I/C	2 I/S	Repair I/C.
5	Art / El Cajon	Damaged conduit	20-25 I/S	Repair conduit.
6	6th / Broadway and 8th / Broadway	Damaged conduit	4 I/S	Wireless radio installed
7	Torrey Pines east of Ivanhoe	Damaged I/C	1 I/S (est)	Repair I/C.
8	Sorrento Valley / Vista Sorrento	Damaged conduit	6 I/S (est)	Repair I/C.
9	Rancho Bernardo / Via Del Campo	Missing I/C	11 I/S	Replace I/C.
10	Westview Pkwy, Galvin to Compass Pt S	Damage, needs conduit and IC	5 I/S	Repair I/C.
11	Mira Mesa, Cam Ruiz to Westview	Damaged I/C	9 I/S	Replace 6 pair with new 12 pair.
12	Calle Cristobal / Cam Santa Fe to Propico	Conduit and I/C damage	3 I/S	Repair I/C.
13	Harbor / Market	Damaged I/C	1 I/S	Repair I/C.
14	Harbor / Front	Damaged I/C	1 I/S	Repair I/C.
15	Harbor / 1st	Damaged I/C	1 I/S	Repair I/C.
16	Harbor / 5th	Damaged I/C	1 I/S	Repair I/C.
17	Harbor / Park	Damaged I/C	1 I/S	Repair I/C.
18	Broadway, Pacific to Harbor	Damaged I/C	8 I/S (est)	Contractor to replace.
19	Pacific Beach: Balboa, Mt Everest to Clairemont and Mission Bay / Garnet.	Wireless design issue.	50 to 60 I/S	Replace with Broadband Ethernet radios.
20	Kearny Mesa	Pairs maxed out.	20 (est)	Rework pairs

No	LOCATION	PROBLEM DESCRIPTION	AFFECTED AREA	PROPOSED RESOLUTION
21	Genesee, Clairemont Mesa to Linda Vista and Linda Vista / Wheatley	Pairs maxed out.	25 (est)	Replace cable in run. Need to go to Convoy / Arrow.
22	Del Mar Heights Rd	Channel is missing on the south side of the 56.	10 (est)	Link north side of 56 to south side.
23	Pomerado Rd / Miramar, Kearny Villa to Scripps	Project never worked.	3 I/S (est)	New wireless.
24	Pacific Beach	Questionable wiring, 3 masters & only need 2.		Rearrange pairs.
25	General	Dial-ups are difficult to work with. Spring Canyon is down. 3 leased lines on High Bluff, 1 on Navajo Rd and 1 on Scripps.		Replace dial-ups with cell modems and I/S to Enet.
26	El Cajon Blvd	Rigid metal pipe is rotted.		New conduit.
27	El Cajon Blvd	Fiber Optic Interconnect has been hit and should be replaced. Conduit and Cable is kinked badly in many places.		Replace conduit and cable.
28	El Cajon Blvd, Park / El Cajon to 1st / Washington	Under bridge. Fiber cable is too tight, no slack in pull boxes.		Replace cable.
29	El Cajon Blvd / 30th	Loss issues		Replace fiber.
30	California / Hawthorne	Splices and terminations are a mess.		Quote being produced.
31	1st / Elm	Vault was not installed. Fiber was hit and could not fit a closure, installed 336 cabinet		Install vault and splice closure.
32	Downtown	Conduit in basements.		Install conduit in street.
33	General, Mission Valley, Pacific Highway, 32nd to National City	No trace wire in conduit.		Install trace wire
34	General, Port and misc fiber locations.	Pull boxes used instead of fiber vaults. Job built to non-City spec. Used double stacked #6's. Fiber not organized or properly hung.		Improve build to City spec.
35	General, Caltrans intersections	Access issues. City uses Caltrans I/C pairs and goes through Caltrans cabinets.		Remove I/C from cabinets and pull back to box.
36	Park / El Cajon	FOIC damaged		Repair FOIC.
37	Texas / Meade	FOIC Damage, pull box is too small. Patch panel not appropriate solution.		Install vault. Pull cable to Camino Del Rio South.
38	Mux Locations	Single mode mux, no cards. Multimode mux, spare parts a problem. Costs $20k to replace the OTN mux.		Decommission muxes and install switches.

* I/S – Intersection
* I/C – Interconnect
* FOIC – Fiber optic interconnect

The repair issues at individual locations often result in groups of offline intersections. For example, the repair issue at the intersection of Art Street and El Cajon Boulevard results in another 20 to 25 offline intersections. General repair or build issues at various locations around the City are also listed. Approximately 204 traffic signals are directly affected by communication repair issues as surveyed with maintenance staff. It is expected that the actual number of traffic signals affected by repair issues throughout the City is greater.

In addition to the location specific issues, general comments and suggestions were provided by maintenance staff. The common issue was that there are not enough resources in the maintenance shop to fix all the known communication issues. The following general comments were noted:

- Inspection: Not enough resources and inspectors are overwhelmed. Contractors may say nothing when something is damaged and bury it. Multiple contractors in the same area complicate matters. Inspectors are sometimes unaware of damage.
- Inspection: Shop has to chase Contractors. Damage can be forgotten if shop doesn't keep on it. Have to hold contractors responsible. Temp fixes end up permanent. Contractors make excuses: locates, shallow pipe, etc. Set a uniform policy and enforce fines.
- Multi-agency work: Often don't see work through and systems never work. RE's are on Contractors side. Utilities don't need permits, have a franchise agreement and not supervised by City.
- Staff resources: Not enough resources in the shop to fix all the comm. issues. Maintenance deals with traffic signal emergencies and this is a priority. Communications is secondary. Maintenance staff has no time to deal with the inspectors. PM's and calls are full time. Shop is down 2 staff.
- Documentation: Generally bad documentation and/or lack of documentation.
- General: Need to replace broken pipe and cable segments. Subcontractor could replace pipe and shop to install cable. Patching is not a good solution. Boring machine is available but can't use it since an operator is needed to do the work. Small jobs would be ok but no time.
- Tools: Have fusion splicer and old OTDR is being calibrated. New splicers and meters would be useful.

3.1.3 Deficiency Summary

The traffic signals in the City were sorted into the following categories for mapping and quantification purposes:

- Traffic signal with no issues and existing communication infrastructure present.
- Traffic Signal with no communication due to repair.
- Traffic signal with no communication due to gap.

Table 3-2 provides a summary of the condition and number of associated traffic signals Citywide.

Table 3-2 Traffic Signal Conditions Summary

Traffic Signal Type	Quantity
City of San Diego Total	1531
Existing Communication Infrastructure Present	1046
No Communication Due to Repair	178
No Communication Due to Gap	307

3.2 Deficiency Resolution

Considerations for solving communication deficiencies gaps or repair issues include: signal location and proximity to other offline signals, proximity to nearest communication media, conduit location, condition of the existing media, whether or not the existing communication equipment are outdated or obsolete, and bandwidth requirements (not typically a concern for traffic signal data rates alone). These considerations, in combination with budgetary and schedule constraints, lead the selection process of alternative solutions and communications infrastructure to recommend for implementation.

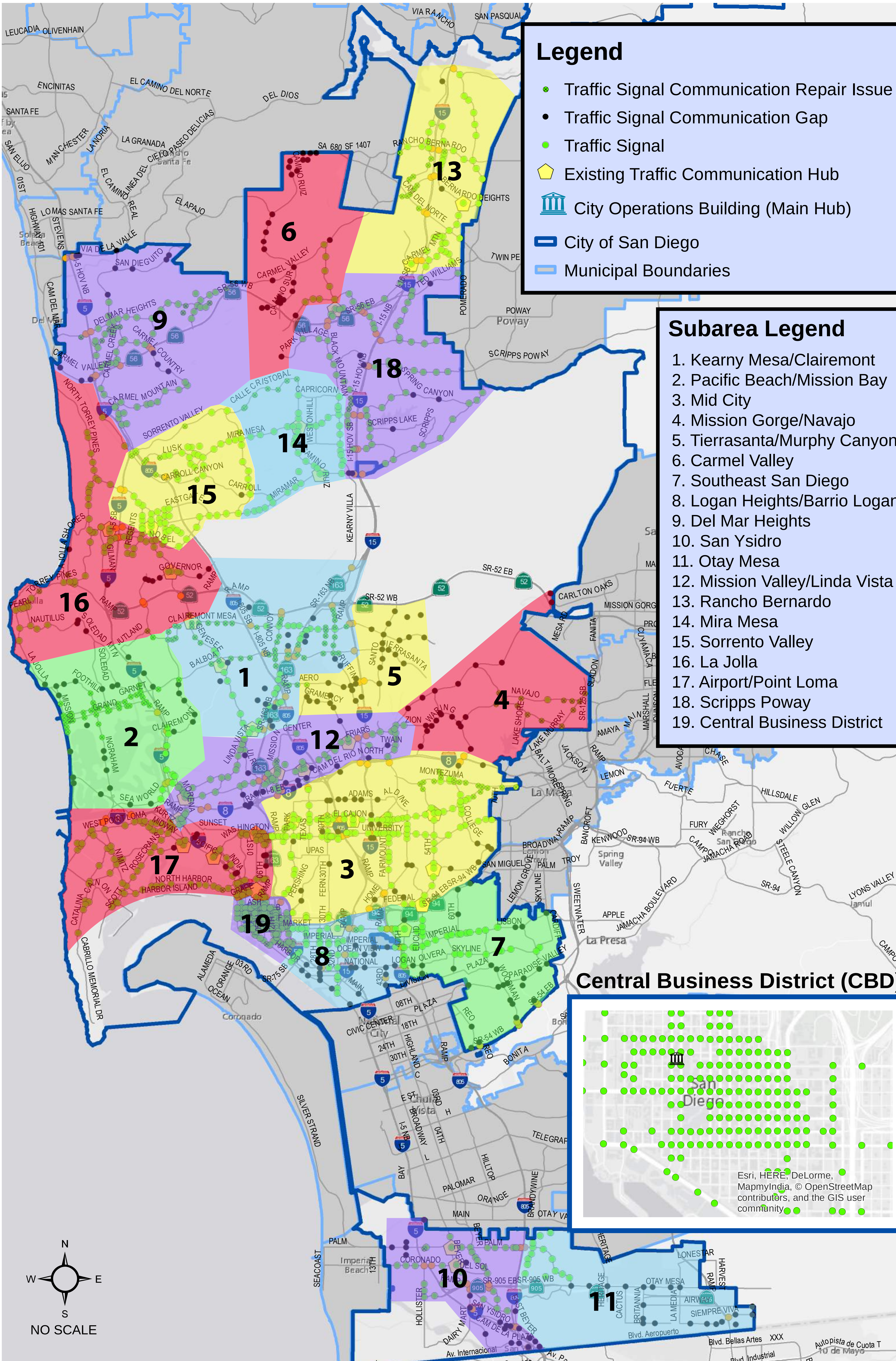
Gap issues for individual intersections may need a single link to an existing subarea of signals (or communication channel) and this is the simplest type of gap to resolve. Larger groups of intersections that have no communications may require their own communications channel. The most cost effective and timely method to resolve a gap in communications for either an individual intersection or group of intersections is through wireless interconnect. As such, wireless technology was considered for resolving communication gaps. Communications system architecture and general equipment recommendations are provided in detail in Section 6.

Repair deficiencies needs to be looked at on a case by case basis to determine the appropriate solution to deploy. Table 3-1 previously shown includes a column of proposed resolutions for each repair issue. These include conduit, cable, and/or reconfiguration repairs contingent on the particular condition.

3.3 Subareas

All communication deficient traffic signals were logically grouped into subareas. These are generally organized by coverage area, with boundaries established by locations of the deficient signals, and named according to the communities covered and given a subarea number. Nineteen subareas were created to cover all 485 communications deficient traffic signals.

Figure 3-1 on the following page illustrates the general location and boundaries of the 19 subareas within the City of San Diego. See **Appendix D** for a detailed map of each individual subarea.



TRANSPORTATION & STORM WATER

STACK TRAFFIC CONSULTING, Inc.

City of San Diego
Traffic Signal Communications Master Plan
Subareas

Figure 3-1

Order of magnitude cost estimates were developed for each subarea implementation based on: recommended deficiency resolution, quantity of associated equipment and materials, installation costs, design and construction management cost, and contingency. The recommended communication link is described on the detailed order of magnitude cost estimate for each subarea and included in **Appendix D**. **Table 3-3** provides a summary of individual subarea statistics.

Table 3-3 Subarea Summary

No	Name	# Def. Signals	# Gap Signals	# Repair Signals	Cost Estimate Option A	Cost Estimate Option B
1	Kearny Mesa/Clairemont Mesa	72	18	54	$1,246,500	$1,693,500
2	Pacific Beach/Mission Bay	71	29	42	$1,462,500	
3	Mid City	50	30	20	$1,465,500	$2,512,500
4	Mission Gorge/Navajo	33	20	13	$767,250	
5	Tierrasanta/Murphy Canyon	30	30	0	$441,750	
6	Carmel Valley	28	28	0	$525,750	
7	Southeast San Diego	28	28	0	$927,000	$1,074,000
8	Logan Heights/Barrio Logan	24	23	1	$417,000	$564,000
9	Del Mar Heights	21	13	8	$627,750	
10	San Ysidro	21	20	1	$381,000	$678,000
11	Otay Mesa	19	19	0	$426,000	
12	Mission Valley/Linda Vista	19	18	1	$1,130,250	$1,877,250
13	Rancho Bernardo	14	2	12	$353,250	$650,250
14	Mira Mesa	12	1	11	$426,750	$723,750
15	Sorrento Valley	12	1	11	$314,250	$461,250
16	La Jolla	12	10	2	$218,250	$515,250
17	Airport/Point Loma	10	9	1	$327,000	$969,000
18	Scripps Poway	8	8	0	$337,500	$484,500
19	Central Business District	1	0	1	$461,250	$1,058,250

As cost and/or time may be prohibitive, the order of magnitude cost estimates A and B represent alternative methods for establishing the communication link between the subarea and TMC. Scenario A is based on utilizing cellular wireless technology to resolve a subarea gap to the TMC. Scenario B is based on replacing hub multiplexor equipment with Layer 3 routing equipment and establishing a dedicated fiber path with Ethernet communications between the subarea and TMC. Scenario A is a lower barrier option given time and cost constraints, while Scenario B is ideal in establishing a long term and reliable network.

This information was provided to the City of San Diego staff to determine the prioritization of subareas.

4 Future Road Network Communications Infrastructure

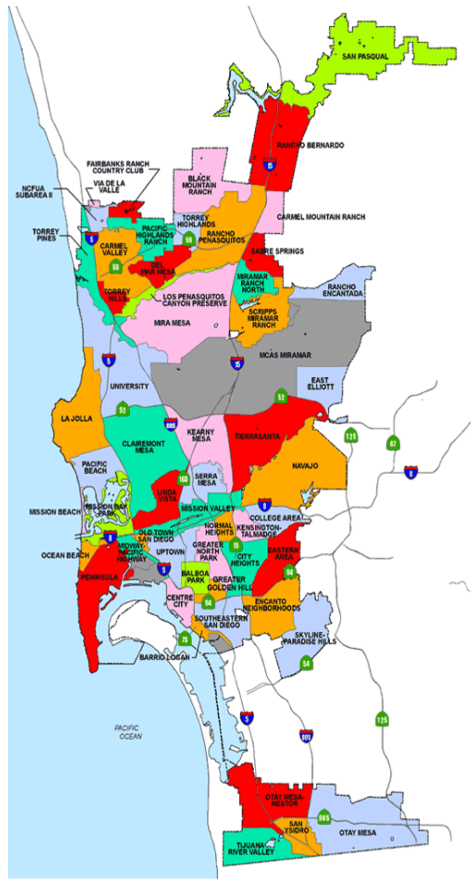
The future road network for the City of San Diego has been assessed to determine opportunities to expand the existing communication infrastructure. These new roadways, roadway widening, and new traffic signal projects provide an opportunity to connect existing traffic signals that are offline or have no communication to them. The future roadway projects were compiled through researching the Public Facilities Financing Plan (PFFP) for each community within the City of San Diego. In addition, SANDAG's 2050 Regional Transportation Plan (RTP) was referenced for additional roadway projects not contained in the City's PFFP.

