



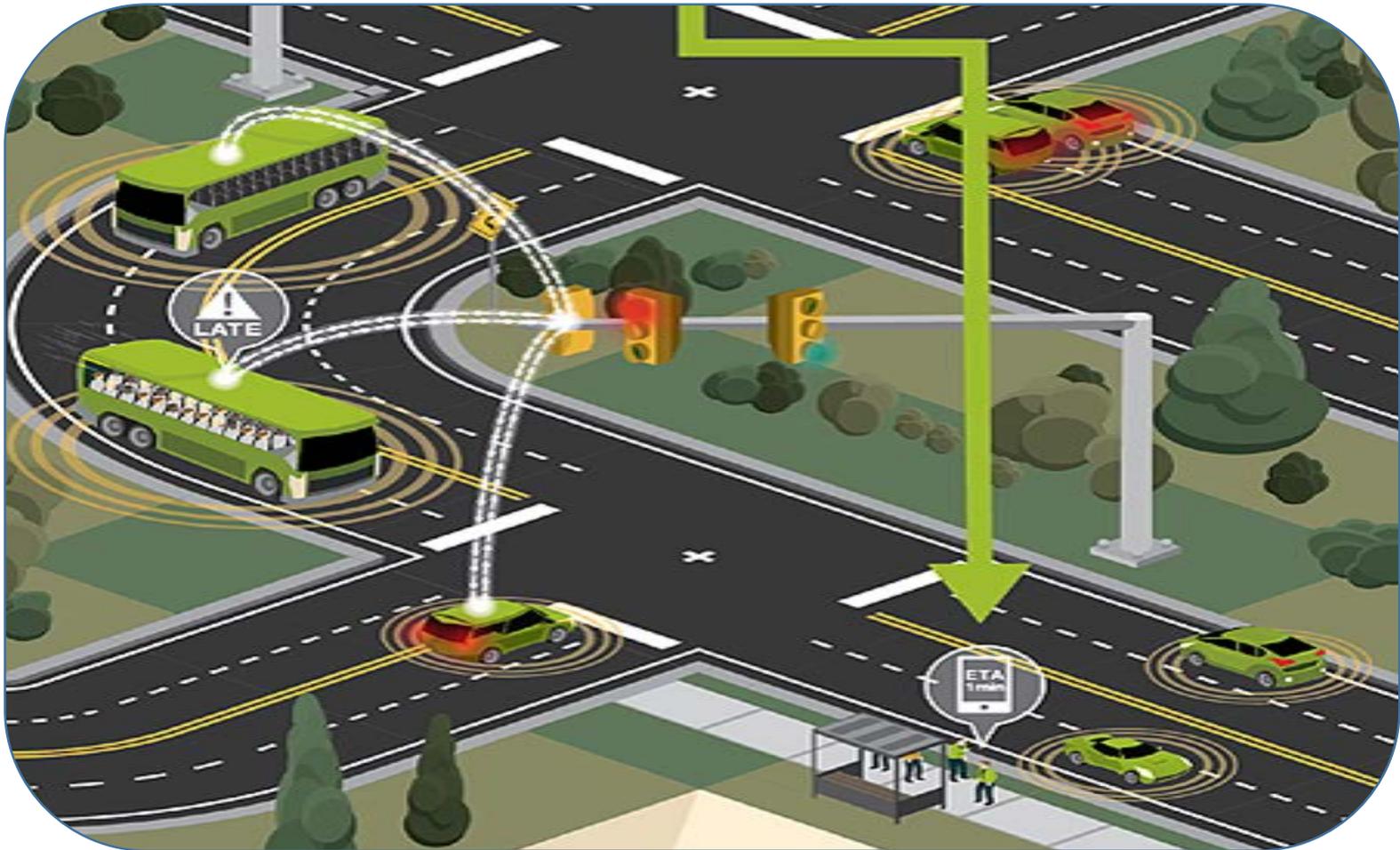
W E L C O M E



U.S. Department of Transportation
Office of the Assistant Secretary for
Research and Technology

Module 20:

Application of Arterial Management/Transit Signal Priority Standards



Instructor



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**Senior Technical Staff
Consensus Systems
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Learning Objectives

Specify and Test a Transit Signal Priority Implementation

Describe how Transit Signal Priority may be provided in a **Connected Vehicle Environment**

Explain the Role of Transit Signal Priority in **Integrated Corridors**

Review **Case Studies** where Standards were Used to Provide Transit Signal Priority

Learning Objective 1

**Specify and Test a Transit
Signal Priority
Implementation**

Identify Potential Issues with NTCIP 1211 v02

NTCIP 1211 v02

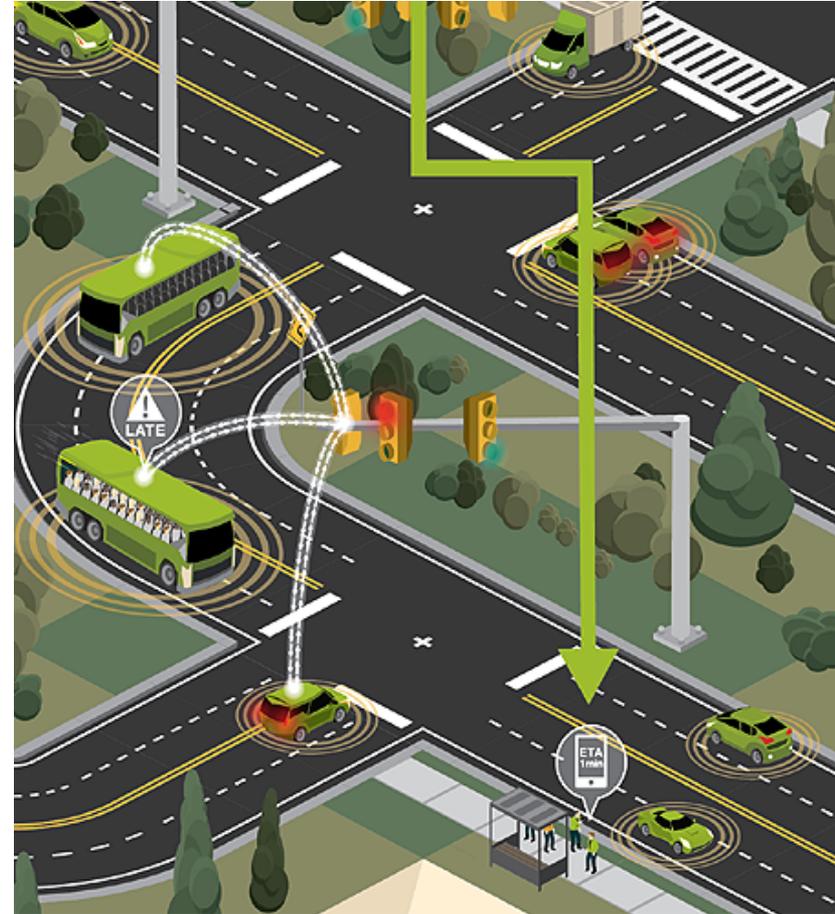
- National Transportation Communications for ITS Protocol (NTCIP) Object Definitions for Signal Control and Priority

Review

- Priority Request Generator (PRG)
- Priority Request Server (PRS)
- Controller (CO)

Architectures

- The standards support several different architectures



Identify Potential Issues with NTCIP 1211 v02

Priority Requests

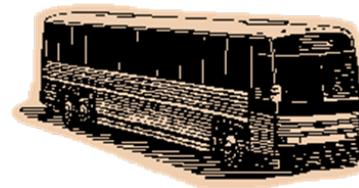
- Priority Strategy
 - Defines which **approaches** the requesting vehicle will **enter** and **exit** an intersection
 - **Required** within the priority request
 - The **requestor** is **expected** to maintain a database of priority strategies



Identify Potential Issues with NTCIP 1211 v02

Priority Requests

- **Vehicle Type:** Could be public safety or transit vehicles



- **Vehicle Class:** A category of vehicle type. For example, bus rapid transit vs express vs local transit service



- Vehicle type and class needs to have an agreed upon **regional definition**
 - Could be an issue for inter-regional vehicles

Identify Potential Issues with NTCIP 1211 v02

Transit Communications Information Profiles (TCIP)

- ITS standard defining standardized interfaces for the **exchange of information (data)** among transit business systems, subsystems, components, and devices
- Not widely deployed in the United States

