

CONNECTING INTERSECTIONS AND VEHICLES

Contents

- Current State
 - Deployment
 - Messages used in communication
 - Standards and Guidelines
- Testing Interoperability
 - Connected Vehicle Pooled Fund Study
- Further Evaluation
 - Framework for automated continuous evaluation
- Other System Applications
 - Weather Management Systems

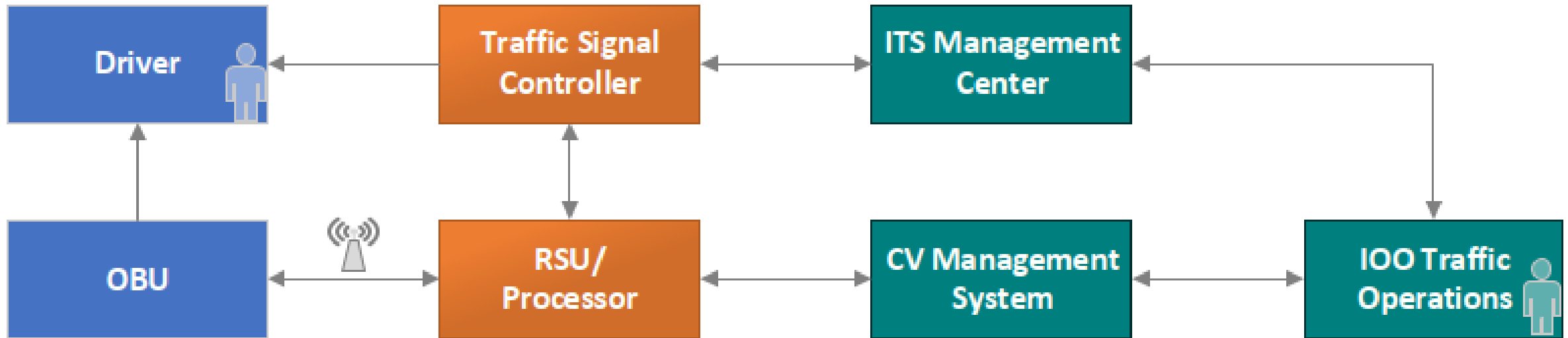


Current System

Vehicle

Roadside

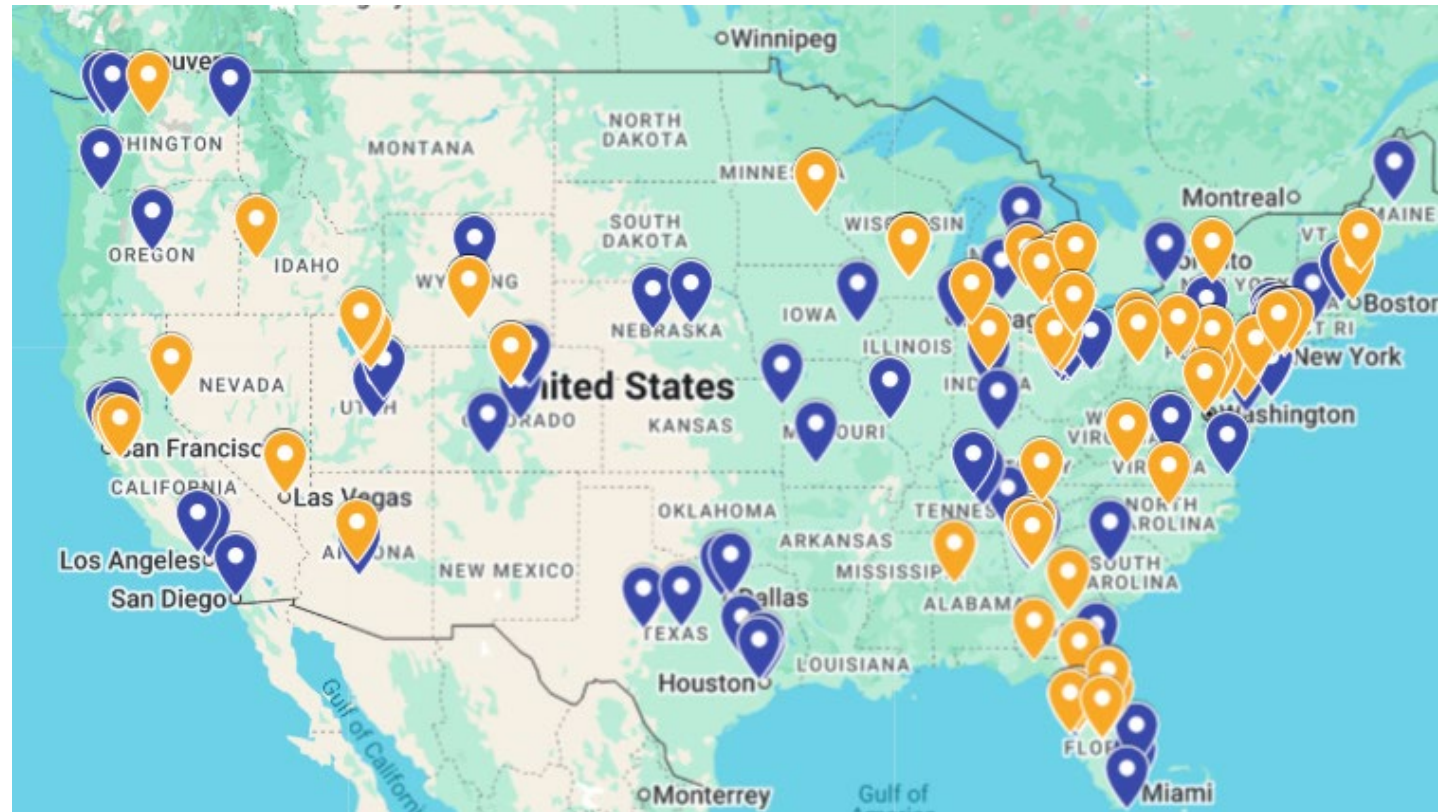
Center



Current Status