4.1 PFFP

There are 52 communities in the City of San Diego (see **Figure 4-1**). Each community has an adopted community plan that contains specific proposals for future land uses and public improvements. Within each community plan, there are identified public facilities that are required to comply with the City's General Plan and Community Plan. The PFFP implements these planned public facility projects. Currently, there are 41 approved PFFPs.

Only transportation-related projects contained within the approved plans were considered and documented for the future road network. New roadways and road widening were summarized and inventoried to include: project name, project description, and the anticipated year of construction per the PFFPs. The projects were entered into a new layer in GIS where the attribute table defines the starting intersection, ending intersection, and projected year. Projects that stipulated design and construction to be scheduled when funding is identified were cataloged as "to be determined" (TBD); projects that specify funding by sub-developers were further classified.

Figure 4-1 Community Planning Areas



4.2 SANDAG 2050 RTP

The SANDAG 2050 RTP was also referenced to gather information on future roadway projects that are planned to be constructed over the next 35 years. RTP Appendix A (2050 RTP Projects, Costs, and Phasing) was used to obtain additional information on each respective project. Due to funding limitations and uncertainties, only arterial projects contained in the revenue constrained plan were inventoried. Within the City of San Diego, seven projects have been identified and summarized in Table A.8 (Phased Arterial Projects – Revenue Constrained Plan).

4.3 Future Projects Summary

Appendix E contains the complete summary of all future transportation-related projects in the City of San Diego. Communities that have planned road widening or new construction include: Rancho Bernardo, Black Mountain Ranch, Pacific Highlands Ranch, Torrey Highlands, Rancho Penasquitos, Mira Mesa, University, Mission Valley, Old San Diego, Midway/Pacific Highway, Uptown, Southeastern San Diego, Otay Mesa, and San Ysidro.

The future road network in the City of San Diego is illustrated on the Traffic Signal Communication Master Plan map contained in **Appendix A**. The map contains layers for new roadway construction, new traffic signals, and road widening projects that are planned per the SANDAG 2050 RTP and approved PFFP's.

4.4 Future Traffic Signals

Through the research of the City's adopted PFFPs, a total of 65 signals have been identified for future construction. The future traffic signals were summarized by community, signal location, and the anticipated year of construction per the PFFPs. The traffic signals were entered into a new layer in GIS where the attribute table defined the intersection location and projected year. Those with design and construction contingent on funding are cataloged as TBD. **Table 4-1** below shows the number of future traffic signals that were identified by their respective communities within the City of San Diego.

Table 4-1 Number of Future Traffic Signals by Community

Community	# of Future Traffic Signals
Barrio Logan	4
Black Mountain Ranch	1
Carmel Valley	1
College Area	1
Greater North Park	2
La Jolla	1
Linda Vista	1
Mira Mesa	2
Navajo	2
Otay Mesa	4
Pacific Highlands Ranch	4
Peninsula	6
Rancho Bernardo	3
Rancho Encantada	3
Rancho Penasquitos	2
San Ysidro	5
Scripps Miramar Ranch	1
Serra Mesa	4

Community	# of Future Traffic Signals
Skyline/Paradise Hills	5
Southeastern San Diego	3
Tierrasanta	3
Torrey Pines	1
Uptown	6

Appendix F contains the complete list of all future traffic signals in the City of San Diego.

5 COMMUNICATIONS EQUIPMENT UPGRADES RECOMMENDATIONS

An intelligent and modern traffic signal communication network helps optimize traffic flow and alleviate traffic problems associated with congestion. The communications network delivers traffic information from intersection to intersection and ultimately back to the central management system at the City TMC where operators can monitor traffic and make real time control changes. A functioning communication system is essential for a signal system to operate efficiently.

5.1 Future Network Elements

The future City of San Diego traffic signal communications network should meet the following goals.

- Compatible with current and future industry standards,
- Eliminate single vendor dependency,
- Increase equipment availability,
- Increase system capacity,
- Reduce system cost,
- Redundant, self-healing,
- Provide more bandwidth for current and future applications such as:
    - Video monitoring of the real time traffic conditions,
        - IP cameras
        - Video Walls
- Changeable Message Signs (CMS),
    - Bluetooth Travel Time Measurement Systems,
    - Transit and Emergency Vehicle Signal Priority,
    - Adaptive Traffic Control Systems,
    - Future Smart ITS Cabinets,
        - Conflict Monitors
        - Uninterruptible Power Supplies (UPS)
    - V2V and V2I Systems.

5.2 Future Communication Network Standardization and Recommendations

Ethernet is the most prevalent communications protocol in the world. This dominance of Ethernet protocol in both consumer and business equipment has led to a continuing trend of dropping per-port prices. The upcoming “Internet of Things” (IoT) applications will cause even further decline in Ethernet equipment price and availability.

The newer traffic, transportation, and ITS devices are all either standardized on Ethernet interface or offer Ethernet interface as an option. Additionally, the yet to be invented future devices that can be used in the City of San

Diego Traffic Signal Communication Network will most likely support Ethernet interface. As it stands right now, Ethernet provides a “future proof” network for a long time to come.

For these reasons Stack recommends that the future City of San Diego traffic signal communication network be based on the Ethernet protocol.

Stack further recommends that all existing proprietary time division multiplexers (both the OTNs and ADCs) be discarded and replaced with Layer 3 Ethernet routers. These new routers are to serve as the hubs of the new backbone.

Utilizing the existing fiber plant with new Layer 3 routers will provide easily implemented 10, 40, or 100 Gigabits per second (Gbps) ring based redundant and self-healing backbone networks.

Major router manufacturers are already offering layer 3 routers that support 10, 40, and 100 Gbps fiber interfaces. Although the current equipment prices today may be very expensive for 40 and 100 Gbps ports, these prices are sure to come down by the project implementation time.

When this project is in the pre-RFP design phase, the design consultant is encouraged to perform a cost/benefit analysis and recommend the backbone speed based on the City’s future data traffic load forecast.

The Internet Protocol (IP) packets run inside the “payload” portion of the Ethernet protocol frames. Each device supporting Ethernet protocol also uses IP. Each IP device (source or destination device) configured for a unique IP address can communicate over the Ethernet network without respect of the distance and communication medium, as long as there is a path between the source device and the destination device. Each Ethernet/IP device can communicate with any other Ethernet/IP device over the same network, without the need for a dedicated path between the two.

Stack recommends preserving the existing copper wire infrastructure investment that is in place throughout the City of San Diego, thus saving money on infrastructure costs.

Using Very high bit rate Digital Subscriber Line (VDSL) equipment, the same low speed analog modem based corridor infrastructure can be cost effectively converted to a high speed Ethernet/IP platform.

Stack recommends that all existing analog modems be replaced with VDSL based Field Ethernet Switches (FES).

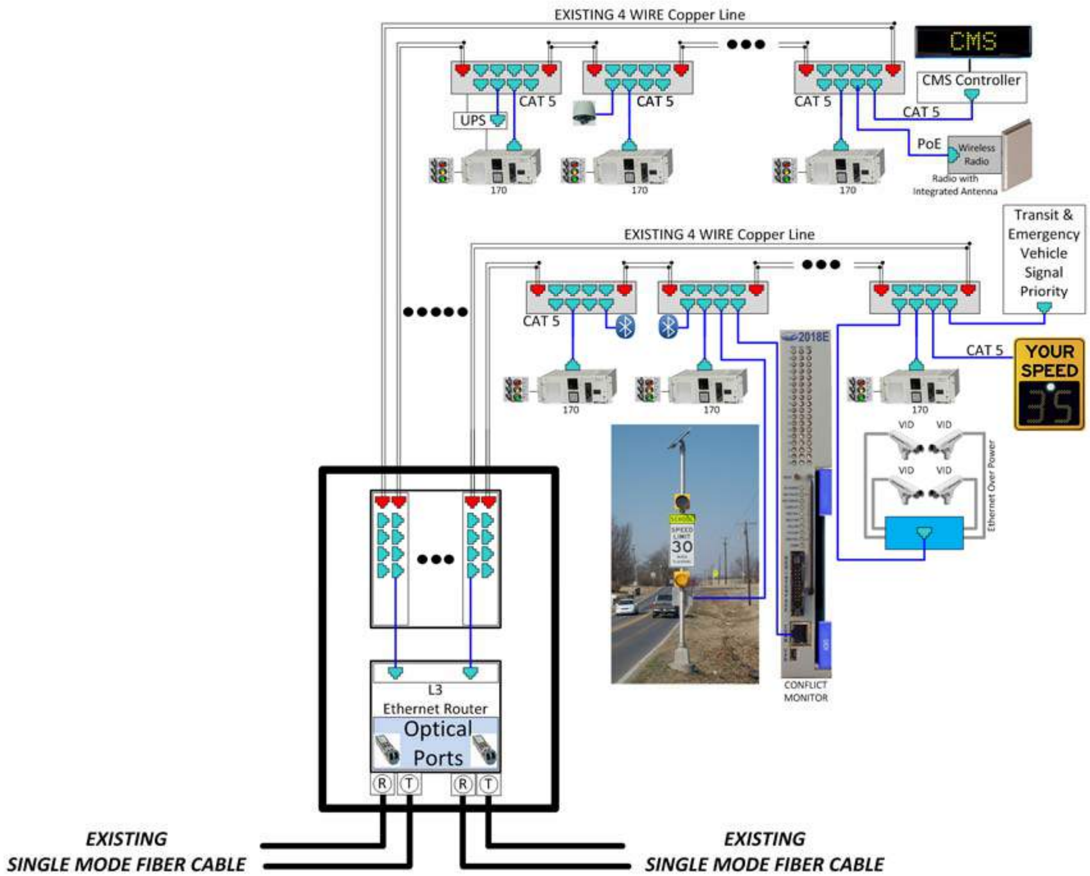
A ring based redundant and self-healing field equipment network can be easily implemented utilizing the existing copper plant and VDSL based Field Ethernet Switches (FES).

In order to eliminate controller replacement costs, Stack also recommends that all of the existing 170E controllers currently communicating over their serial ports be upgraded with a serial to Ethernet converter card, making them capable of communicating over the new Ethernet network. New controllers will be modern traffic controllers, which meet the requirements of the National ATC standard, have one or more imbedded Ethernet ports and do not need supplemental equipment.

The future Ethernet/IP protocol network shall be designed as a two-tiered network. Tier 1 will utilize the layer 3 node equipment connected to each other in a ring network fashion using 10 Gbps or higher speed links. Tier 2 will utilize the layer 2 field Ethernet devices such as VDSL switches, Field Ethernet Switches, Wireless broadband radios connected to each other also in a ring network fashion at various speed links, depending on the equipment on that link.

The copper based future Ethernet network sample scheme is shown on **Figure 5-1** below.

Figure 5-1 Future Copper Based Network Example



The existing signal communication system accessed via the dial-up lines throughout the City will be converted into wireless access via either:

- 4G Wireless routers, communicating to the TMC over the Internet of Things (IoT) Network.
- Dedicated, City owned wireless radios connecting to the nearest layer 3 router.

While City owned wireless radios are ideal, the ability to tie these radios into existing backhaul networks is often hampered by line of sight and or cost restrictions. For example, a single 4G wireless router may suffice in remote locations where utilizing wireless radio would demand the use of several radios and repeaters (each needing their own source of power and line of sight). Schematic examples of the above wireless communications options are shown on **Figures 5-2** and **5-3**, in listed order.