Defining **system architecture(s)** supported is key

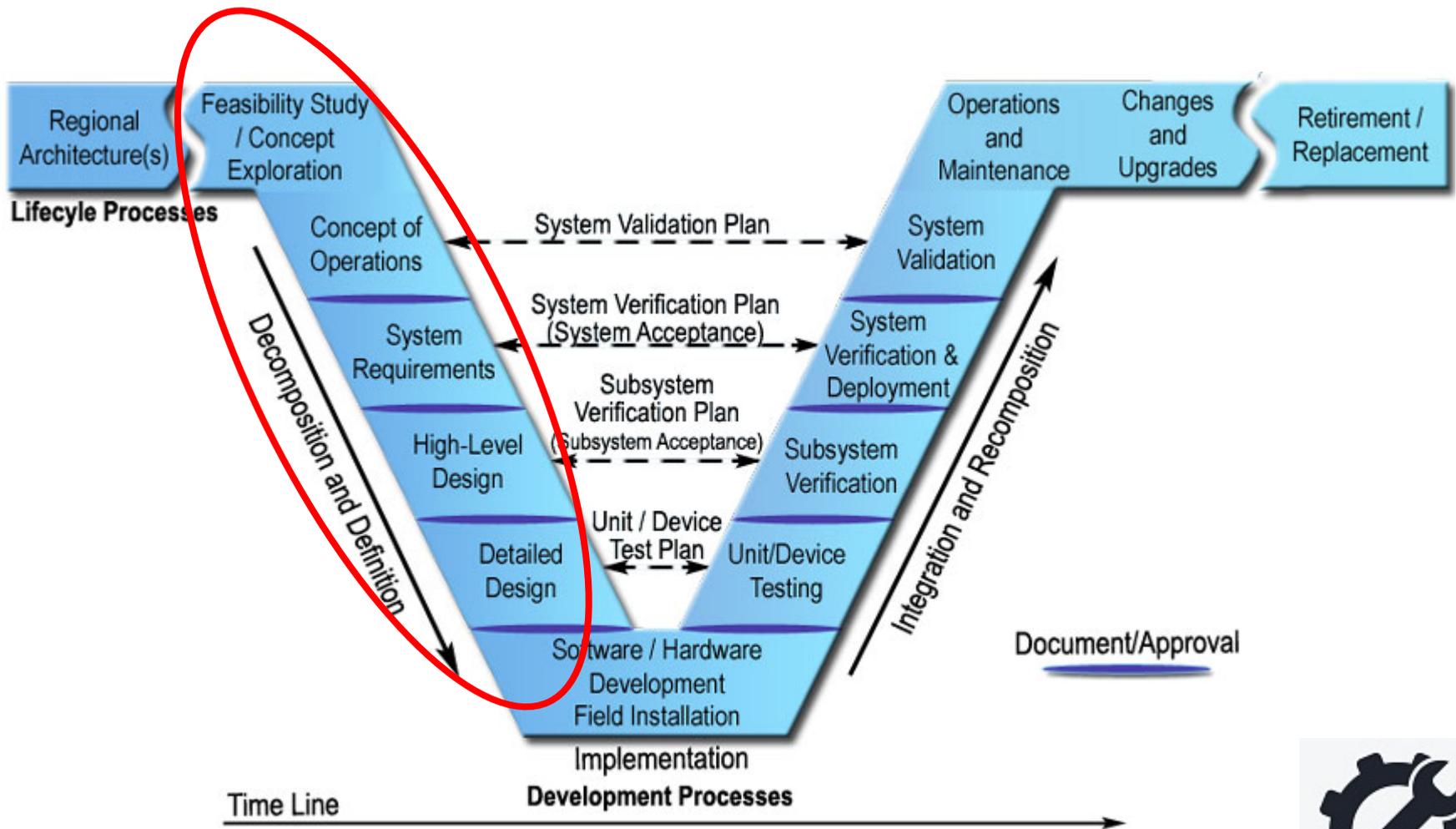
- TCIP identifies 5 transit signal priority (TSP) scenarios
- NTCIP 1211 v02 identifies the same 5 system architectures plus one additional

Test a Standards-Based TSP Implementation

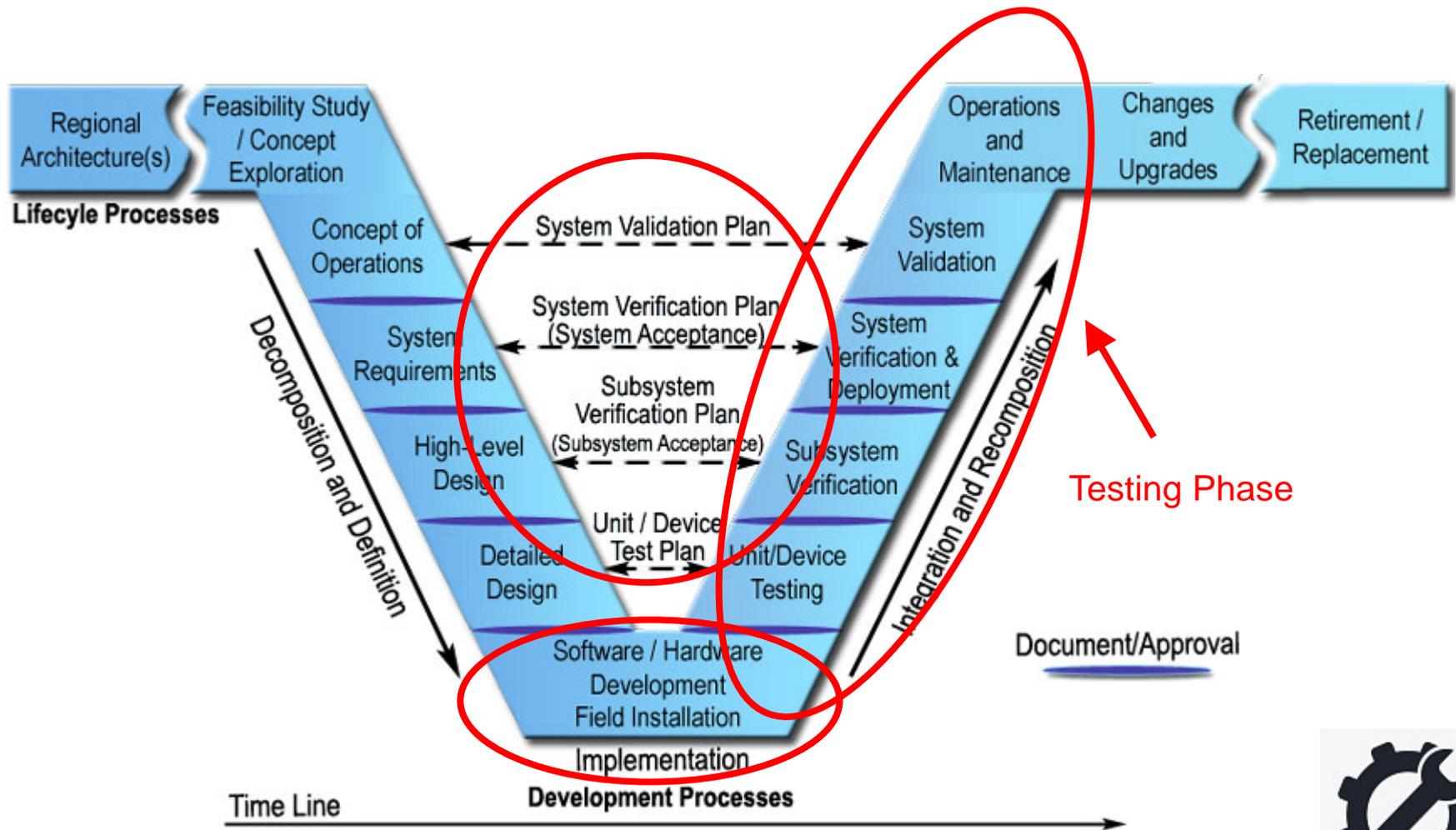
Why Perform Testing?

- To meet a payment milestone
- To **identify errors/bugs** so they can be corrected
- To verify that the system **was built correctly**
 - The system interface must meet the procurement specification and satisfy the requirements (Was the system built right?)
- To validate that **the right system was built**
 - The system interface must satisfy the initial user needs (Was the right system built?)

Test a Standards-Based TSP Implementation



Test a Standards-Based TSP Implementation



Verification

Ongoing process that builds quality into the system through a systematic approach of **verification of requirements** – i.e., “you built the system right.”