- CV Deployment efforts
 - 101 Planned Sites
 - 70 Operational sites

- MAP, SPaT & BSM messages
 - Red Light Violation Warning
 - SAE J2735
 - CTI 4501



Testing – Connected Vehicles Pooled Fund Study

- Partnership of transportation agencies (est. 2009)
- Part of the FHWA Transportation Pooled Fund program
- Led by VDOT supported by UVA
- Focuses on Research for deployment

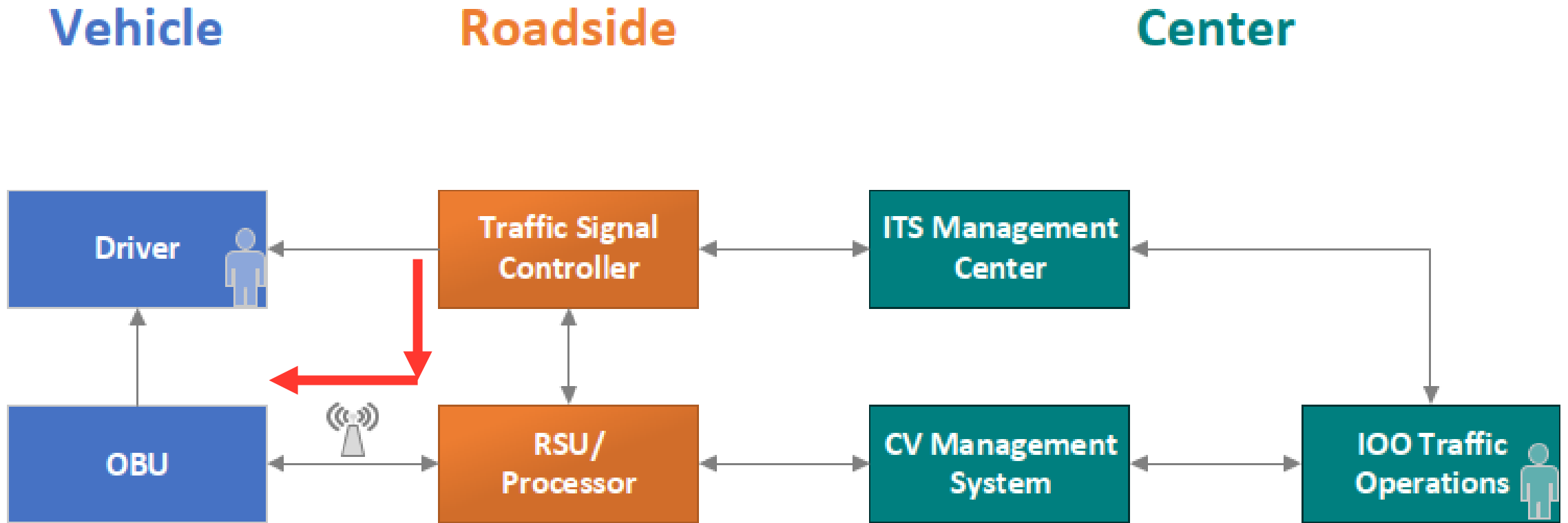
Testing – Connected Vehicles Pooled Fund Study