Figure 5-2 Future IoT over Cellular Wireless Network Example

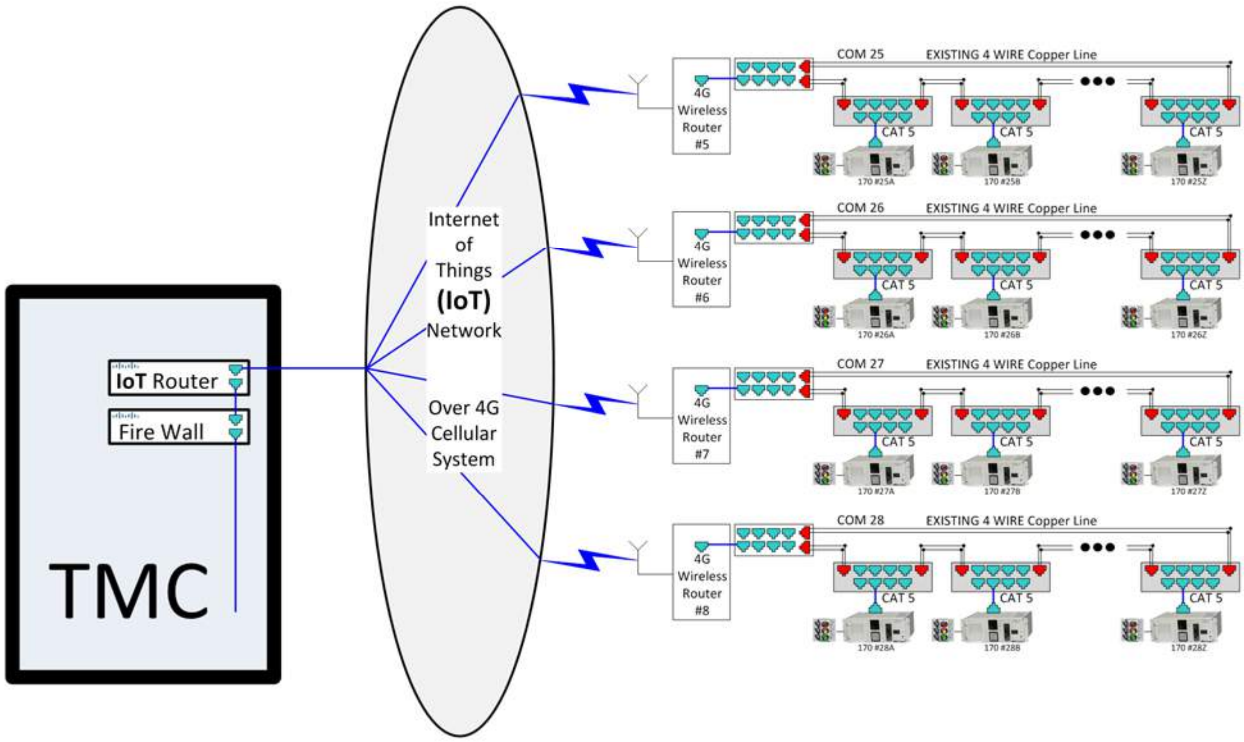
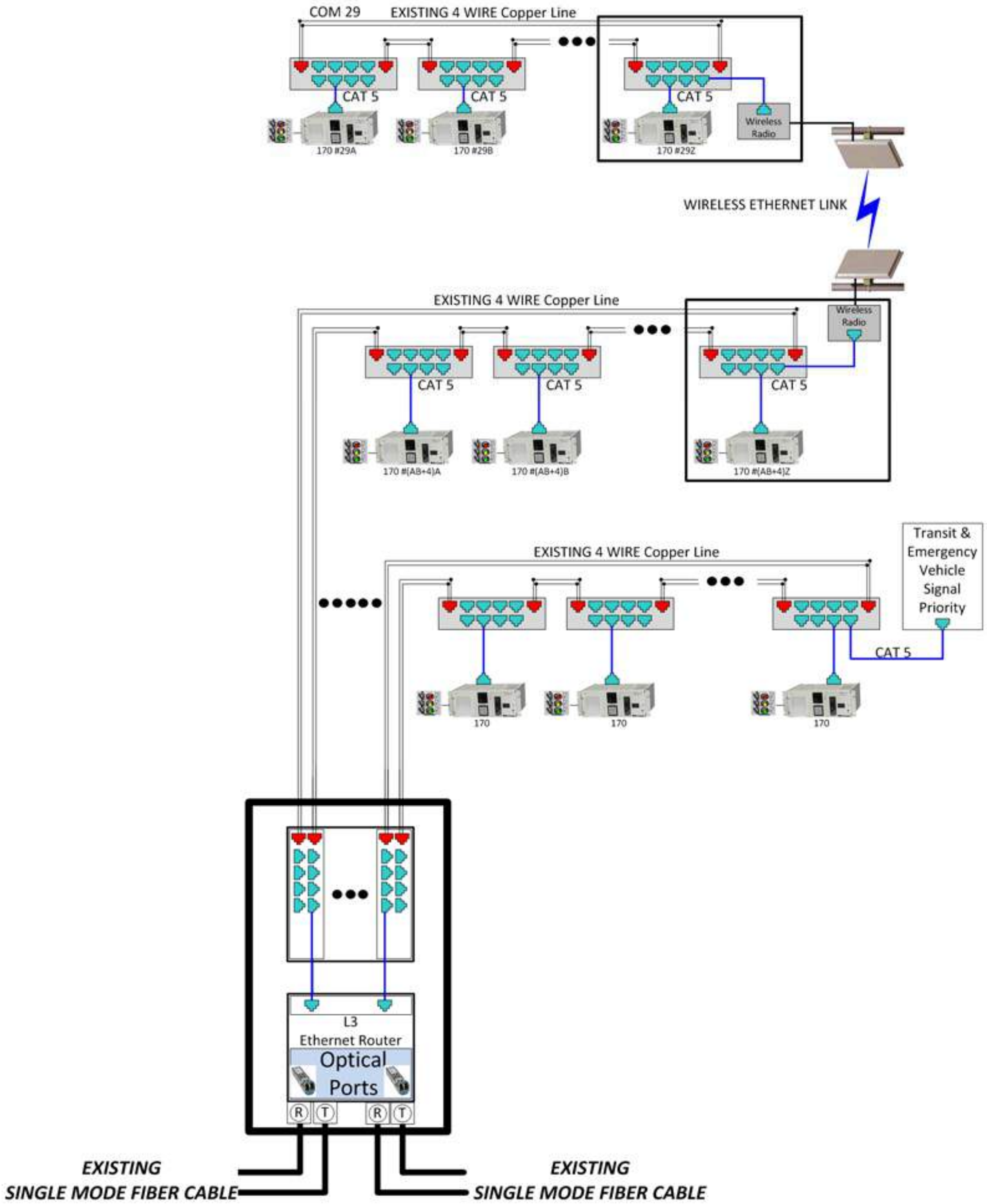
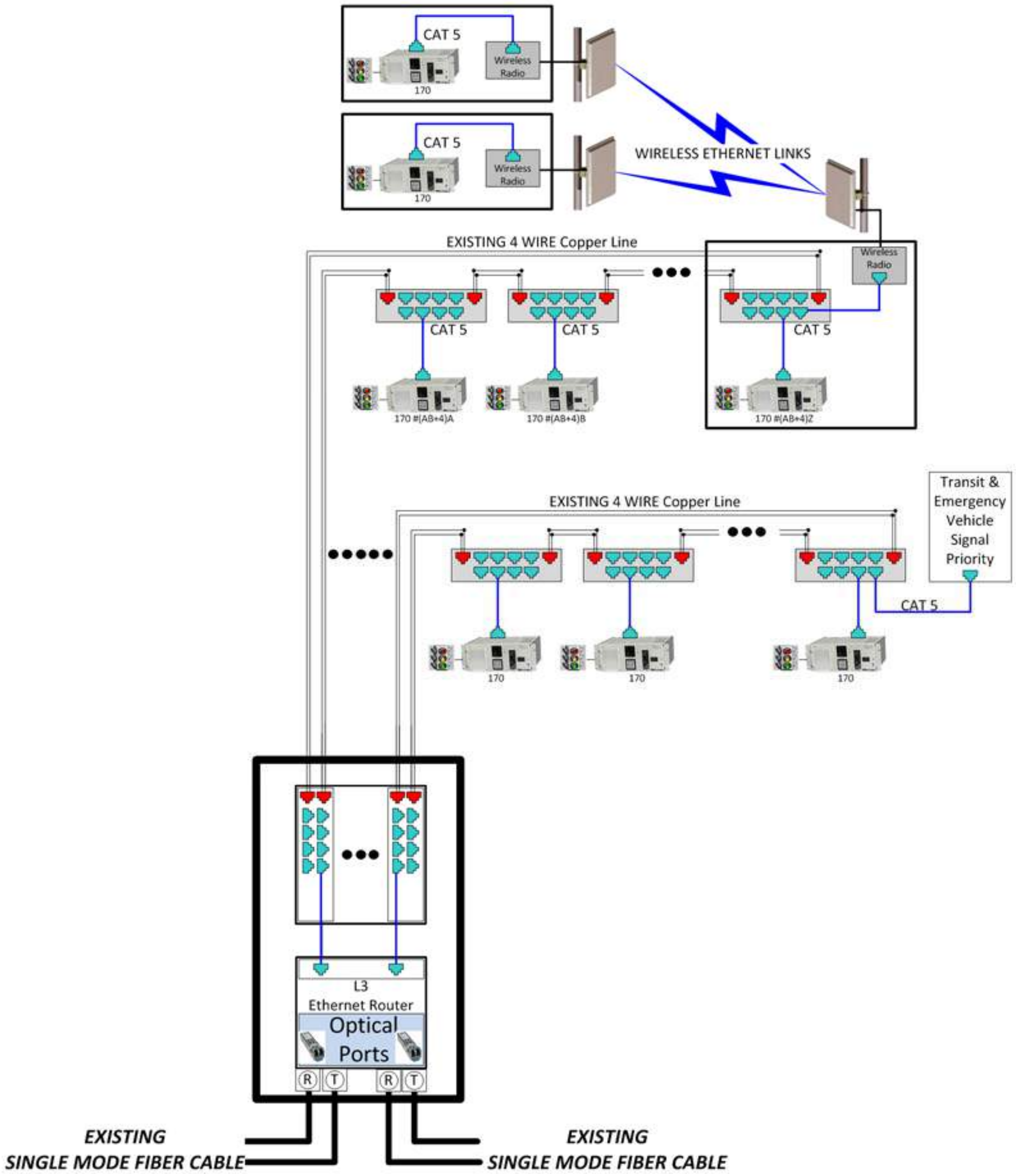


Figure 5-3 Future Owned Wireless Network Example



The gap intersections currently connecting to the network via existing 900 MHZ serial (EIA-232) digital, low bandwidth, wireless radios will be converted into high bandwidth wireless Ethernet links as shown on **Figure 5-4** below.

Figure 5-4 Future Communication Gap Wireless Network Example

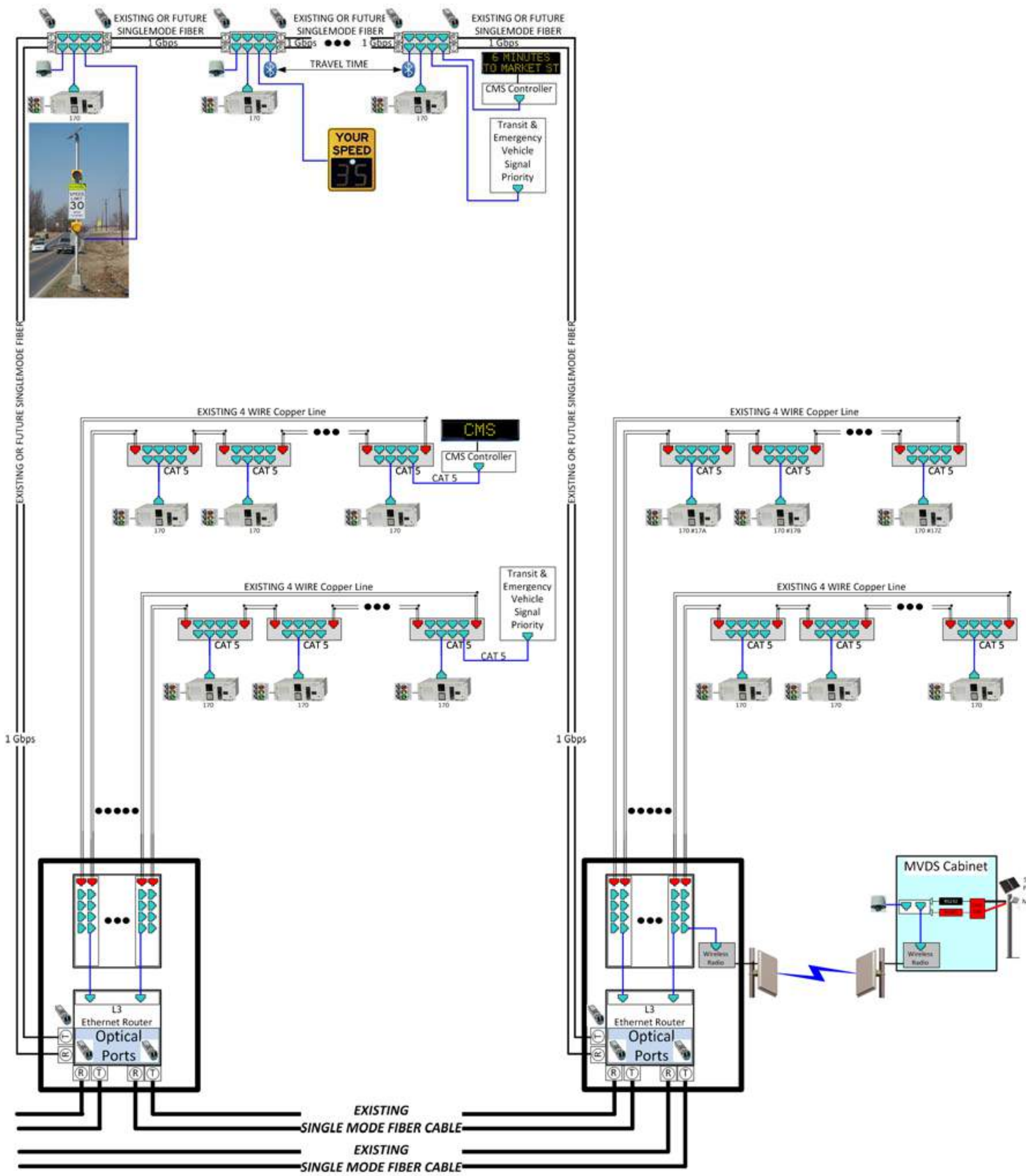


Currently there is no existing fiber optic network directly connecting intersections. In the future, where necessary, a fiber based Ethernet network may be implemented connecting intersections on an existing or new corridor. A layer 2 Field Ethernet Switch (FES) with dual 1 Gbps singlemode fiber ports should be installed at each intersection on a fiber based corridor.

In order to prevent real-time video traffic packets from flooding other ports such as the 170E ports, and rendering the port unusable, it is an absolute requirement that the FESs be compatible with the latest Internet Group Management Protocol (IGMP) version (version 3 or higher).

The beginning intersection's FES on the corridor should be connected to the appropriate layer 3 node router and the last intersection's FES should be connected to the next appropriate layer 3 router (but not the same layer 3 router as the beginning intersection's FES connection) over the existing or new singlemode fiber optic cable plant, to **provide a redundant and self-healing ring architecture**. This architecture is shown below in **Figure 5-5**.

Figure 5-5 Future Redundant and Self-Healing Ring Architecture



5.3 TMC Communication Ports

All of the Digiboards at the TMC will be removed and discarded and will be replaced with “Virtual Com Port” software provided by Digi. The Virtual Com Port software allows the existing Traffic Controller software that was communicating with the existing 170E controllers to communicate over the new Ethernet network without any hardware or firmware changes to the 170E controller in the field. Only a new Digi N2S-170 Card will be installed in the modem slot of the 170E controller.

5.4 Bandwidth Requirements

The existing traffic communications network utilizes a 2400 baud serial network with a maximum bandwidth of 2.4 kbit/s. Though robust and sufficient for the marginal data of traffic controller units, serial networks have no place in a modern ITS architecture. In comparison, the bandwidth of a 10 Gbps Ethernet network has 100 thousand times more capacity than the current serial network. The vast bandwidth of a modern Ethernet network dramatically increases accessibility to all ITS devices and applications within the traffic signal network, including streaming video from CCTV cameras and emerging technologies such as Connected Vehicles. While the initial upgrade to Ethernet will effectively over-provision the capacity requirements of existing technology, the use of managed network switches allows for resource reservation control mechanisms ensuring Quality of Service (QoS) can be delivered to critical applications and/or devices.

5.4.1 Traffic Control Cabinet Assemblies & Components

Originally developed under the restrictions of legacy communication networks, the assemblies and components of a traffic control cabinet utilize a minimal portion of the overall bandwidth available in an Ethernet network. One cannot overlook the cumulative impact of thousands of devices; however, a single IP surveillance camera consumes several orders of magnitude more than the bandwidth consumed by all of the traffic controllers within a network. The traffic control devices consuming minimal bandwidth include:

- Traffic Controller Unit
- Cabinet Monitor Unit / Conflict Monitor Unit
- Preemption Phase Selector
- Battery Backup Unit

5.4.2 IP Surveillance Cameras

To date, IP video streaming is the chief consumer of network bandwidth in a traffic signal communication network. Live video is paramount to the effective management of signal operations at individual intersections and along arterial routes. Video detection cameras and Pan-Tilt-Zoom cameras are commonly used to monitor traffic. The bandwidth utilized by the aforementioned cameras ranges from 0.5 to 5Mbit/s per camera; however, when calculating the actual bandwidth utilized by an IP video camera system one must consider the following factors:

- Resolution

- Compression
- Frames per second
- Number of Cameras

5.4.3 Demand for Real-Time Data

The future of transportation management relies on the use of traffic data for a multitude of mobility applications that will allow travelers to make informed travel decisions. As many of these applications have only begun to surface in the form of pilot deployments, the bandwidth requirements are not fully defined; thus, a best-effort network with over-provisioned capacity is ideal.