- **Unit/Device Testing** – e.g., test a standalone PRG, PRS or an interface
- **Subsystem Verification** – e.g., tests a specific interface and its immediate environment, typically under laboratory environment
- **System Verification and Deployment** – e.g., tests the entire transit signal priority system, including the management center software

Validation

- Answers the question: Can I operate the system and satisfy all my stakeholder's user needs?
- Ensures **the requirements and the system are the right solution to the stated problem** – i.e., “you built the right system.”
- The system is **validated when**:
 - **Approved** by the key stakeholders and agencies
 - **All** the project **requirements are fulfilled**
 - **Corrective actions have been implemented** for any anomalies that have been detected

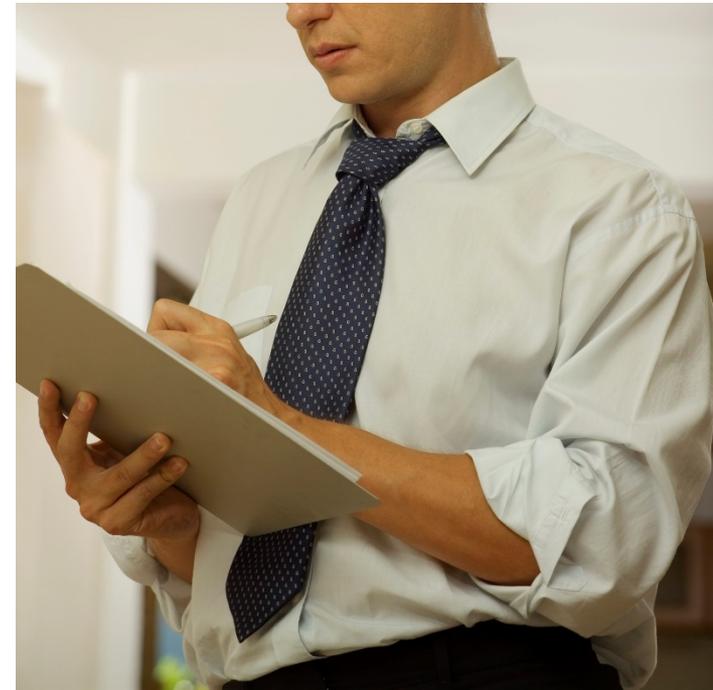
What are We Testing?

- **Compliance with the procurement specification**
 - Does the system fulfill all the requirements (shall statements) in the procurement specification?
- **Conformance with the standards**
 - Does the system fulfill the requirements selected for the system as specified in the standard?
 - The system must also fulfill other specified (user-selected) requirements of the standards it references
- Conformance is NOT compliance!

What are We Testing?

Conformance:

- Testing that the **proper protocols are being used**
 - E.g., NTCIP 1103 – NTCIP Transportation Management Protocols
- Testing that the data exchanges occur **as defined by the standard**
 - Correct **sequence of events and data content** is being exchanged
 - Correct **handling** of error messages
 - Correct **structure** of the data content



How to Test a Standards-Based TSP Implementation

Recall structure of NTCIP 1211 v02

- Defines **user needs**
- Defines **requirements**
- Defines a **single** design for each requirement

A Joint Standard of AASHTO, ITE, and NEMA

NTCIP 1211 version v02

National Transportation Communications for ITS Protocol Object Definitions for Signal Control and Prioritization (SCP)

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How to Test a Standards-Based TSP Implementation

Protocol Requirements List (PRL)

- ❑ **Traces a user need with the requirements** that satisfies the user need
- ❑ A completed PRL indicates what **features and requirements have been selected** for the procurement specification

Protocol Requirements List (PRL)						
User Need ID	User Need	FR ID	Functional Requirement	Conformance	Support	Additional Specifications
2.5.1.2	Determine Priority Request Criteria			M	Yes	
		3.5.1.3.1	Retrieve Priority Request Settings	M	Yes	
		3.5.1.3.2	Retrieve Reservice Period for a Vehicle Class	M	Yes	
		3.5.1.3.3	Retrieve Priority Request Time To Live Value	M	Yes	



How to Test a Standards-Based TSP Implementation

Requirements Traceability Matrix (RTM)

- Defines the design (dialogs, messages, and data elements) that **must be used** to fulfill a requirement

Requirements Traceability Matrix (RTM)					
FR ID	Functional Requirement	Dialog ID	Object ID	Object Name	Additional Specifications
3.5.1.3.1	Retrieve Priority Request Settings				
		4.3.1.1	5.1.2.7	prsProgramData	
3.5.1.3.2	Retrieve Reservice Period for a Vehicle Class				
		G.1	5.1.1.5	priorityRequestReserviceClass1Time	
			5.1.1.6	priorityRequestReserviceClass2Time	
			5.1.1.7	priorityRequestReserviceClass3Time	
			5.1.1.8	priorityRequestReserviceClass4Time	
			

How to Test a Standards-Based TSP Implementation

Requirements to Test Case Traceability Table (RTCTT)

- **Traces each requirement selected** (in the PRL) **to the test case(s)** that verifies the requirement is fulfilled
- Indicates the **test case(s) that must be passed** to fulfill the requirement
- Verifies test case(s) **capture testing all requirements** at least once

Requirement		Test Case	
ID	Title	ID	Title
3.5.1.3.1	Retrieve Priority Request Settings	C.1.3.1	Retrieve Priority Request Settings
3.5.1.3.2	Retrieve Reservice Period for a Vehicle Class	C.1.3.2	Retrieve Reservice Period
		C.1.3.3	Retrieve Reserve Period – No Such Class

How to Test a Standards-Based TSP Implementation

Multiple test cases may be needed to **completely test** a requirement

- Each test case may test a **different set of values**
- Each test case may test **different conditions**

Each test case should confirm that the interface:

- performs the **same sequence of data exchanges (and events)** as defined in the standard
- **uses the data concepts** (messages, data frames or data elements) indicated in the RTM



ACTIVITY



Question

Which of the following is NOT a reason to perform testing?

Answer Choices

- a) To identify bugs or errors so they can be corrected
- b) To verify the system fulfills the requirements of the specification
- c) To validate the right system was built
- d) To check a box that we did it

Review of Answers



a) To identify bugs or errors so they can be corrected

Incorrect. Testing is performed to find and fix problems



b) To verify the system fulfills the requirements of the specification

Incorrect. Testing is performed in order to verify that requirements are fulfilled



c) To validate the right system was built

Incorrect. Testing can be used to verify that the system built satisfies the original user need



d) To check a box that we did it

Correct! Testing is not done to satisfy a chronological list but completed to ensure that a stable, needed system was created

Learning Objective 2

Describe How Transit Signal
Priority May be Provided in a
**Connected Vehicle
Environment**

What is a Connected Vehicle Environment?

Vehicles broadcast:

- Current position with other vehicles and the roadway
- Sensor information with other vehicles and the roadway



Vehicles receive information:

- Reduce the likelihood of incidents
- Improve mobility (e.g., reduce delays)



Could be a smartphone on a pedestrian or bicyclist



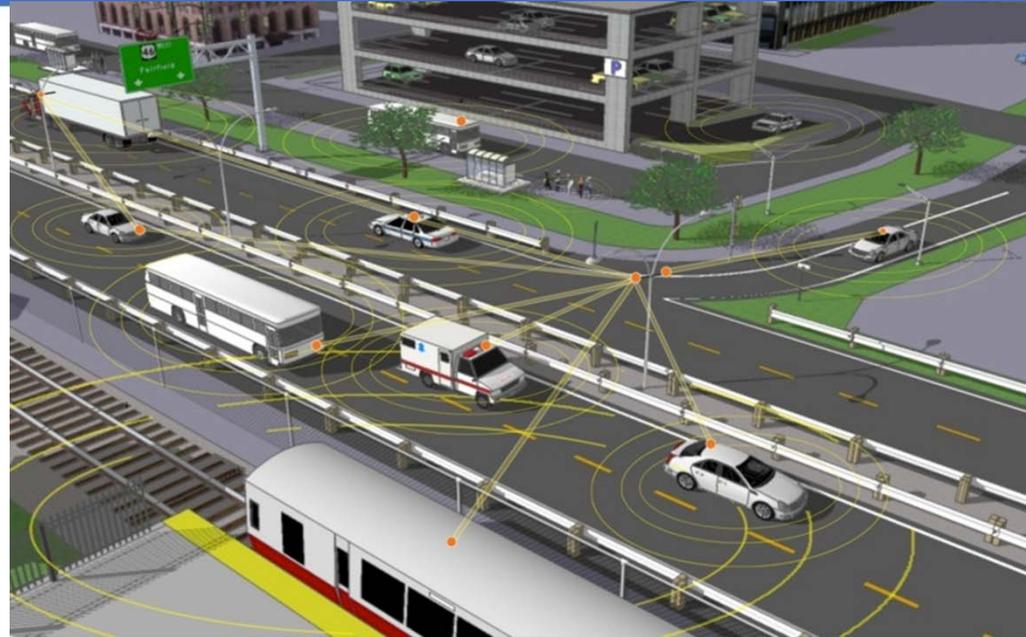
What is a Connected Vehicle Environment?

Example Vehicle Data

- Latitude and Longitude
- Speed
- Direction
- Turn Signal Status
- Vehicle Length and Width

Example of Infrastructure Data

- Signal Phase and Timing
- Speed limit on roadway
- Estimated Time of Arrival for Transit Vehicle



NHTSA ANPRM

- August 2014, National Highway Traffic Safety Administration (NHTSA) released an **Advance Notice of Proposed Rulemaking (ANPRM)** and a supporting research report
 - Federal Motor Vehicle Safety Standard (FMVSS) No. 150, to require vehicle-to-vehicle (V2V) communications capability for light vehicles and to create minimum performance requirements for V2V devices and messages
 - V2V and vehicle-to-infrastructure (V2I) systems could potentially address 81% of all vehicle crash types
- **Notice of Proposed Rulemaking (NPRM) expected in 2016**

What is a Connected Vehicle Environment?

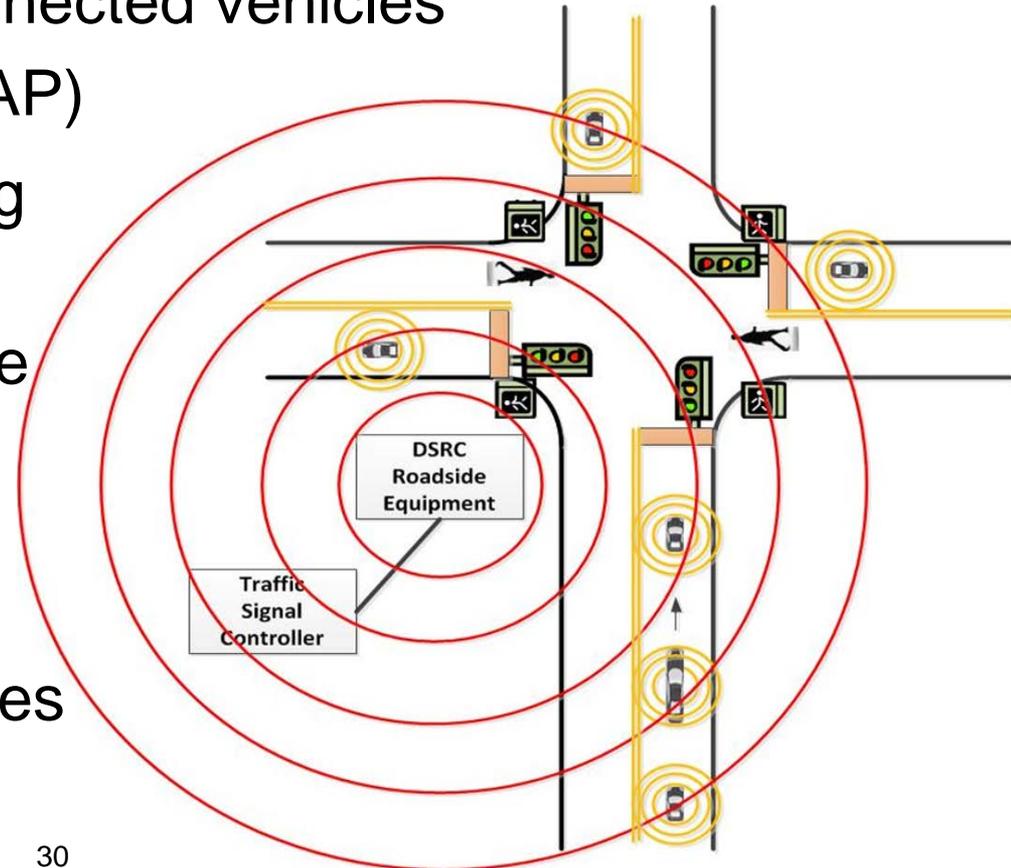
- **V2V** communications will open the gates for **V2X**:
 - **V2I** (Vehicle to Infrastructure)
 - **V2P** (Vehicle to Pedestrians)
- Opportunity to use the V2V data being broadcasted and vehicle's ability to receive wireless data to:
 - Improve **roadway safety**
 - Improve **mobility**
 - Improve the **environment**

What Information is exchanged for TSP in a CV Environment?

SAE J2735: Dedicated Short Range Communications (DSRC) Message Set Dictionary

Defines the dictionary for connected vehicles

- MAP Data Message (MAP)
- Signal Phase and Timing (SPAT)
- Signal Request Message (SRM)
- Signal Status Message (SSM)
- Also specifies data frames and data elements



What Information is exchanged for TSP in a CV Environment?

▪ **Signal Request Message (SRM)**

- Broadcast by a vehicle (**On-Board Equipment (OBE)**) to infrastructure (**Road-Side Equipment (RSE)**)
- Asks for service, including preemption/priority treatment from one or more signal controllers



What Information is Exchanged For TSP in a CV Environment?

SRM: Mandatory Elements

- Requestor identifier (e.g., vehicle id)
- Request identifier (id of the request)
- Request type (new, update, cancel)
- Lane, approach or connection identifier

SRM: Optional Elements

- Estimated time of arrival
- Estimated duration
- Requestor information (role, vehicle type, priority level)
- Occupancy, schedule adherence information

What Information is exchanged for TSP in a CV Environment?

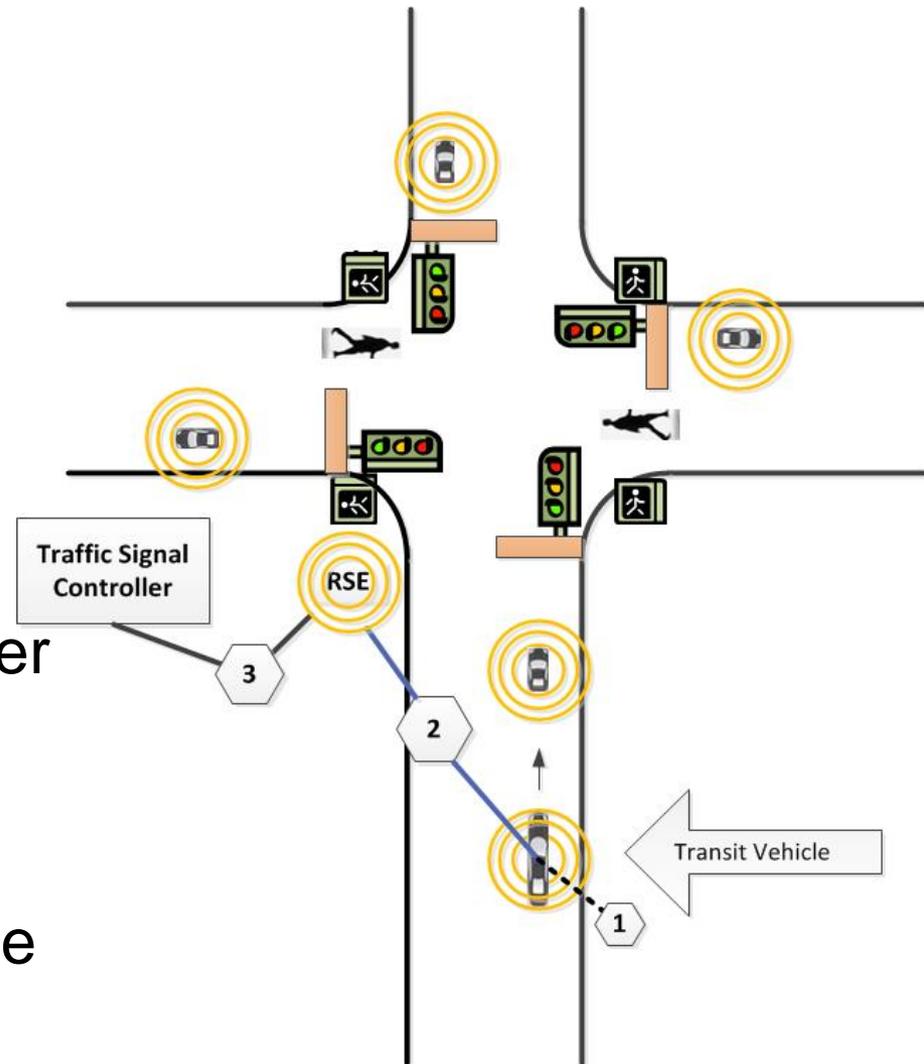
Signal Status Message (SSM)

- Broadcast by infrastructure to the vehicles/OBEs
- Response to all the signal priority requests received
- Contains:
 - **Identifier of the intersection**
 - **Status of service request(s)** for a specific lane or approach

What Information is exchanged for TSP in a CV Environment?