5.4.4 Connected Vehicle Technologies

Proof-of-concept deployments of Vehicle-to-Infrastructure (V2I) technology have highlighted the need for a reliable communication backbone. The use of 3G or WiMAX backhauls were leveraged where other means of communication were cost prohibitive; however, both 3G and WiMAX introduced bandwidth fluctuations leading to roadside equipment latency. Intuitively, the lowest latency was experienced when utilizing wired backhauls, such as the fiber/Ethernet network proposed in this document. As with the demand for real-time data, Connected Vehicle pilot deployments are only beginning to emerge; thus, it is best to over-provision bandwidth to ensure the communications infrastructure can support the service requirements of Vehicle-to-Infrastructure network traffic.

5.5 Future Traffic Signal Communications Architecture Example

The future traffic signal communications architecture example is shown schematically in **Appendix C** of this document. This is a full size 24x36 schematic fold out plan.

6 ITS Element Recommendations

The goal of these recommendations is to gain operational efficiency by having real time 24/7 access to every ITS device in the network and dynamically monitoring each and every one of the devices from the TMC, for immediate fault analysis and quick repair.

6.1 Traffic Management Center

A modern Traffic Management Center providing a dedicated workspace for operations staff, and communications and management systems, should be implemented as part of future system expansion. The new TMC operator workstations should be ergonomically configured for at least four operators.

All traffic operations hardware and software should reside on City owned computers located at the TMC. In order for the City to be in 100% control of its resources at any given time, cloud based software should not be used.

6.1.1 Video Wall

Real time video images of multiple video cameras can be remotely and simultaneously viewed on a video wall. A video wall of a minimum 3 rows of 4 LCD displays per row should be installed for continuous real-time monitoring of the traffic conditions for timely remedial action. These LCD displays should be 4K resolution capable, and should have no more than 6mm gap between two adjacent displays to provide one single contiguous video screen. During the RFP phase, more detailed specifications for the room, LCD displays, video wall display controller, and the number of simultaneous video images to be displayed should be developed.

6.2 Central System Software

At the core of a modern and reliable ITS communication infrastructure resides a collection of ITS central software systems. These software systems provide remote connectivity to ITS field devices; enabling TMC operators to maintain and actively manage the operation of the traffic signal system. The ITS devices managed by central system software include:

- Traffic signal controllers
- Video cameras

- Traffic cabinet devices (conflict monitors, input & output modules, etc.)
- Emergency vehicle & transit priority preemption equipment
- Detection devices
- Battery backup units
- Traffic performance devices
- Communication network devices

The key functional roles of each software system include:

- Display of real-time operational status of ITS field devices
- Collection and storage of ITS device data
- Provide a platform for the integration of new technologies
- Distribution of event notifications to system operators and maintenance staff
- Exchange of information between agencies (Center-to-Center)
- Enabling advanced operations

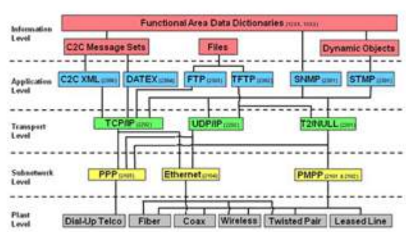
6.2.1 Communication Protocols

Each central system software will need to support the communication protocol best suited for the field device with Ethernet being the future method of device communication. For instance, legacy traffic controllers utilize EIA-232 serial communication or Ethernet; thus a traffic signal system should support both Ethernet and EIA-232.

The extensibility and sustainability of central system software requires the support of the **National Transportation Communications for ITS Protocol (NTCIP)**. The support of NTCIP enables an agency to:

- Increase procurement options and avoid single vendor dependency
- Exchange data between agencies and other central systems (TMDD)
- Reduce software development costs
- Integrate emerging technologies into an existing central system
- Manage multiple ITS devices with a single software solution

NTCIP Framework



While NTCIP has clear value in promoting interoperability, proprietary systems should not be ignored when demonstrating enhanced effectiveness[1].

6.2.2 Architecture and Extensibility

The historically common client-server architecture with desktop based user interfaces can no longer support the technological and accessibility needs of an agency. System operators require user interfaces supported by a variety of technology platforms such as smart tablets, web-browsers, and mobile phones in addition to desktop computers.

Stack recommends rugged laptops with 4G/LTE communication capabilities assigned to each operator to allow for programming and troubleshooting of field devices and remote connection to the TMC servers/devices.

Much like NTCIP, service oriented architecture (SOA) promotes interoperability and adaptability. The general nature of an SOA allows for the integration of new software technology without the re-development of server-side software. Furthermore, programs that consume data provided by the service do not need to utilize the same software technology as the service provider; thus an SOA delivers a platform for innovation without high development costs.

6.2.3 Traffic Management Software

As previously noted, several systems may be required to properly maintain all ITS devices; however, the keystone of a fully functional signal system is the traffic management software.

The fidelity of device communications is paramount to an operator's ability to confidently respond to the information provided by the traffic management software. The center-to-field communications engine of a TMS continually collects the real-time status of the traffic controller at each intersection and allows operators to actively manage signal timing parameters.

Given reliable communication to each intersection, the traffic management software shall provide the following functions and benefits:

- Real-time device status and fault diagnostics
- Signal timing modifications to individual or groups of traffic controllers
- Collection of volume, occupancy, and speed (VOS) data from roadway sensors
- Congestion indicators and operational performance measures
- Access to historical data (operation logs, split utilization, VOS, errors, etc.)
- Advanced strategies such as responsive and/or traffic adaptive
- User defined event notification (congestion, alarms, user activity, etc.)
- Synergy and integration with other GIS facilities/data

6.2.4 Ethernet Network Management

Network Monitor Software/Management software (like Orion, Whats Up Gold, SNMPc) with SNMP and report generating capability should be utilized for real time problem diagnostic aid for quick location and resolution of network related issues.

6.2.5 Ethernet Network Security

The traffic signal system network is a private Local Area Network without public interfaces; however, as with all public infrastructure, the network may be vulnerable to physical breach as network components often reside in remote and/or isolated public spaces.

6.2.5.1 Wired networks

The most common threat to traffic signal networks is related to copper theft. While new laws and coordination between law enforcement and salvage yards has curbed the rate of theft incidents, the problem persists and should be mitigated by securing network hub cabinets, communication vaults and pull boxes.

Network layer firewalls provide rule sets and packet filtering to control incoming and outgoing network traffic. Firewalls should be placed at the network perimeter between the traffic signal network and other private or public networks. A distributed-firewall strategy (firewalls placed between network hubs) will prevent intrusion of the entire network when a security breach occurs at an isolated network branch.

6.2.5.2 Wireless Networks

Wireless radios should be configured to:

- Utilize WPA2 Encryption
- Password protected configuration

6.2.5.3 Virtual Private Network

Remote users to the system will need connect securely to a Virtual Private Network. Effectively managing VPN users and their access privileges is an important consideration. When implementing an SSL VPN deployment, the following should be considered:

- Strong User Authentication and Password Policy
- Cryptographic Algorithms
- Session Timeout
- VPN Policy & Desktop Anti-virus requirements

6.3 Fiber Plant

All future backbone communications medium should use a minimum of 96 strands single mode fiber optic cable where there is an existing conduit and where there will be new conduit installed.

In order to allow easy route modifications and temporary network reconfigurations, all backbone communications fiber cable should be terminated on industry standard fiber optic patch panels residing in the TMC and in the field cabinets.

The local drop connections (for the fiber FES connections) should use 12 strand single mode fiber optic cable. All local drop communications on fiber cable should be terminated on industry standard fiber optic patch panels residing in the field cabinets. Stack recommends:

- Traffic Operations fiber strands are not to be shared.

- No other VLANs on Transportation & Storm Water Department fiber.
- Traffic Operations network must be totally independent from other departments' networks.
- No sharing of the layer 3 routers,
- No sharing of the layer 2 FESs.
- Owned communications wherever and whenever possible.
    - The ultimate goal is a wired network.
- Use city owned point to point or point to multipoint line of sight broadband Ethernet radio links to shoot shorter gaps where no agency connections exist.
- Use cellular to shoot wider gaps where no agency connections exist.
- Utilize other City department communications when advantageous to shoot a gap.
- If available and not planned for future use, other fiber buffer tubes may be shared.
- If it is absolutely necessary and as a last resort, a set of costly DWDM or Optical Transport Network equipment may be used to share the same physical fiber strand pairs to provide extra bandwidth over the same fiber for other departments, while still keeping the Traffic Operations data independent from other departments' data.

6.4 Traffic Signal Communication Network Devices

The implementation of Ethernet/IP based communications allows for all IP compatible devices to be readily connected to the network including:

6.4.1 Layer 3 Router Rings

Layer 3 routers will be utilized to form the redundant and self-healing backbones of the network. There will be multiple intersecting rings architected to provide the utmost redundancy and self-healing capability possible. The future network architecture should be designed such that there will not be a single point failure that impacts multiple intersections.

Most ITS networks implemented within the past 4 to 5 years are using 1 Gbps backbone speed and 100 Mbps FES speed. Within the past two years the equipment prices have come down and these speeds have migrated towards 10 Gbps backbone speeds and 1 Gbps FES speed.

The network port speed of the layer 3 switches is usually determined by the type of Small Form factor Pluggable (SFP) electrical/optical interfaces. The SFPs convert the electrical Ethernet packets to optical Ethernet packets. The determining factors for SFP selection are:

- Fiber optic cable type, multimode or singlemode
- Speed of the network connection, 1 Gbps, 10 Gbps, 40 Gbps and 100 Gbps
- Distance between the layer 3 router connections.

A correct set of (may be identical) SFPs should be utilized at each end of the fiber pairs connecting two layer 3 nodes to each other.

Temperature hardened (-40°C to +85°C, with no fans) layer 3 routers are hard to find. Field cabinets that will house the layer 3 equipment should be air conditioned and UPS protected.

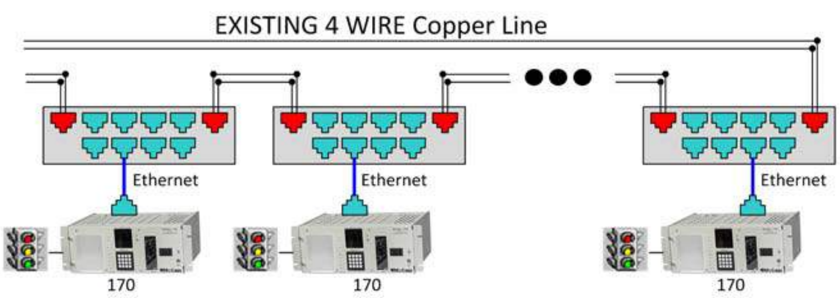
The speed of the Layer 3 equipment, therefore the speed of the backbone, should be selected after a careful cost/benefit analysis.

6.4.2 Layer 2 Managed Ethernet Over VDSL Switches

The VDSL equipment connecting to the existing copper cable plant cost effectively transforms the corridor's network architecture from the low speed analog to high speed Ethernet/IP protocol, allowing the same intersection to be able to use new ITS devices and or services mentioned in section 5.1.

Each intersection should utilize a two - VDSL port layer 2 Ethernet switch to provide dynamic alternate routing. **Figure 6-1** below shows the conversion from the low speed analog to high speed Ethernet/IP protocol over the existing copper cable plant.

Figure 6-1 Future VDSL Conversion



Most city signalized intersections will fall within the VDSL signal distance limitation.

VDSL equipment can provide communications for distances up to 5 kilometers and speeds up to 35 Mbps. The cumulative data traffic should be carefully calculated for the selection of the appropriate VDSL switch.

The VDSL equipment should be temperature hardened (-40°Cto +85°C, with no fans). For ease of installation and for one less equipment to spare, the VDSL equipment should directly connect to the 110 VAC power lines without an external AC to DC power converter.

The existing surge suppressor at the end of copper wires may need to be replaced.

Since the future network will provide the real time video viewing capability to the TMC via IP cameras, it is an absolute requirement that these VDSL switches be compatible with the latest Internet Group Management Protocol (IGMP) version (version 3 or higher) in order to prevent real-time video traffic packets flooding other ports such as the 170E ports, and rendering that port unusable.

6.4.3 Layer 2 Managed Ethernet Over Fiber Switches

In the future, where necessary, a fiber based Ethernet network may be implemented connecting intersections on an existing or new corridor. A layer 2 Field Ethernet Switch (FES) with dual 1 Gbps singlemode fiber ports should be installed at each intersection on that corridor.

The network port speed of the FESs is also determined by the kind of Small Form factor Pluggable (SFP) electrical/optical interfaces. These SFPs convert the electrical Ethernet packets to optical Ethernet packets. The determining factors for SFP selection are:

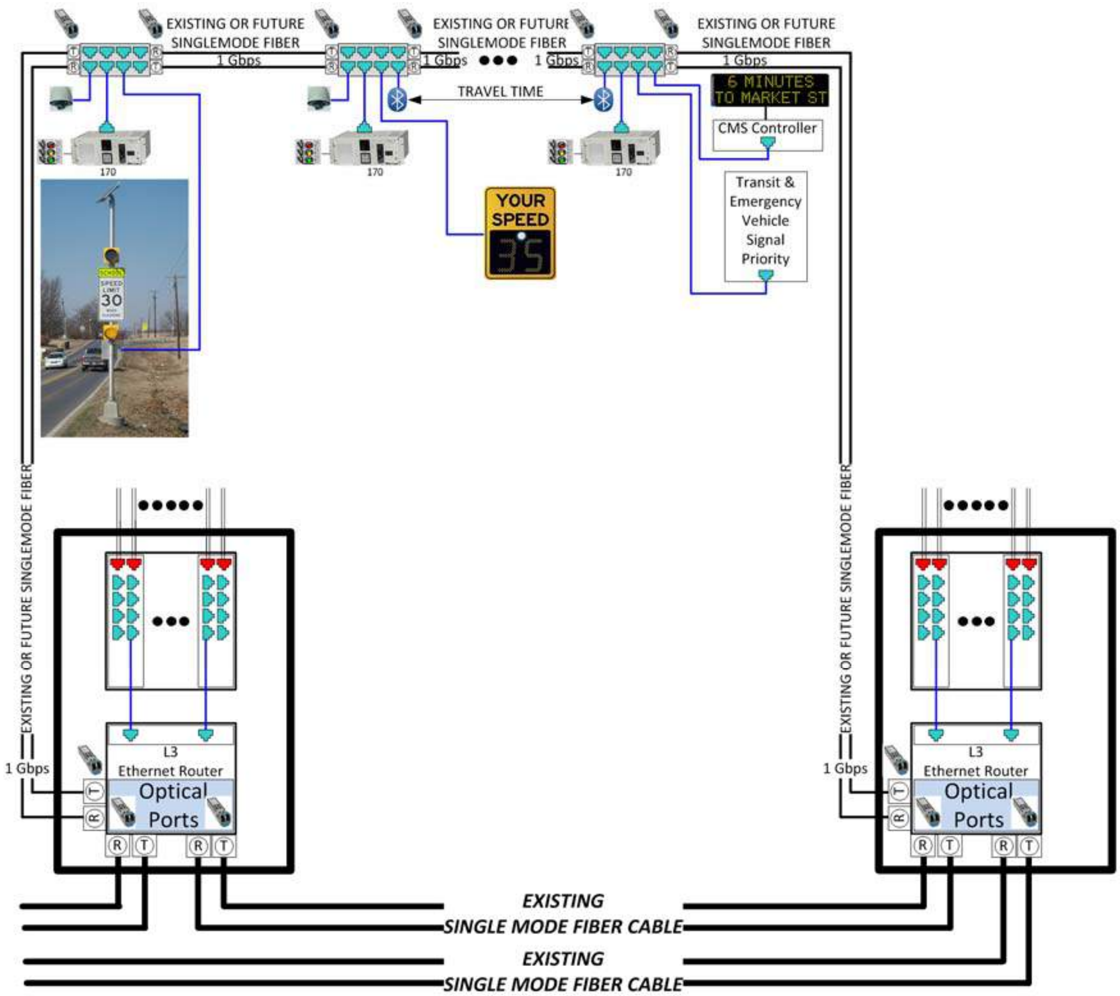
- Fiber Optic cable type, multimode or singlemode.
- Speed of the network connection, 100 Mbps or 1 Gbps.
- Distance between the two FES connections.

A correct set of (may be identical) SFPs should be utilized at each end of the fiber pairs connecting two FESs to each other.

The FES equipment should be temperature hardened (-40°Cto +85°C, with no fans). For ease of installation and for one less equipment to spare, the FESs should directly connect to the 110 VAC power lines without an external AC to DC power converter.

Figure 6-2 on the next page shows the redundant self-healing network architecture of the Fiber FESs and layer 3 backbone routers.

Figure 6-2 Redundant Network Architecture



Although **Figure 6-2** shows the FESs connecting to singlemode fiber, utilizing correct multimode SFPs, the FES can connect to the existing multimode fiber plant.

6.4.4 Layer 2 Managed Wireless Broadband Radios

To cover the gaps where there is no existing copper based connectivity, city owned wireless broadband radios will provide point to point or point to multipoint wireless Ethernet/IP connectivity between intersections, and then from the last intersection in the corridor to the next intersection where there is a physical route to the layer 3 router. **Figure 6-3** on the following page shows the wireless broadband radio connectivity.

The wireless radios should be compliant with 802.11n or 802.11ac wireless networking standards. Current 802.11 n or 801.11ac radios provide up to 300 Mbps bandwidth for distances up to 20 miles. These radios require line of sight connectivity.

Depending on the geography of the intersections to be connected, a mesh network broadband wireless architecture can also be implemented, although less likely, due to the lack of having line of sight connectivity.

Wireless broadband radios come in two different radio-antenna configurations:

- Wireless broadband radios with external antenna
- Wireless broadband radios with antenna in the same package

Wireless broadband radios with external antennas are located inside the controller cabinet, powered from the cabinet via a 12 or 24 VDC power supply and connected to the external antenna via LMR 400 type coaxial cable using a transient voltage surge suppressor (TVSS). The external antenna is usually mounted on top of the pole or the mast arm at the intersection. At the remote locations a panel antenna points toward the next intersection antenna. Depending on the geography of the remote antennas relative to the central radio, a panel or more likely an omni antenna should be used at the central radio site.

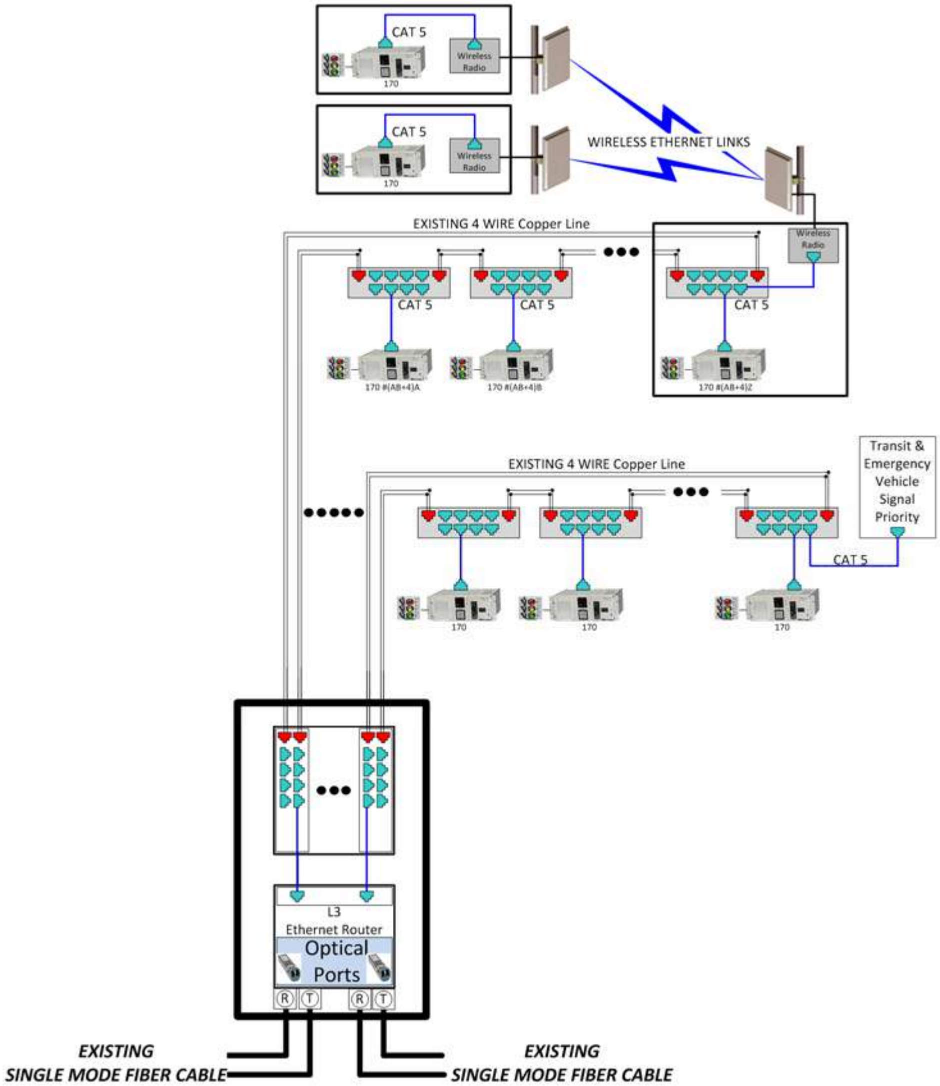
Wireless broadband radios with antennas in the same package are located on top of the pole or the mast arm at the intersection and fed by a single cable carrying both the power and Ethernet signal. This configuration is called Power over Ethernet (PoE). Inside the controller cabinet a PoE injector powered from the cabinet's 117VAC power supply connects to the radio/antenna combination over a weather proof CAT5 cable, providing both the 12 or 24 VDC power and Ethernet signal to the radio from the Ethernet switch via the PoE injector. An appropriate (Ethernet plus DC power) transient voltage surge suppressor (TVSS) should also be used to connect the radio/antenna combination to the PoE injector.

Depending on the geography of the remote antennas relative to the central radio, a panel or more likely an omni antenna should be used at the central radio site. A physical corridor analysis should be performed before deciding the radio/antenna types.

The same wireless broadband radios can also be used to bring the now dial-up intersections to the Ethernet network.

The wireless broadband radio equipment should be temperature hardened (-30°Cto +70°C, with no fans).

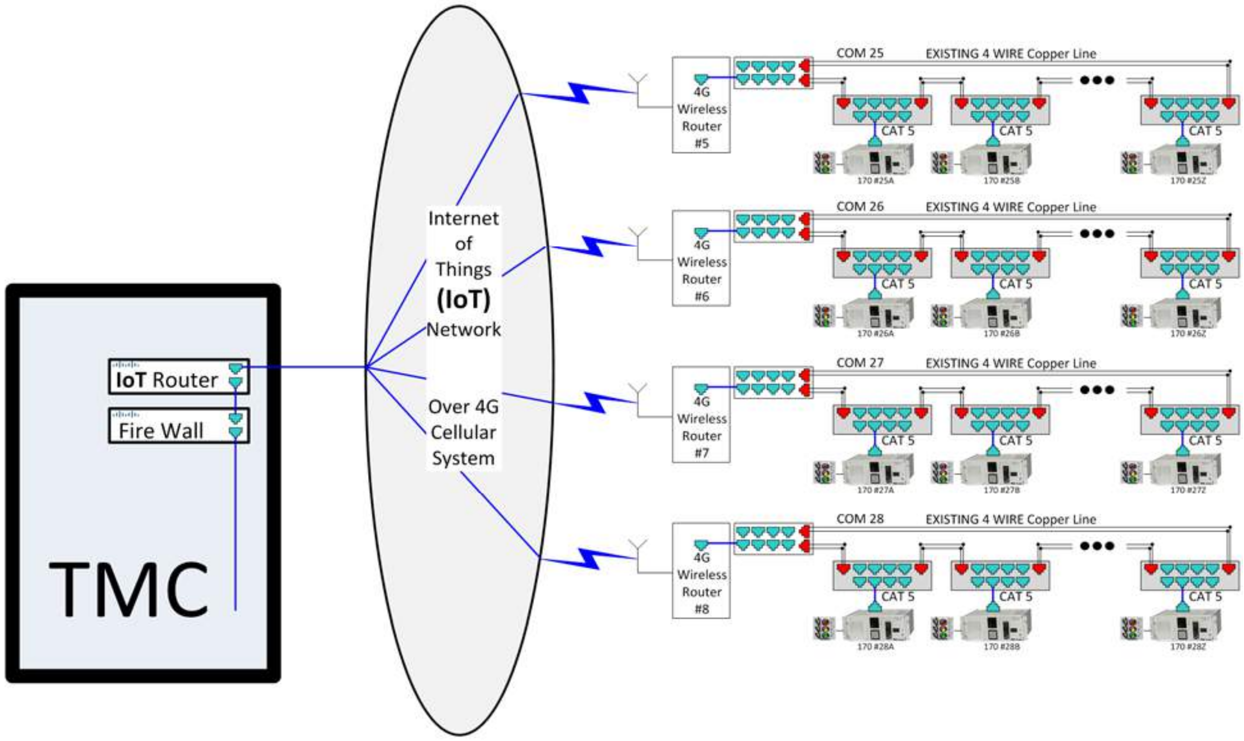
Figure 6-3 Wireless Radio Connectivity



6.4.5 4G Wireless Routers

As an alternate solution to the layer 2 managed wireless broadband radios, 4G wireless routers communicating to the TMC over the Internet of Things (IoT) Network may be considered. The 4G wireless routers network connectivity is shown below in Figure 6-4.

Figure 6-4 4G Cellular Connectivity



Advantages:

- 4G Cellular service provided by the incumbent Internet Service Provider (ISP)
- The IoT service provider has more technicians available to manage the network and fix problems,
- Access to the 4G router from anywhere with an Internet connection
- Access to the ITS device(s) connected to the 4G modem from anywhere with an Internet connection

Disadvantages:

- Monthly recurring charges.
  - If 4G service selected city should sign a SINGLE CONTRACT for bundled services covering all the intersections served by the 4G wireless routers.
- The available bandwidth is currently up to 10 Mbps downlink and 1 Mbps uplink.
  - These downlink/uplink speeds most probably will increase since the wireless networks are constantly being upgraded.

6.5 Travel Time Measurement Systems

A variety of travel time measurement systems have emerged as ideal mechanisms for constantly monitoring arterial performance, incident detection, and identification of irregular traffic patterns. While the exact technology utilized to anonymously track a MAC address varies by vendor, the most widely deployed travel time measurement systems utilize Bluetooth®.

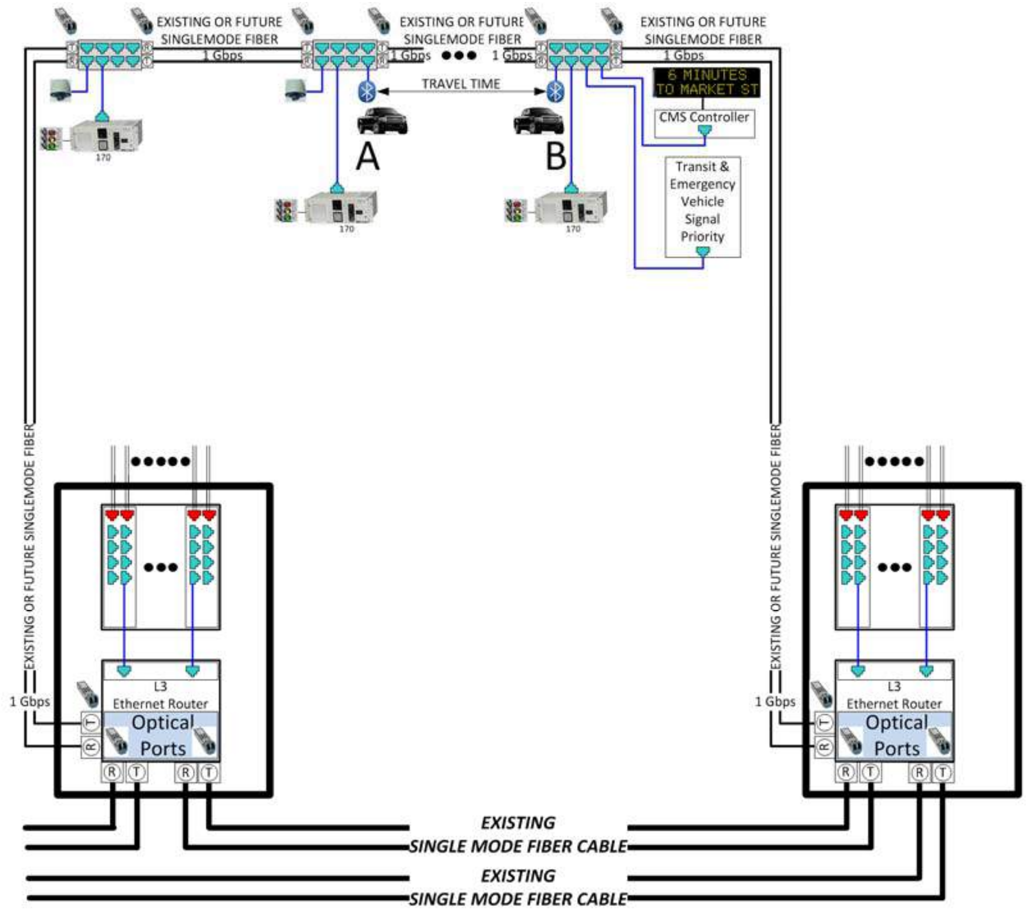
Bluetooth is a wireless communications protocol used in cell phones, headsets, music players and laptops. Each Bluetooth device has a unique Media Access Control (MAC) address. Since cell phone usage has become ubiquitous, Bluetooth based travel time measurement systems have started to come to the market. The system works as follows:

The Bluetooth readers are shown with the icon in **Figure 6-5** below. Both Bluetooth readers at intersections A and B communicate with the "Travel Time System" software running on a dedicated PC located at the TMC, or housed in Bluetooth Travel Time Measurement System vendor's server.

A vehicle with a Bluetooth device (usually a cell phone with Bluetooth service is turned ON) whose MAC address is 00-0C-F1-56-98-AD passes in front of the first Bluetooth reader at location A. Its MAC address is read, randomized and stored in the software. The same vehicle continues its travel on the corridor toward the next selected Bluetooth reader at location B. Its MAC address is again read, randomized and stored. The software finds that both the reader A and the reader B detected the same Bluetooth device and it took T seconds for the vehicle to travel the distance L between points A and B. The software calculates the speed of this vehicle and puts it into its database with time and date stamp for each vehicle record for archival purposes.

The accuracy of the speed calculations increases with the number of Bluetooth devices detected between the same two reader points, A and B. The bigger the sample size, the better the average value of the travel time and the speed of the corridor. This information can be integrated into a Changeable Message System (CMS) or website to inform the traveling public about how long it will take for them to get to their destination, and can offer them to make alternate route choices, leading to reduced congestion. With this travel time and speed data in hand, the city traffic engineers can better plan for future timing settings of the 170E or 2070 controllers.