Example:

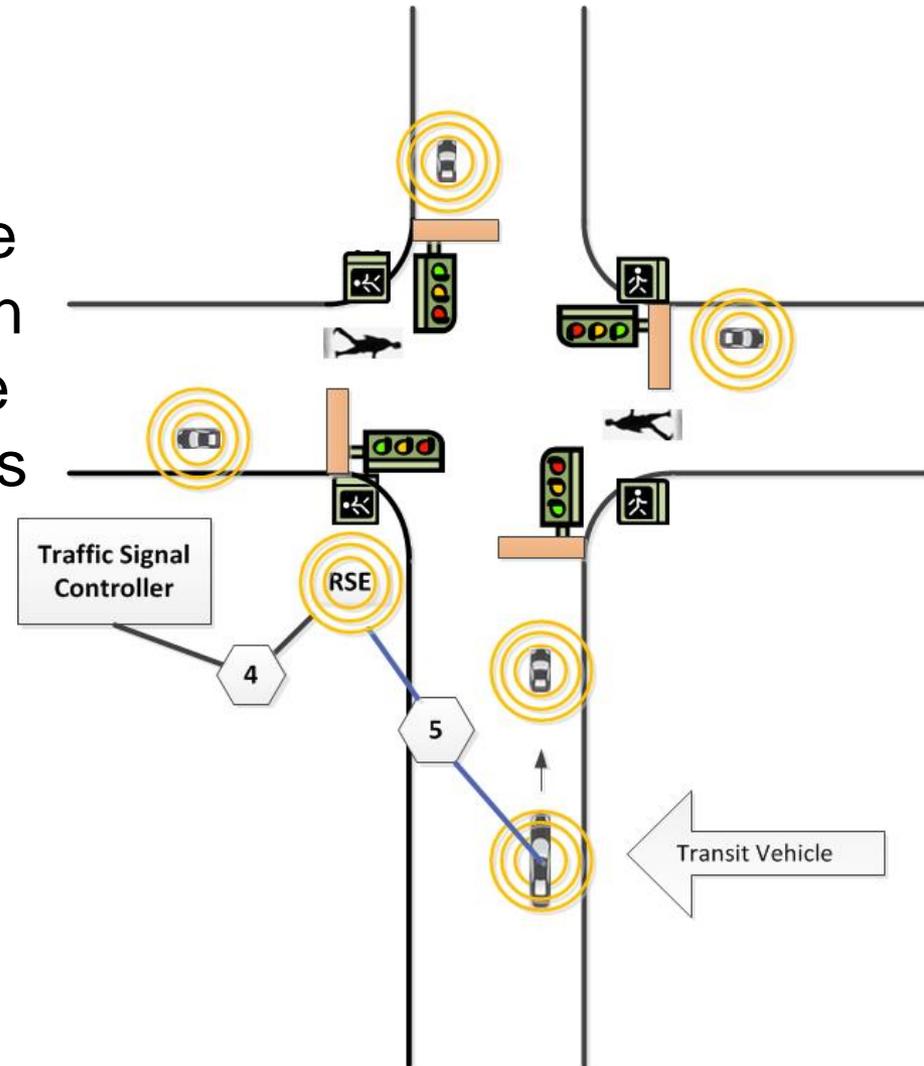
1. A transit vehicle approaching a signalized intersection enters the DSRC range
2. The transit vehicle wirelessly broadcasts a SRM, with its ETA and the identifier of the lane to enter and egress out of the intersection
3. The signal controller receives and processes the SRM request



What Information is exchanged for TSP in a CV Environment?

Example:

4. The signal controller provides the RSE with the SSM data so the RSE can broadcast a SSM with the status of all SRM requests received
5. The RSE broadcasts the SSM. The transit vehicle receives the SSM and travels through the signalized intersection when service is provided



ACTIVITY



Question

Which ITS standard defines the messages and data elements for a connected vehicle environment?

Answer Choices

- a) NTCIP 1211 v02
- b) SAE J2735
- c) TCIP
- d) NTCIP 1103

Review of Answers



a) NTCIP 1211 v02

Incorrect. NTCIP 1211 v02 supports TSP, but not necessarily for a connected vehicle environment



b) SAE J2735

Correct! SAE J2735 was developed specifically to support a CV environment



c) TCIP

Incorrect. TCIP supports transit business, but not necessarily for a CV environment



d) NTCIP 1103

Incorrect. NTCIP 1103 defines the protocols for managing transportation field devices

Learning Objective 3

**Explain the Role of Transit
Signal Priority in Integrated
Corridors**

Impact of TSP on Integrated Corridor Performance Measures



What is Integrated Corridor Management (ICM)?

- **Optimizes existing transportation infrastructure** along a corridor, making transportation investments go further
- Enables travelers to make **informed travel decisions** and dynamically shift modes during a trip
- **Reduces travel time**, delays, fuel consumption, emissions and incidents
- **Increases travel time reliability** and **predictability**

Impact of TSP on Integrated Corridor Performance Measures

How can TSP contribute to an ICM?

- **Increases** transit travel time **reliability** and **predictability**
- Can **decrease transit travel time**, reducing overall delay and making transit more attractive
- **Increase capacity** of the transit route
- **Enforce changes** to transit schedules

Impact of TSP on Integrated Corridor Performance Measures

Examples where TSP contributed to an ICM

- Dallas US 75 ICM
- Minneapolis, MN



ACTIVITY



Question

Which of the following is not a benefit of using TSP in ICM?

Answer Choices

- a) Decrease travel times
- b) Improve travel time reliability
- c) Improve the quality of transit data collected
- d) Improve throughput and use of transit capacity

Review of Answers



a) Decrease travel times

Incorrect. TSP can decrease travel time



b) Improve travel time reliability

Incorrect. Travel Time reliability could actually be the most significant benefit of TSP



c) Improve the quality of transit data collected

Correct! The quality of transit data is unrelated to TSP



d) Improve throughput and use of transit capacity

Incorrect. TSP can improve throughput as transit is given priority through the arterial network and can contribute to higher usage of the transit system

Learning Objective 4

Review Case Studies Where
Standards Were Used to
Provide Transit Signal
Priority

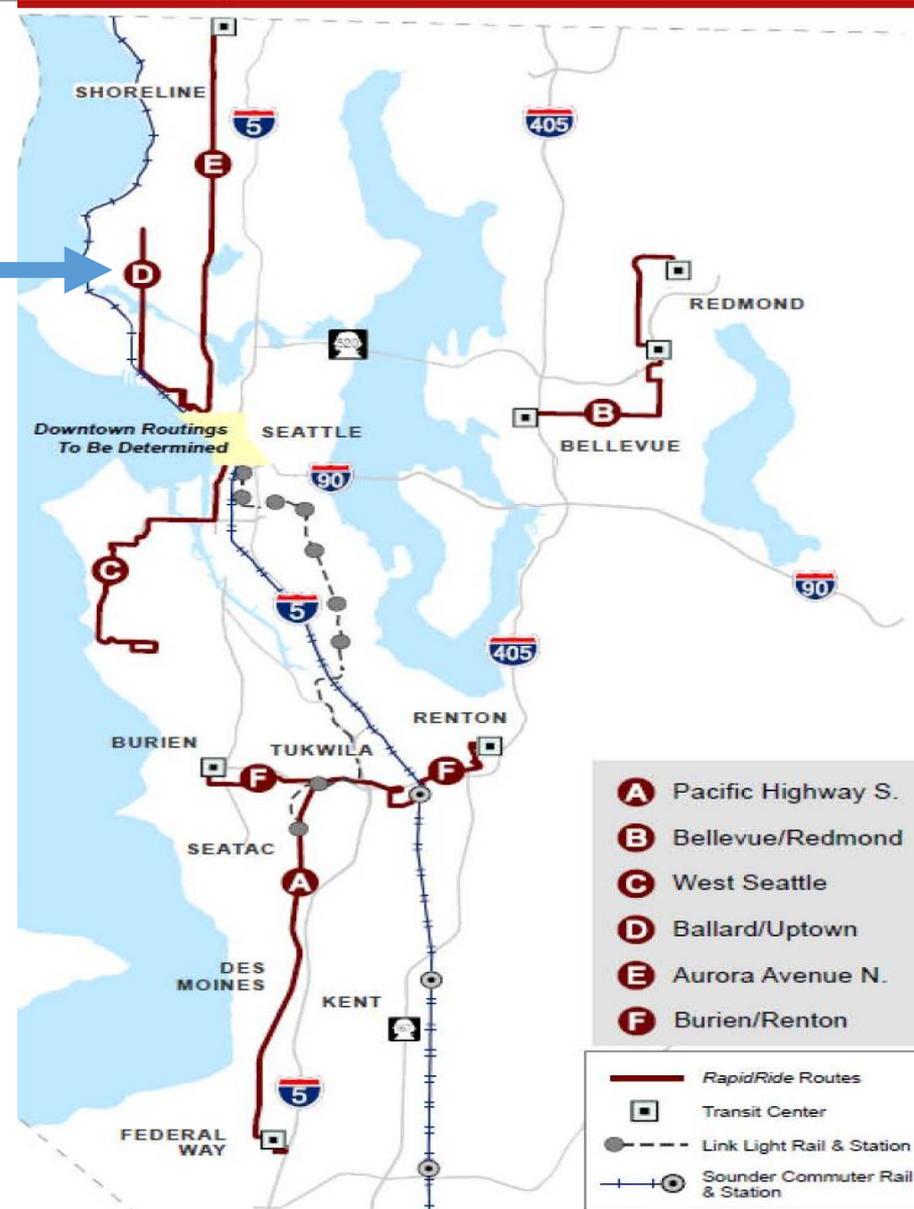
CASE STUDY



Case Study Example – King County Metro (Seattle)