Figure 6-5 Bluetooth Travel Time Device Connectivity



6.6 Emergency Vehicle and Transit Signal Priority Systems

"Every second counts". Time can be a friend or your worst enemy in an emergency. Emergency responders know that getting to the scene safely and quickly is a critical part of their job. Each second lost can multiply damage or reduce the chance of survival. If the emergency response vehicles such as ambulances and fire trucks can eliminate waiting for the red light on their way to an emergency, they will save more lives and reduce damages.

Emergency vehicle and transit signal priority (TSP) systems allow on-board devices inside the authorized emergency and transit vehicles to communicate with the equipment located at the intersection. The communications methodologies used are either infrared, GPS, or secure wireless. The equipment sends a priority or preemption call to the controller to change the light to green, allowing the emergency or transit vehicle to go through the intersection without stopping for the light.

The central application running on a PC located at the TMC constantly communicates with each intersection based traffic signal priority device over the Ethernet/IP network and logs in every emergency and TSP request. In addition the application also provides configuration and management functions of the system.

6.7 Uninterruptible Power Supplies

Uninterruptible Power Supplies (UPS) should have an Ethernet/IP interface and be network manageable with built-in web GUI and SNMP support.

The UPS's should be capable of backing up the whole traffic signal including the traffic lights for a minimum duration of 1 hour at full load and a minimum duration of 4 hours when all lights are flashing.

The UPSs should be temperature hardened (-40°Cto +74°C).

6.8 Closed Circuit Television (CCTV) Cameras

Based on the identified need at the selected locations such as at the corner of the intersection, or in the middle of the corridor, or in front of a school, or close to a hospital, or close to a stadium, etc., High Definition IP (HDIP) cameras should be installed. The CCTV cameras will allow TMC personnel and other traffic operations staff to view the traffic conditions in real time and take the necessary appropriate actions. The real-time video images can be viewed on either the video wall or any PC monitor. The CCTV cameras should:

- Be temperature hardened and meet IP65 requirements.
- Provide a minimum of 720p resolution. 1080p or higher is preferable.
- Utilize H.264 or newer stable encoding algorithm.
- Provide at least two individually configurable video streams.
- Generate JPEG Snapshots and transmit these still pictures to an ftp site or multiple ftp sites directly from the camera at user selectable intervals.
- Provide Pan, Tilt, and Zoom (PTZ) for precise image control.
- Provide up to 64 presets with privacy zones
- Be PoE compatible
- Be temperature hardened (-34°Cto +74°C, with no fans)

With the multi-stream generating CCTV cameras, the City can provide access to the real time IP camera images over a web portal to its citizens and to the news media free of charge. The cost of maintaining the web portal can be compensated by advertisement revenue.

The City's Transportation & Storm Water Department should view the real time CCTV images on the new video wall or their TMC workstations, but not record the images. The recorded images of incidents such as accidents will be requested by the courts causing the department's valuable resources to be dedicated to the court related activities. However, cooperation with the courts or with the Police Department can occur with a Network Video Recorder (NVR) located at the TMC, but owned and operated by the entity other than the Transportation & Storm Water Department.

6.9 Changeable Message Signs (CMS)

CMSs should be installed based on identified need at selected locations. These CMSs can provide:

- Traveler Information such as accident or congestion.
- Travel Time info.
- Special event operations announcement for congestion times.
- Amber alert.
- Silver Alert for senior citizens wandering around.
- Public Service Messages.

Since the CMSs come with Ethernet/IP compatible CMS controllers, the authorized TMC operators can place appropriate messages to inform the public.

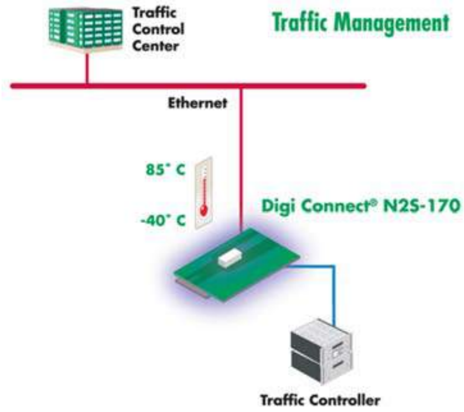
The "standard" CMSs are monochrome and text based providing 18 characters per line on three rows. These are the NTCIP compatible CMSs.

The newer generation CMSs are graphics based full color but not NTCIP compatible. Based on the department's needs, both types of CMS should be considered and a detailed RFP spec should be written.

6.10 Device Servers

Device Servers also called Terminal Servers are the serial to Ethernet converter devices used to connect the legacy serial based devices and networks to Ethernet/IP networks. Device servers should be temperature hardened (-40°Cto +85°C, with no fans). Serial to Ethernet devices will be used to connect 170 traffic controllers to Ethernet networks as these legacy controllers do not natively support Ethernet. Serial to Ethernet devices may also be utilized to preserve a serial branch when trunk networks are converted to Ethernet. The schematic below illustrates this example:

Figure 6-6 Device Server Connectivity



6.11 Solar Power

Where appropriate ITS devices should be powered by solar based energy systems. For long life and ease of maintenance, gel batteries are recommended.

6.12 Network Related Recommendations

- A Separate Virtual Local Area Network (VLAN) should be used per service.
  - For example the 170E traffic controllers could be on VLAN 1, IP cameras on VLAN 2, UPSs on VLAN 3, CMSs on VLAN 4, Ethernet Network Management on VLAN 99, etc.
- Where necessary and appropriate IP sub netting should be used.

6.13 170E Controller Upgrade

The existing 170E controllers will not be replaced but will be enhanced with a Digi N2S-170 card housed inside the 170E controller slot for converting the 170E from serial communications protocol to Ethernet/IP communications protocol.

6.14 Advanced Transportation Controller (ATC)

Developed by a consortium of professional transportation groups (AASHTO, ITE, and NEMA), the Advanced Transportation Controller Standards provide an open architecture hardware and software platform that can support a variety of ITS applications including traffic signal control. In essence, traffic controllers that meet the ATC standard are built for the technology of today and into the future.

The common features of an ATC that exceed the capabilities of a 170 traffic controller include:

- Dramatic increase in processing power and storage capacity
- Open Source Operating System (Linux)
- Dual NIC and often built-in unmanaged switch for networking other ITS devices

- Intuitive menu-driven display
- Additional Inputs for use at complex railroad crossing and other applications (C11 inputs)
- Advanced traffic controller software
    - o New operations that increase mobility
    - o NTCIP communication compliance for interoperability
    - o Network connectivity tools
    - o Advanced Transit Priority Routines
- API for universal interface between application programs

6.15 Communication Hub Cabinets and Vaults

A combination of communication hub cabinets and fiber vaults will serve to collect data from peripheral networks and tie nodes into the main fiber trunk of each subarea. The existing infrastructure exposes the fiber trunk as the fiber optic is pulled into the above ground cabinet. A simple traffic incident or cabinet knockdown would damage the trunk and bring a large portion of the network down until the fiber can be repaired and/or replaced.

Stack recommends the use of ITS/ATC communication hub cabinets and fiber vaults. The combination of hub cabinets and vaults serve to collect data from peripheral networks and tie nodes into the main fiber trunk of each subarea without exposing the fiber backbone above ground.

Communication hub cabinets may serve intersection control assemblies and components in addition to network communications equipment. The latest ITS and ATC traffic control cabinets utilize compact, high density components that leave abundant space for network equipment. ITS/ATC hub cabinets shall be outfitted with fiber optic termination panel which patches the hub network into the main fiber trunk via the underground vault. The communication hub cabinets shall be outfitted with Air Conditioning which will provide greater option in network equipment selection (as the equipment will not need to be temperature hardened).

Beyond offering additional space for network equipment, the ITS/ATC cabinets offer:

- Detects a dark approach through load current monitoring
- Manages up to 120 detector inputs and 32-channel outputs
- Safeguards against accidental contact per NEC
- Enables migration to 48 VDC or ultra-low power LEDs
- Provides continuous monitoring of FTR and flasher status
- Allows for hot swappable output assembly

6.16 Virtual Serial Ports

Device server manufactures provide their “Virtual Serial Port (VSP)” software with their products. This VSP software redirects any existing software’s data destined to a given COM port in the PC to an IP address and a port number. As an example if the newly installed VSP software is configured for COM 99 to be mapped to 192.168.1.99 port 2201 in the PC that is running 170E controller software and if the 170E controller software is sending the data “00 11 ab cd ef” to COM 99, this data “00 11 ab cd ef” is now put on the Ethernet port of the same PC and is sent to the Ethernet/IP device 192.168.99 on port 2201. The Ethernet/IP device is the Digi N2S-170 card whose IP address and port numbers are 192.168.1.99 port 99. With this VSP software all the Digiboard hardware cards are removed and replaced by the VSP.

6.17 Newer Devices and Applications

The following is a brief description of applications that are relatively new or becoming more widely used in the traffic systems industry.

6.17.1 Smart Phone Apps

The City may develop and provide its citizens smart phone apps for dissemination of congestion information. The cost of the maintaining this service can be recovered from an ad based revenue model.

6.17.2 Web Portal

The web portal can be used for City traffic operations to directly communicate with its citizens on traffic related matters. This portal can provide the real time traffic camera images for the citizens to view. It can also show a snapshot picture coming from the same traffic cameras. The city could provide the traffic flow information obtained by the Bluetooth Travel Time system on the portal in the form of “congestion mapping”. By informing public, the City Traffic Operations can improve the service it provides to its citizens.

6.18 Adaptive Signal Control

A handful of adaptive signal control technologies have emerged over the last decade, each presenting their own unique approach to enhancing the flow of traffic along defined routes. As defined by the FHWA Model Systems Engineering Documents for Adaptive Signal Control Technology Systems[2], prior to the selection of an adaptive signal control technology, an agency should produce the following documents:

- Concept of Operation
- System Requirements
- Verification Plan
- Validation Plan

The TSCMP identifies adaptive signal operations for approximately one-third of the traffic signals in the City.

6.19 Connected Vehicle Applications

The USDOT has already begun several research projects for Connected Vehicle Applications in form of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications for safety[3]. The next generation of traffic controller software should provide a mechanism for the implementation of V2I technology as the relay of traffic signal timing information to vehicles is an initial focus.

7 IMPLEMENTATION PHASING PLAN

The promotion of the existing Serial communication system to a modern future-ready Ethernet system is a critical and monumental task in addressing the mobility needs of San Diego. The communication infrastructure is imperative for the next generation of traffic control devices and innovative technologies such as connected vehicle applications.

Transforming the existing network, composed of thousands of field devices spread over 370 square miles, requires a staged approach where critical deficiencies are addressed first, followed by a strategic conversion of the remaining communication infrastructure. The communications equipment and ITS element recommendations are described in Section 5 and 6, respectively. The implementation phasing plan for the system is described below and illustrated on Figure 7.1 on the following page.

7.1 Phase 1: Critical Deficiencies (Year 1-3)

Establishing communication with an intersection yields immediate benefits in the maintenance and operation of the intersection; thus, addressing communication gaps and repairs provides the greatest return on initial investments. This document details the 500 plus communication deficiencies and logically groups deficient intersections into subareas, providing the outline for a number of smaller sized communication projects. As there are varied challenges in establishing communication with each subarea, the order of magnitude cost estimate is meant to provide guidance when establishing the overall project schedule. The initial projects of Phase 1 will serve to establish the network foundation when upgrading the majority of existing infrastructure in Phases 2 and 3.

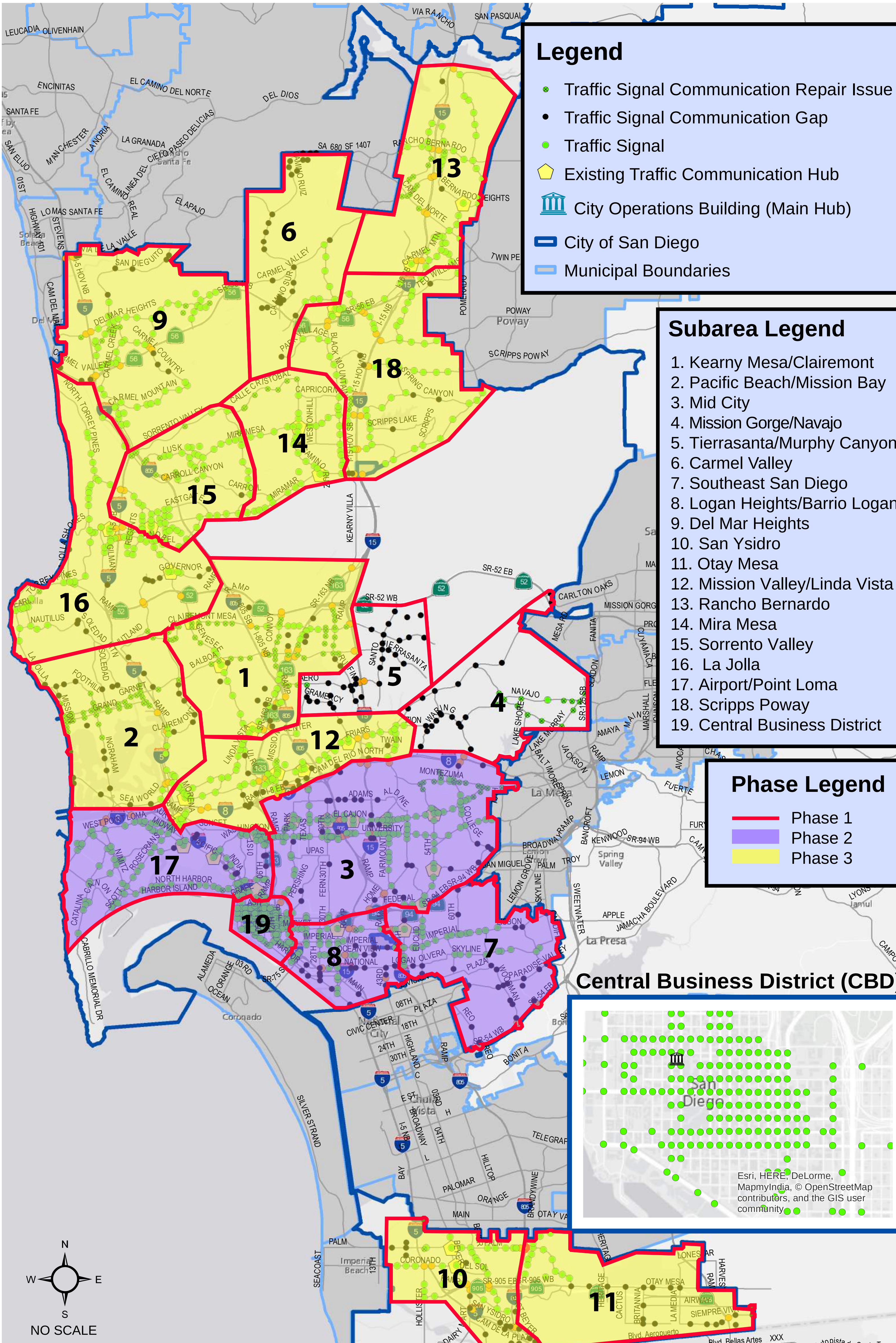
7.2 Phase 2: Central Business District (Year 4-6)

As a best practice, the transformation of the legacy network shall begin centrally and expand outward into peripheral networks. This approach will dramatically reduce the complexities that would be faced if one were to bring Ethernet communications through a central region that remains serial based. Thus, Phase 2 will constitute Ethernet upgrades of intersections contained by the Central Business District (i.e. Downtown). The downtown region encompasses nearly one third of the intersections; hence, providing balance to the execution of this communications overhaul.