Introduction

- 6 Bus Rapid Transit corridors
- 2 non-BRT corridors (additional planned)
- Approximately 200 TSP installations
- 13 local partner jurisdictions



Case Study Example – King County Metro (Seattle)

System Architecture

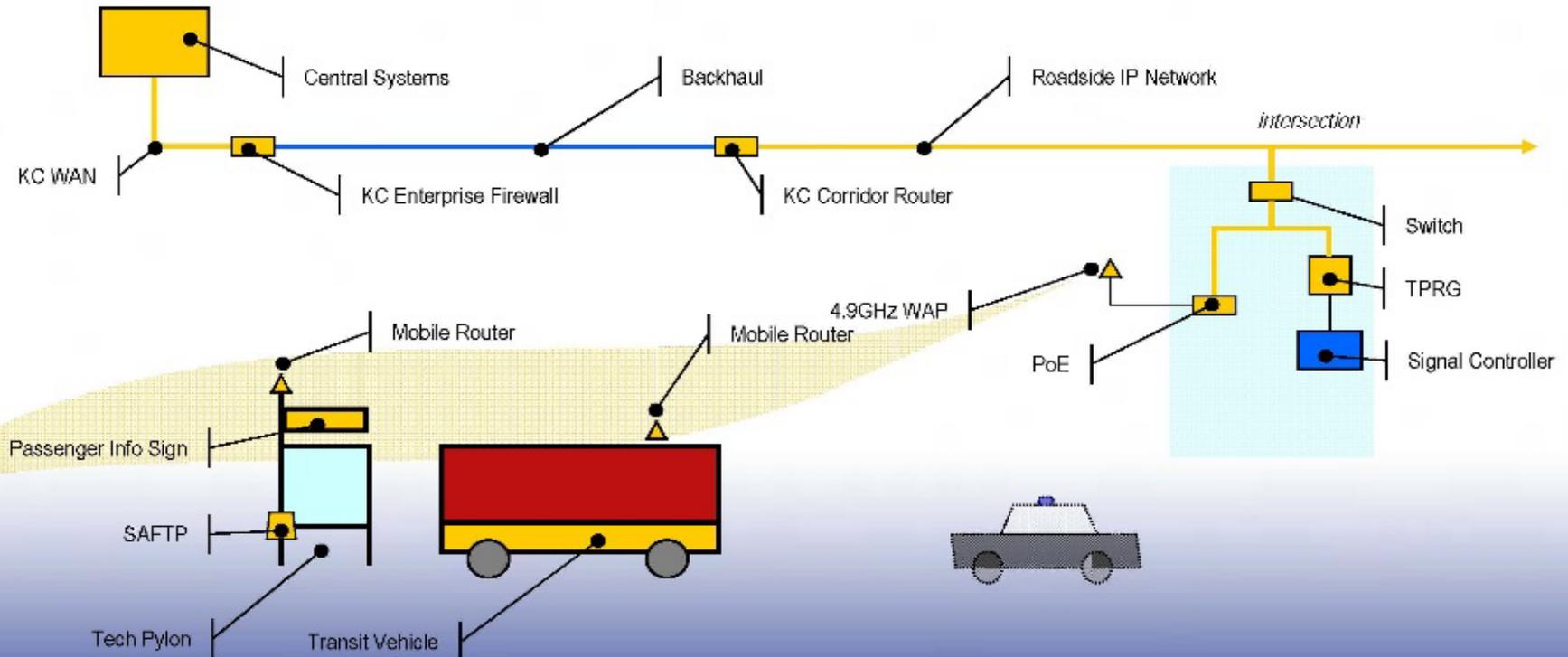
- Can operate **any of the 5 TSP scenarios in TCIP**
- The bus initiates the request based on its location and the location of priority intersection approaches.
 - Can be **easily changed, based on route or time-of-day**
 - **Accommodates** complex strategies such as check-in/check-out and near-side stops
- Transit vehicles communicate directly to the Transit Priority Request Generator (TPRG)

Case Study Example – King County Metro (Seattle)

System Architecture

KC Metro Transit ITS Architecture Connected Vehicle Network

RapidRide ITS Architecture



Case Study Example – King County Metro (Seattle)

ITS Standards

- Supports the **full TCIP dataset**
- Request message: 25 defined fields + 10 user fields. **All transmitted, logged, and stored**
- **Logs phase, PRG action, and priority type**



Case Study Example – King County Metro (Seattle)

Lessons Learned

- **Systems engineering process helpful**, especially specifications and testing
- **TSP algorithms vary** between vendors
- Took advantage of standards
 - Use of **IP/Ethernet standards** made design, implementation, and O&M more **cost-effective**
- High bandwidth communications **do not limit size or frequency of data**

Case Study Example – New York City

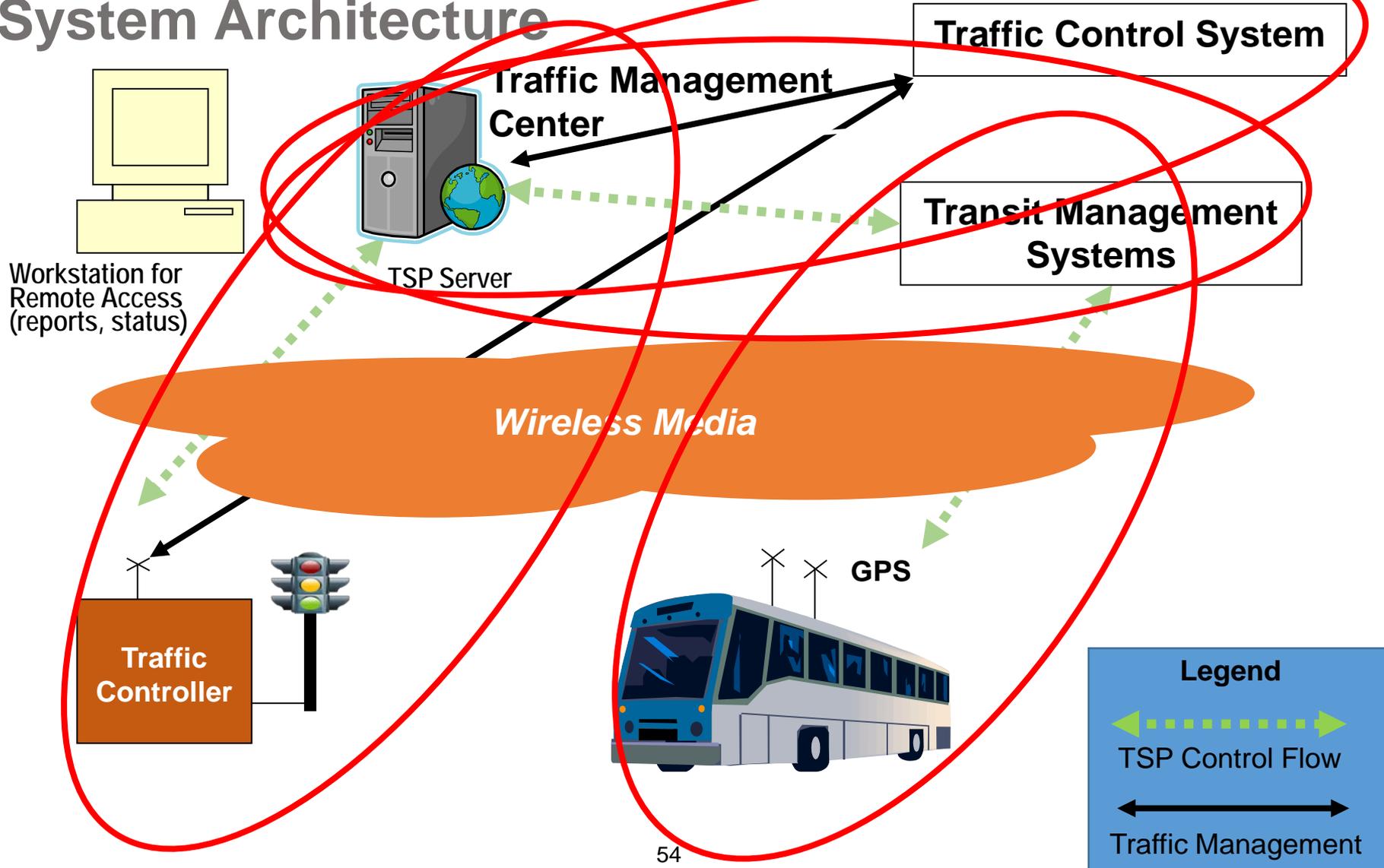
Introduction

- **12,400** signalized intersections, **nearly all under computer control**
- MTA has a fleet of approximately 6,000 buses, approximately **5,000 buses on the street at a time**, all with GPS and wireless communications with the transit management center
- Previous trials showed **decreases of 15-23% in travel time**



Case Study Example – New York City

System Architecture



Case Study Example – New York City

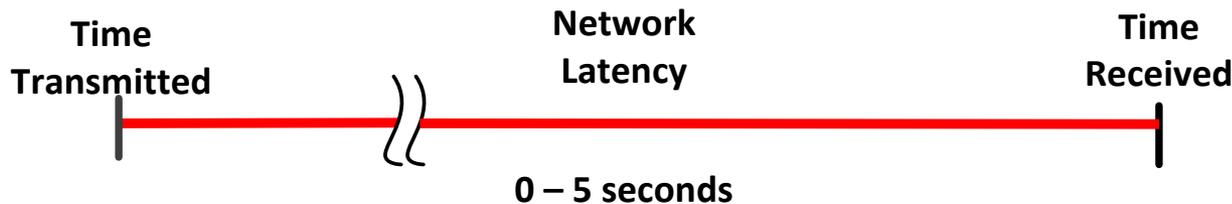
ITS Standards

- **Already using NTCIP** for communications between the TMC and signal controllers.
- Adopted NTCIP 1211 **with extensions**
 - **NOT** Conformant to NTCIP 1211
 - Priority request: Objects to support **latency** (absolute time), **vehicle speed, vehicle location, intersection identifier, route identifier**
 - Priority status: **intersection identifier, priority response status**

Case Study Example – New York City

Lessons Learned

- Took advantage of **existing communications infrastructure**
- Implementation issues with NTCIP 1211 v01
 - **Communications network latency** has an impact
 - Function of the communications network
 - High latency can impact operations
 - Was addressed in NTCIP 1211 v02



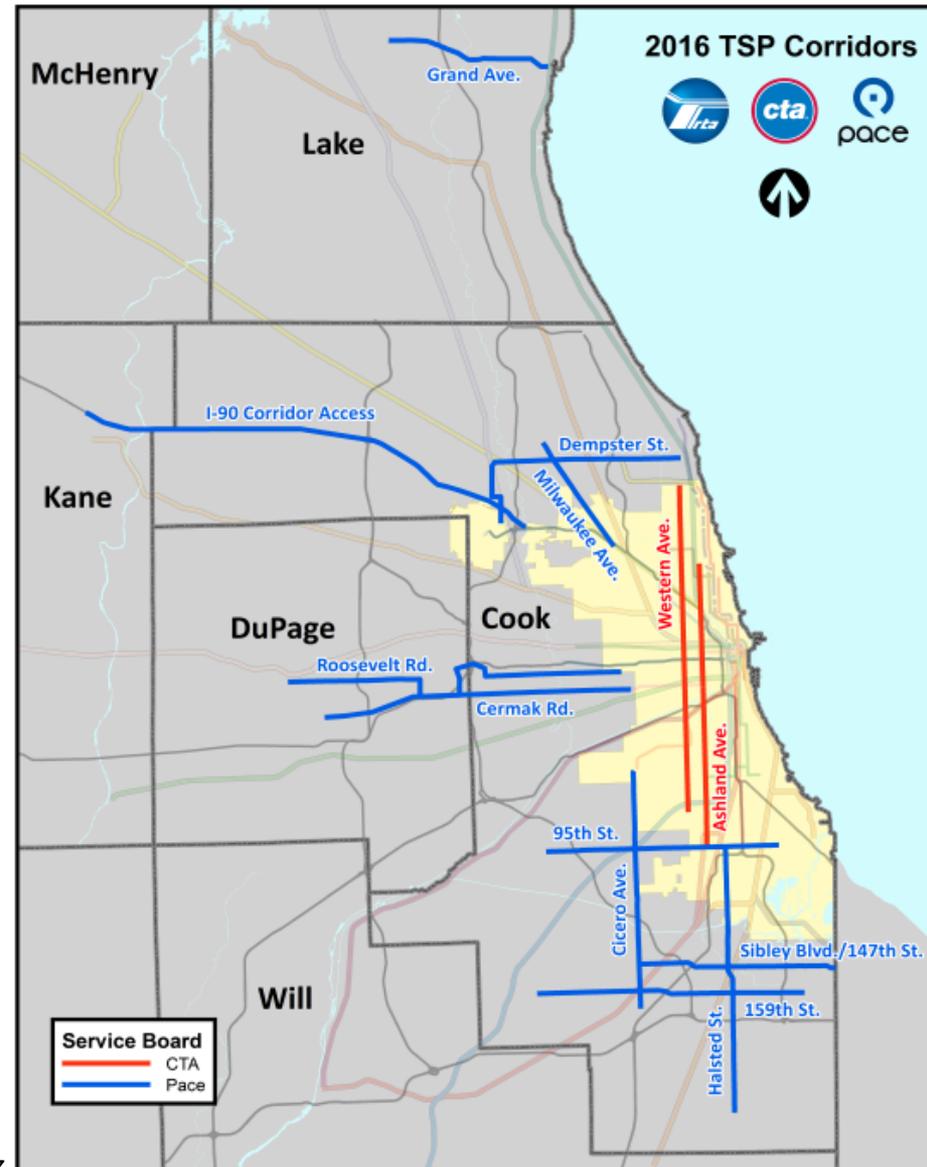
- **Clock source**
 - Can be an issue if the time for a component has a different source (e.g., GPS, Coordinated Universal Time, electrical power grid)

Case Study Example – Chicago

Introduction

Regional Transit Signal Priority Implementation Program (RTSPIP)

- Goal: Develop and implement a **regional TSP** system for Metropolitan Chicago
- \$40 million, with **100 miles of roadway, 400 intersections, 13 arterial corridors and 4 counties**



Case Study Example – Chicago

Introduction

Previous demonstrations yielded benefits

- **Improved schedule adherence**
- **Reduced travel time – up 15% reduction**
- However, difficult to evaluate performance

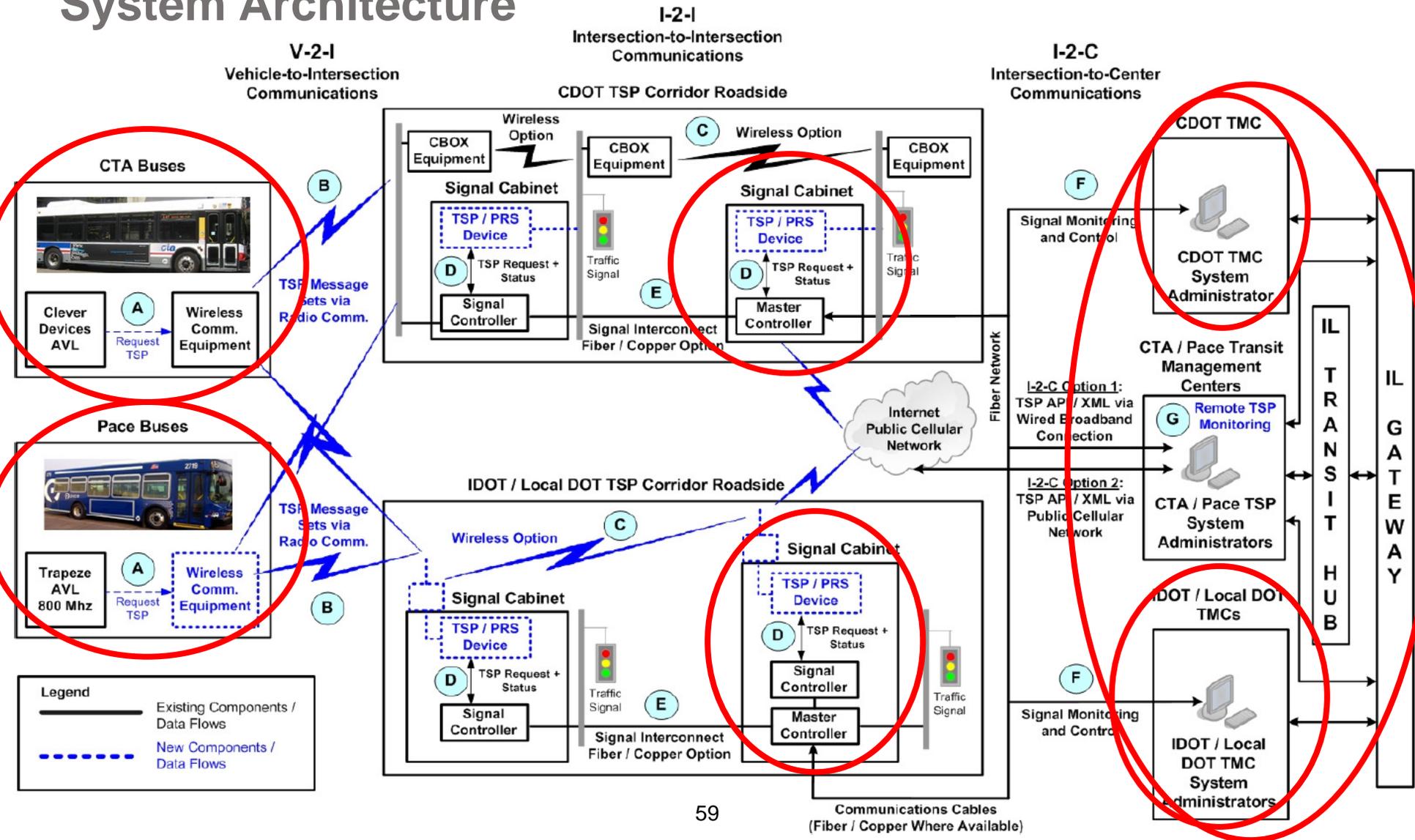


Developed Regional Open Standards

- Not tied to a single TSP vendor
- Simplify Operations and Maintenance (O&M)
- Centralized monitoring of TSP activity