7.2.1 Phase 2 Strategic Deployment

System migration from serial data communication to IP based Ethernet communication will be implemented in a seamless process. The goal is to convert all existing 170E controllers using serial data communications to Ethernet. Existing serial communications to non-converted controllers will continue un-interrupted as each channel is converted to Ethernet.

The process will start from the TMC and move outward. A Layer 3 Ethernet switch will be installed in the TMC and a second layer 3 Ethernet switch will be installed at 1st Street and Hawthorne. The switches will be connected using a pair of dark (unused) fibers.



TRANSPORTATION & STORM WATER

STACK TRAFFIC CONSULTING, Inc.

City of San Diego
Traffic Signal Communications Master Plan
Implementation Phasing Plan

Figure 7-1

Controllers on communication channel 74 (Grape Street and Hawthorne Street) will have plug in 170E serial to Ethernet converters and VDSL switches installed. The controllers on this channel will be disconnected from the multiplexer and connected to the layer 3 Ethernet switch. All controllers on channel 74 have been converted. By connecting two more dark fibers at 1st and Hawthorne to the layer 3 Ethernet switch the conversion process can move outward to the next termination cabinet and repeat the process until all channels and controllers have been converted to Ethernet.

The controllers in the Central Business District (CBD) are all on copper interconnect. The conversion process will start with the installation of a VDSL switch in the TMC for each channel. A 170E serial to Ethernet converter and a VDSL switch will be installed in each traffic signal cabinet on the channel. One channel at a time will be converted to Ethernet. During the conversion period, existing serial communications will not be interrupted to non-converted controllers on other channels.

Using the process described, all serial controllers will be converted to Ethernet with minimal disruption to existing communications.

7.3 Phase 3: Peripheral Networks (Year 7 -10)

The existing network is that of a decentralized system with communication hubs serving as collectors of several arterials before sending communication back to the central system. The final phase of the communications overhaul will call for the replacement of existing hubs and extending Ethernet communication to each intersection serviced by the hub. The implementation of phase 3 focuses on the remaining third of intersections with the advantage of new Ethernet networks to connect to in the interior of the City.

7.4 ITS Elements Deployments

The ITS elements deployments consist of the devices and equipment that provide functionality that serve critical functions and/or result in operational advantages for the City's traffic management system. The individual ITS elements include hardware, software, and communication components that comprise a subsystem in the overall system architecture. The ITS elements included in the three phased deployment consist of the following:

- Traffic Management Center (TMC)
- Web Portal
- ITS Traffic Signal Cabinet
- ATC Controllers
- Conflict Monitors
- Emergency Vehicle Preemption System
- Detection Systems
- Adaptive Signal Control Systems
- Changeable Message Signs

- CCTV Cameras
- Battery Backup Systems

The Traffic Management Center (TMC) is the focal point of the City's traffic signal communication and management system. It serves as the physical location for staff, workstations, display systems, and communications system connections. The TMC is assigned the highest priority of ITS elements and is included in Phase 1.

The deployment of the City of San Diego web portal is contained in phase 2. The deployment of the remainder of the ITS elements is divided evenly between phases 2 and 3 consistent with the central and peripheral communications network deployments.

7.5 Operations and Maintenance Staffing

A well operated and maintained traffic signal communication and management system is primary to achieve and sustain the quality of life benefits realized through implementation of state-of-the-art traffic systems. Appropriate staff levels are critical to sustain an optimized system.

The *Federal Highway Administration (FHWA) report: Traffic Signal Operations and Maintenance Staffing Guidelines (2009)* provide a guideline to estimate staffing needs required to effectively operate and maintain traffic signal systems. The report also defines the roles and responsibilities of traffic operations and maintenance staff.

7.5.1 Traffic Operations Engineer

This is typically a professional position with skill and ability in the specialized application of traffic operations. The responsibilities include complex engineering activities, managing, directing and supervising the planning, design, implementation, optimization and distribution of traffic systems and timing plans for traffic signal projects.

The FHWA guidelines recommend a staffing level of 1 traffic operations engineer per 75-100 signals to actively support the traffic system[1]. This equates to 16 dedicated traffic operations staff to actively support the City of San Diego traffic signal system at an optimal level.

7.5.2 Signal Maintenance Technician

This position is typically responsible for the installation, diagnostics and maintenance of all electronic equipment pertaining to traffic signal operation. Maintenance technicians provide emergency maintenance in the event of a malfunction or damage and preventive maintenance performed on a regular schedule to keep the system in proper working order. This position must have knowledge related to the application of sophisticated electronics and communications technologies to traffic control applications.

The FHWA guidelines recommend a staffing level of 1 technician per 30-40 signals to actively support the traffic system[2]. This equates to 39 dedicated traffic signal maintenance staff to actively support the City of San Diego traffic signal system at an optimal level.

7.5.3 Operations and Maintenance Staffing Recommendations

The City of San Diego's traffic signal operations and maintenance staff has not increased proportionately to the number of traffic signals. Staff levels are much lower than guidelines advise. The traffic operations staff has varied responsibilities in addition to operating traffic signals which reduces their ability to actively manage the system. On the maintenance side, many staff retired and these positions have been left open, causing each technician to maintain a larger number of intersections.

Staff qualifications make for improved operations and maintenance service. Traffic signals have evolved. The engineer and technician are expected to work with electronic and electrical systems, communications systems, computer and software systems. This Traffic Signal Communications Master Plan recommends changes in traffic control technology and the use of Ethernet communications which require increasing knowledge of electronics and greater computer literacy.

The operations and maintenance (O&M) staff for traffic signals have overlapping areas of responsibility and staff skills are complimentary. The most well managed systems occur when operations engineers and maintenance technicians work side by side. The following are recommendations for O&M staffing:

- The traffic signal/ITS staffing should be a combination of traffic operations engineers and maintenance technicians.
- The traffic signal/ITS O&M staff should be exclusively dedicated to traffic signal system related activities.
- Duties include managing the TMC, implementing new operations and systems, troubleshooting and maintaining the communications lines, equipment, and ITS elements in the field and TMC.
- The traffic signal/ITS O&M staff should comprise of 5 operations engineers and 3 technicians. This is in the order of double the existing staff dedicated to traffic signal/ITS related duties and equates to roughly 200 signals per staff.
- The traffic signal/ITS O&M staff should have expertise in traffic operations, communications systems, Ethernet networking, and ITS devices.
- If necessary, existing personnel will be trained on Ethernet based communication architectures and protocols.
- There should be regular training and classes set up to learn new systems and how to troubleshoot and repair.
- The TMC should be manned 24/7 with 3-4 staff working 8 hours during the day and one of them during the night.
- The City should contract the services of an on-call ITS and traffic signal operations engineering firm to provide highly technical services. This would provide much needed staff support during the

TSCMP implementation. This would also provide flexibility in staffing levels as needed as in-house staffing levels are met.

Although the TSCMP recommended staff allocations are lower than FHWA guidelines, the TSCMP recommendations provide twice the existing staff which will significantly improve the City's ability to actively operate and maintain the traffic signal system.

If combining operations engineers and technicians in one group does not work due to policy limitations, then pursuing a dialog and agreement between Transportation Engineering Operations Division and Street Division to assign 3 technicians dedicated to TMC and ITS maintenance is strongly recommended.

Staffing the TMC and ITS O&M group is spread among the three implementation phases with two positions in phase 1, three positions in phase 2, and three positions in phase 3. The phased staffing levels coincide with the TSCMP systems deployment.

7.6 Order of Magnitude Cost Estimate

The overall deployment cost for the San Diego Traffic Signal Communication Master Plan communication systems, ITS elements, and staffing needs for each implementation phase is presented in **Table 7-1**. The detailed (itemized) cost estimates are contained in the Appendix.

Table 7-1 Citywide TSCMP Deployment Cost Estimate

Subarea / Item #	Subarea	Phase 1	Phase 2	Phase 3	Total
1	Kearny Mesa/Clairemont Mesa	$1,693,500	$0	$1,137,000	$2,830,500
2	Pacific Beach/Mission Bay	$1,462,500	$0	$90,750	$1,553,250
3	Mid City	$2,512,500	$3,099,750	$0	$5,612,250
4	Mission Gorge/Navajo	$767,250	$0	$0	$767,250
5	Tierrasanta/Murphy Canyon	$441,750	$0	$0	$441,750
6	Carmel Valley	$525,750	$0	$66,000	$591,750
7	Southeast San Diego	$1,074,000	$432,000	$0	$1,506,000
8	Logan Heights/Barrio Logan	$564,000	$780,750	$0	$1,344,750
9	Del Mar Heights	$627,750	$0	$478,500	$1,106,250
10	San Ysidro	$678,000	$0	$2,300,250	$2,978,250
11	Otay Mesa	$426,000	$0	$115,500	$541,500
12	Mission Valley/Linda Vista	$1,877,250	$0	$1,781,250	$3,658,500
13	Rancho Bernardo	$650,250	$0	$990,750	$1,641,000
14	Mira Mesa	$723,750	$0	$884,250	$1,608,000
15	Sorrento Valley	$461,250	$0	$763,500	$1,224,750
16	La Jolla	$515,250	$0	$1,155,750	$1,671,000
17	Airport/Point Loma	$969,000	$2,112,000	$0	$3,081,000
18	Scripps Poway	$484,500	$0	$1,087,500	$1,572,000
19	Central Business District	$1,058,250	$2,887,500	$0	$3,945,750
	Sub Total Communications	**$17,512,500**	**$9,312,000**	**$10,851,000**	**$37,675,500**
20	TMC	$780,000	-	-	$780,000
21	ITS O&M Staff	$180,000	$270,000	$270,000	$720,000
22	ITS Elements	-	$62,302,500	$62,296,000	$125,378,500
	Grand Total	**$18,472,500**	**$71,884,500**	**$73,417,000**	**$163,774,000**

(1) Each phase will be implemented in stages (based on subarea priority) as funding becomes available.

The order of magnitude cost estimate is $163.8 million. This includes soft costs such as engineering and management. This projection includes eight additional staff positions at build-out.

7.7 Funding Sources

There are several potential funding sources for the Traffic Signal Communications Master Plan implementation. These include the City's Public Facility Financing Plans, Transnet, General Fund, and grant opportunities.

7.7.1 Public Facilities Financing Plans

The City of San Diego funds public improvements including transportation infrastructure through Public Facilities Financing Plans (PFFP). The PFFP's are funded through an impact fee collected at building permit issuance as part of the costs of land development[3]. The typical PFFP plan update takes 15 months[4]. In order for the TSCMP improvements to receive funding through the PFFP's the improvements have to be currently planned or associated with a project or the City initiates the update process. Considering the 15 month update timeline it is recommended to start the update process in order to receive funding through the PFFP's in time for phase 2 implementation.

7.7.2 Development Impact Fees (DIF)

Development Impact Fees (DIF) are collected to mitigate the impact of new development through provisions of a portion of the financing needed for public facilities identified in the PFFP and to maintain existing levels of service for that community. Upon determination of the area of benefit and community build-out population, the estimated cost to construct the facilities is divided amongst residential and non-residential development[5].

7.7.3 Regional Transportation Congestion Improvement Program Fees (RTCIP)

These fees were established to ensure that new development directly invests in the region's transportation system to offset the negative impact of growth on congestion and mobility. These fees are assessed on residential development projects only[6].

7.7.4 TransNet

TransNet (since 1988) is the San Diego region's half-cent sales tax dedicated to transportation improvements. Money generated from this tax helps pay for highway, transit, and local street improvements throughout the region. The program was extended in 2008 for 40 years for $14 billion. The San Diego Association of Governments (SANDAG) administers the funds and the SANDAG Board of Directors decides what to do with the funds based on the locally adopted Regional Transportation Plan (RTP), which is updated every three years[7]. Identification of need (this document), and majority approval of the SANDAG Board is required to commit TransNet revenue for future deployment of TSCMP projects.

7.7.5 City General Funds/Capital Improvement Program

The fiscal year 2015 adopted budget includes $310 million for capital improvement projects across the City[8]. The existing funding for traffic systems and ITS projects through the General Fund and Capital Improvement Program (CIP) is insufficient to meet the City's needs. Historically the funding allocations were in the order of $1 million annual; however current annual allocation is $100 thousand[9].

Roadway infrastructure is a major investment of the general fund, though the bulk of the money is allocated to street repairs and related hardscape improvements. Traffic signals are included as a subtype of transportation CIP projects. In order to achieve funding through the general fund/CIP, the improvements identified by the TSCMP need to be prioritized and recommended for adoption in the next fiscal year CIP budget and/or as a reassignment of funds in the current fiscal year's budget.

7.7.6 Grant Opportunities

There are grant opportunities for various types of transportation/roadway related infrastructure improvements. These require significant staff time to apply for and administer. The most applicable grants that should be submitted to fund TSCMP improvements are described below.

7.7.6.1 Highway Safety Improvement Program (HSIP)

The Map-21 Highway Safety Improvement Program (HSIP) achieves a significant reduction in traffic fatalities and serious injuries on all public roads. The HSIP requires a data-driven, strategic approach to improving highway safety on all public roads that focuses on performance. The HSIP also requires a 10% match of funds by the local agency. A highway safety improvement project is any strategy, activity or project on a public road that is consistent with the data-driven State Strategic Highway Safety Plan (SHSP) and corrects or improves a hazardous road location or feature or addresses a highway safety problem[10]. It is recommended that the City apply for HSIP funding as improvements recommended in the TSCMP qualify for the grant and several City corridors would meet the required criteria.

7.7.7 Assembly Bill 1447

On August 20 2014, Assembly Bill 1447 passed and clarifies that synchronization projects can qualify for money raised by California's cap-and-trade program which seeks to cut greenhouse gas emission. The carbon marketplace is expected to raise as much as $1 billion for the state this fiscal year. The TSCMP improvements qualify for funding through this legislation as the recommended technology is proven to reduce Green House Gasses (GHG's)[11]. The cap and trade program money is held by the Greenhouse Gas Reduction Fund and as the process of administering these funds for traffic synchronization projects is determined, the City should present TSCMP improvements for funding.

7.8 Procurement and Delivery Methods

San Diego's Traffic Signal Communication System Master Plan procurement choices will impact deployment effectiveness and return on investment. Procurement and delivery methods include best value procurement, design-bid-build, design-build, and system manager/engineer as prime contractor. The challenge in choosing the optimum method lies in tailoring the specific work into bid packages and projects that balance technical complexity, system quality, cost saving, and deployment schedule. Many of the TSCMP systems can be deployed incrementally by system, or all at once for a given subarea or group of subareas. Contracting options are described below.

7.8.1 Best Value Procurement

The best value procurement process includes a technical alternatives analysis of potential new systems that flow into a set of system requirements that become a technical specification. The technical specs are incorporated in "best-value" bid packages for equipment procurement. The bid advertisements typically result in reduced pricing as vendors compete with each other for equipment purchase agreements directly with the City rather than through a contractor. The best value bid packages and equipment purchase agreements provide for rapid system procurement of desired elements which significantly benefit the schedule in comparison to the typical advertisement process. The systems can be installed and integrated by City staff, the City's on-call ITS consultant firm, and/or contract maintenance company[12].