Case Study Example – Chicago

System Architecture



Case Study Example – Chicago

ITS Standards

- Determined stakeholder needs
- Developed **regional message set**
- Based on NTCIP 1211 v01.38 and leveraged SAE J2735_200912
- Updated dialog definitions
- **Developed test tools to verify correct usage of data objects**
- **Proprietary node** for object extensions

Case Study Example – Chicago

ITS Standards

Object Extensions

- priorityRequestVehicleID_chi
- priorityRequestTSPPhaseRequired_chi
- priorityRequestVehicleLatitude_chi
- priorityRequestVehicleLongitude_chi
- priorityRequestAgencyID_chi
- priorityRequestScheduleLateness_chi
- priorityRequestRouteID_chi
- priorityRequestRunNumber_chi
- priorityRequestVehicleOccupancy_chi

Case Study Example – Chicago

Lessons Learned

- Developed a **flexible** system architecture
- Lots of agencies / but cooperation has been great
- Field data is cumbersome but AVL data is promising
- Many traffic signal controllers are dated but testing new Advanced Traffic Controllers
- Intersection-to-Center communication is limited but TSP could help fill some communication gaps

Case Study Example – MMITSS

Introduction

Multi-Modal Intelligent Traffic Signal Systems

Goals

- Develop a comprehensive **traffic signal system** that **services multiple modes of transportation** in a **connected vehicle environment**

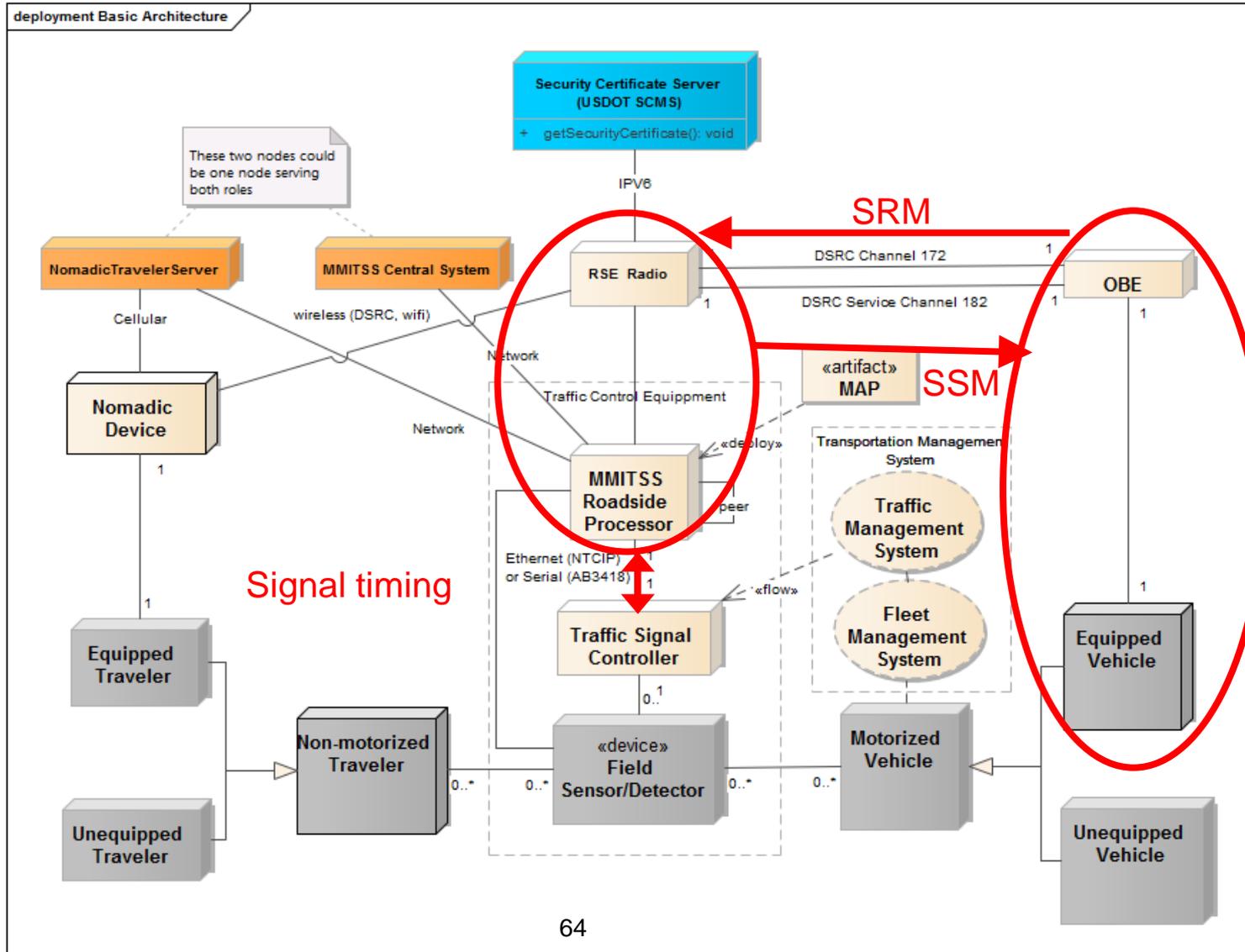
Two locations

- Arizona Connected Vehicle Test Bed
- California Test Network



Case Study Example – MMITSS

System Architecture



Case Study Example – MMITSS

ITS Standards

- Adopted **SAE J2735_200911**
 - SRM and SSM
 - MAP and SPAT
 - Modified SSM to acknowledge receipt of an SRM
- Used **NTCIP 1202** to exchange information between the RSE and the signal controller (with extensions)

Case Study Example – MMITSS

Lessons Learned

Independent analysis found that MMITSS applications effectively:

- Improved **vehicle travel time** and **travel time reliability**
- **Reduced delay** for equipped vehicles (including transit) on the test facility
 - Reduced delay for equipped transit vehicles **by 8.2%**
- Opinion of the evaluators: *MMITSS appears to be effective in allowing system managers to allocate and prioritize system capability/mobility but may not always reduce delay or aggregate system performance*

ACTIVITY



Question

How can ITS standards be used in TSP implementations?

Answer Choices

- a) Extensions to an ITS standard can be used to satisfy a need not supported by the ITS standards
- b) NTCIP 1211 v02, TCIP and SAE J2735 must be used in TSP implementations to conform to TSP standards
- c) All messages and objects defined in the standard must be used to conform
- d) An implementation is allowed to support only one of the system architectures defined in the standard

Review of Answers



- a) Extensions to an ITS standard can be used to satisfy a need not supported by the ITS standards

Correct! The ITS standards allow an implementation to define an extension if the user need is not supported by the standard



- b) NTCIP 1211 v02, TCIP and SAE J2735 must be used in TSP implementations to conform to TSP standards

Incorrect. All 3 standards do not need to be used to conform



- c) All messages and objects defined in the standard must be used to conform

Incorrect. The standards do not require that all messages and data elements be supported



- d) An implementation is allowed to support only one of the system architectures defined in the standard

Incorrect. An implementation may support more than one system architecture defined in a standard, or use a system architecture not defined in the standard

Module Summary

What We Have Learned

1. How to identify requirements that are to be tested and how to test a standards-based TSP implementation.
2. Define what a connected vehicle environment is and what information is exchanged in regards to TSP.
3. Understand and explain the impact of TSP on integrated corridor performance measures.
4. Take away knowledge from each of the case studies reviewed on how to correctly use standards to execute TSP.

Thank you for completing this module.

Feedback

Please use the Feedback link below to provide us with your thoughts and comments about the value of the training.

Thank you!