7.8.2 Design-Bid-Build

Design–bid–build (D-B-B) is the traditional project delivery method in which an agency or owner contracts with separate entities for the design and construction of a project. There are three main sequential phases to the D-B-B delivery method: the design phase, the bidding phase, and the construction phase[13]. This method can effectively be used to deploy physical TSCMP components including communications infrastructure (fiber optic cable, conduit system, pull boxes, etc.), foundations, and structures. It may not be suited for ITS projects that involve software development, computer hardware, system integration, and system configuration. In these instances this method would be counterproductive since these items cannot be as effectively separated between design and construction services, and low bid may result in a contractor that is not capable of performing the required services.

7.8.3 Design-Build

Design–build (D–B) is a project delivery method in which the design and construction services are contracted by a single entity known as the design–build contractor. In contrast to "design–bid–build", design–build relies on a single point of contract responsibility and is used to minimize risks for the project owner and to reduce the delivery schedule by overlapping the design phase and construction phase of a project. A single contract is awarded to a design-build team that is responsible for system engineering, design, and specifications; procurement and provision of all products, systems, and services; construction of all system elements; testing, inspection, and integration of various subsystems[14].

The decision to proceed with the design-build method depends on agency policy and implementation timelines. The D-B method also requires well defined functional specifications. Project costs are typically higher as the contractor takes on greater responsibility. This method may result in engineering decisions being influenced by the builder in a contest of best design versus cost.

7.8.4 System Manager – Integrator

The system manager-integrator (SM-I) is a delivery method in which a consultant performs or oversees the performance of all system/project engineering, design, interface, integration, and configuration functions (under an engineering and design services contract), while one or more contractors perform all related construction activities (under a construction contract). This method combines design and implementation of work components such as testing, integration, configuration, and procurement support under one contract. These components of work are typically small in terms of project cost, and are the most complex components of work and require advanced expertise. The SM-I services are typically procured on a qualifications basis and gives the agency a high degree of control through a single point of management[15].

7.8.5 TSCMP Delivery Method Recommendations

It's critical for the City to maintain as much flexibility in contracting/procurement as possible. Specific components of the TSCMP lend themselves to a particular delivery method. Packaging the various implementations into component projects that best match a delivery method will provide the highest degree of success. The following are delivery method recommendations.

- Advertise for an on-call/as-needed contract for professional services of an ITS System Manager-Integrator consulting firm. The contract should include provision of engineering services for design-bid-build projects. This provides the City with the specialized expertise necessary to ensure successful project implementation, a high degree of flexibility in use of services, qualifications based selection, and the most significant level of control over the most critical aspects of project deployment.

- Utilize the design-bid-build method for traditional construction oriented work including: underground installations, installations requiring machinery, and labor intensive installations. This will simplify the contractors work and increase the likelihood of more competitive bids.

- The best value bid package method should be used in instances where an off the shelf solution is desired for wide deployment. Examples of the systems to procure via best value are: controllers, conflict monitors, CCTV cameras, etc. The contract can be set for multiple years with no minimum purchase requirement and other special provisions. A separate contract would be utilized for installation; or installation by City forces and/or the SM-I service contract.

8 NEXT STEPS

There are significant challenges to implementing the master plan:

- 485 of 1,531 citywide traffic signals are communications deficient due to repair or gap issues.
- The remaining 1,046 traffic signals with communications infrastructure present have antiquated and obsolete communications technology.
- There is a general lack of ITS element infrastructure throughout the City.
- The traffic signal operations and maintenance groups are significantly understaffed.
- The current budget allocated for traffic signal communications infrastructure is highly inadequate at $100k for FY 2015.

This Master Plan is the first big step for the City in rising to meet these challenges. The next step is realizing the recommendations of the Master Plan through immediate action on a series of items that are necessary to quickly move the TSCMP into the implementation phase. The primary focus is on the short-term strategies and priorities that will build success over the course of deployment. The City will ultimately decide the most effective and beneficial approach to continue the process of implementing the Master Plan. Possible next steps for consideration by the City given the TSCMP recommendations include:

8.1 Project Prioritization

Establishing communications to all traffic signals in the City as recommended by the master plan is the most critical and highest priority. The Master Plan identifies a 10 year three phase implementation with priority as follows:

- Phase 1: Resolve communication deficiencies, implement a TMC, and hire two staff.
- Phase 2: Implement TSCMP communications architecture Downtown, implement ITS element recommendations Downtown, and hire 3 staff.
- Phase 3: Implement TSCMP communications architecture on the peripheral network, implement ITS element recommendations on the peripheral, and hire 3 staff.

The subareas identified in Figure 3-1 are prioritized in order of highest to lowest number of traffic signals affected. Project delivery in this order will provide the widest communications coverage possible and the highest potential for visibly improved traffic operations in the near term for the surrounding community. Specific projects will be selected for implementation as funding and staffing permits.

8.2 Staffing

The City traffic signal operations and maintenance groups are understaffed and creating new staff positions is a difficult and lengthy process. The staff resource needs become especially acute considering the expertise needed and workload associated with TSCMP implementation. It is recommended that the City advertise for an on-call/as-needed contract for professional services of an ITS Systems Manager-Integrator-Engineering consulting firm in order to bridge the gap between existing staff resources and immediate Master Plan deployment needs.

8.3 Develop a Priority Project PS&E and Build

Select one subarea for immediate implementation of TSCMP architecture and equipment recommendations. This will provide a benchmark and check for costs, resource needs, and scheduling and related project delivery metrics for future Master Plan deployments.

8.4 Opportunities

There is much opportunity available to the City, both internally and externally, to implement the recommendations of the Master Plan by partnering on infrastructure projects through other departments or agencies and seeking out potential funding sources. The following immediate actions are recommended to ensure opportunities are achieved.

- With the services of a qualified ITS SM-I/Engineering firm the City will have the resources to apply for and administer grant opportunities to fund ITS improvements. The return on investment is significant.
- Seek to reassign funds in the current fiscal year's budget to prioritize TSCMP phase 1 recommendations.
- Assess open development projects and include TSCMP recommendations as a mitigation measure and/or community benefit.
- Assess current and planned CIP projects and opportunities for conduit installation along deficient routes.
- Assess all existing funding earmarked for traffic signal communications improvements and allocate to TSCMP phase 1 implementation.

8.5 Master Plan Monitoring

On a semi-annual basis update the master plan GIS maps and network architecture to reflect implementation progress. This item will track master plan implementation and is intended to sustain a high level of interest and participation amongst staff and management. A full TSCMP update should be conducted every five years.

9 MASTER PLAN COST AND BENEFIT ANALYSIS

Through implementation of this master plan, the community will see a traffic operations department that is actively modernizing the traffic signal system for significant service improvement and benefits that improve the quality of life for all San Diegans. The return on investment is significant.

9.1 Costs

Figure 9-1 on the following page shows the TSCMP annual investment by phase and is also summarized in Table 9-1 below. .

Table 9-1 TSCMP Spending By Phase

Year	Phase 1		Phase 2		Phase 3		Total
	Comm's	ITS Elements	Comm's	ITS Elements	Comm's	ITS Elements	
1	$5,837,500	80,000	-	-	-	-	$5,917,500
2	$5,837,500	170,000	-	-	-	-	$6,007,500
3	$5,837,500	710,000	-	-	-	-	$6,547,500
4	-	-	$3,104,000	20,857,500	-	-	$23,961,500
5	-	-	$3,104,000	20,857,500	-	-	$23,961,500
6	-	-	$3,104,000	20,857,500	-	-	$23,961,500
7	-	-	-		$2,712,750	$15,641,500	$18,354,250
8	-	-	-		$2,712,750	$15,641,500	$18,354,250
9	-	-	-		$2,712,750	$15,641,500	$18,354,250
10	-	-	-		$2,712,750	$15,641,500	$18,354,250
Subtotal	**$17,512,500**	**$960,000**	**$9,312,000**	**62,572,500**	**$10,851,000**	**$62,566,000**	**-**
Total	**$18,472,500**		**$71,884,500**		**$73,417,000**		**$163,774,000**

In the first year of phase 1 for ITS elements, layer 3 network equipment will be implemented in the City Operations Building (COB). In the second year of phase 1 for ITS elements, layer 3 network equipment will be expanded in COB and 1 new staff will be hired. In the final year of phase 1, the TMC will be fully implemented and a second new staff will be hired.

9.2 Benefits

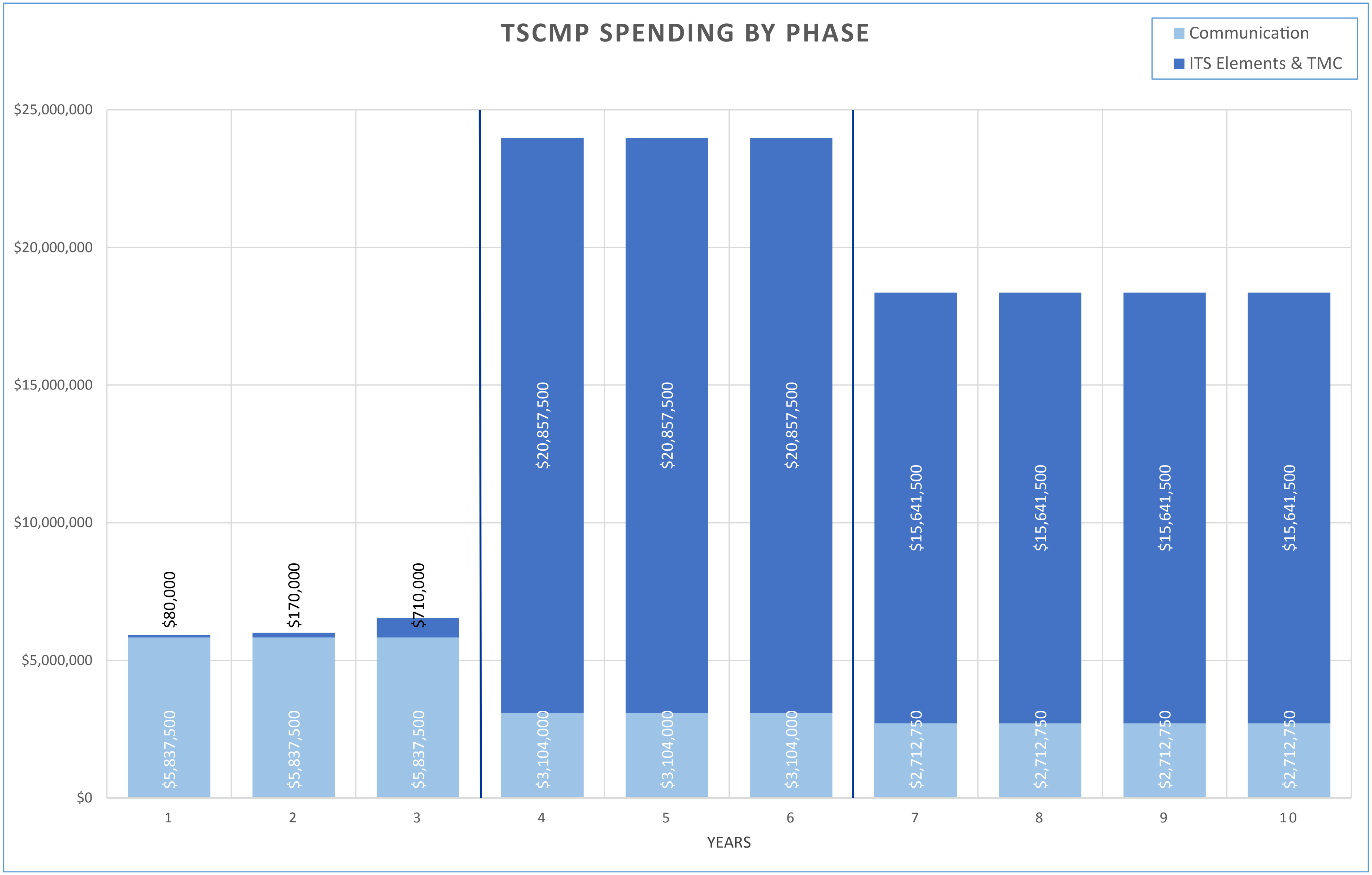
The estimated annual TSCMP benefit[1] for the phase 1 implementation is shown on Table 9-2 below.

Table 9-2 Phase 1 Benefit Summary (Per Year)

# of Int.[1]	TT[2] (hr)	Fuel Con.[3] (gal)	CO Emiss.[4] (MT CO_2e)	TT Savings[5]	Fuel Savings[6]	CO Emiss. Savings[7]	Total Savings	Total Cost (Phase 1)	Benefit: Cost
485	-2.490M	-83.219M	-16,939	$337,550	$318.980M	$1.948M	$321.266M	$6.158M	52

TT=Travel Time, Con. =Consumption, Emiss. =Emissions

Table 9-2 footnotes are listed and explained on the following page 73.



TRANSPORTATION & STORM WATER

STACK TRAFFIC CONSULTING, Inc.

TSCMP SPENDING BY PHASE

Figure 9-1

1. Total number of intersections affected during Phase 1.
2. Hours spent in traffic in San Diego (51 hours per year per traveler) based on the Texas Transportation Institute Mobility Report, 2009.
    a. 80% of the City's population drives to work based on data provided by Zip Atlas and assuming 1/3 of the population City are affected by the Phase 1 improvements.
    b. A typical 15% improvement in travel time based on signal synchronization per ITE Typical Savings.
3. The fuel saved per intersection of 7,835 gallons per day based on Fuel Savings from Retiming, assuming 1/2 of intersections are subject to coordination timing.
    a. A typical 12% reduction in fuel usage based on signal synchronization based on ITE Typical Savings
4. The average CO2e of 41,078 per 200 signals based on the average savings documented from LADOT and OCTA's signal synchronization projects.
5. Travel Time savings of $16.79 per hour of person travel based on 2012 Urban Mobility Report Table 1 per Texas A&M Transportation Institute.
6. Fuel Consumption savings of $3.833 based on California state average cost per gallon for gasoline and diesel per US Energy Information Administration.
7. CO emissions savings of $115/ton based on Highway Economic Requirements System Technical Report per US Department of Transportation.

9.3 Cost Effectiveness

The cost-effectiveness analysis shows that the operational benefits achieved by implementing the phase 1 TSCMP recommendations provide a benefit-cost ratio of more than 50:1, meaning that benefits from these programs save more than $50 for every dollar spent. This cost savings is consistent with State and National benefit-cost ratio reporting of approximately 40 to 60:1[2] return on investment. The savings achieved in phase 1 alone exceed the cost of the complete 10 year TSCMP implementation. The TSCMP recommendations provide significant benefit per dollar spent and this is economically advantageous for San Diego businesses and residents.

9.4 Conclusion

This Master Plan represents a significant opportunity for the City of San Diego to move the traffic communications system and supporting elements to the technological forefront of traffic signal systems. The Plan's purpose is to guide the City on future traffic signal communications and ITS technology improvements. This includes resource allocation related to improvement prioritization, funding sources, and staff levels. The TSCMP ultimately represents benefits to travelers in the form of better traffic signal operation which improves mobility for all modes including motorists, bicyclists, pedestrians, transit, and emergency vehicles. These benefits will result in superior productivity for all businesses, improved public safety, reduced commute times, reduced greenhouse gasses, and an overall improved quality of life for San Diegans.