Objective

- Collect and analyze CV data from three sites:
 - Marysville, OH 6 intersections
 - West Point, GA 3 intersections
 - Park City, UT 6 intersections
- Determine where deployments stand in meeting CTI 4501 guidelines:
 - optional data elements in J2735
 - how each element is expected to be populated and the accuracy
 - progression of data element values from message to message.
 - high level of certainty when the signal will change



Testing – Connected Vehicles Pooled Fund Study

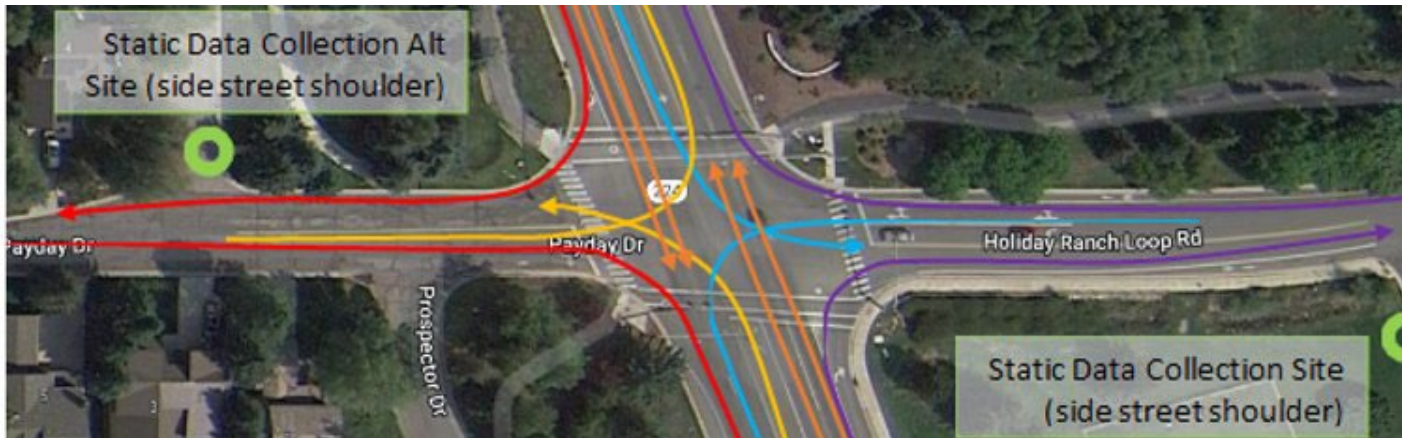


Testing – Connected Vehicles Pooled Fund Study

Video



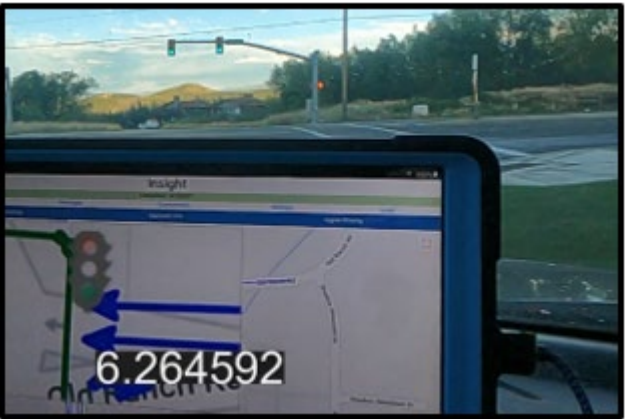
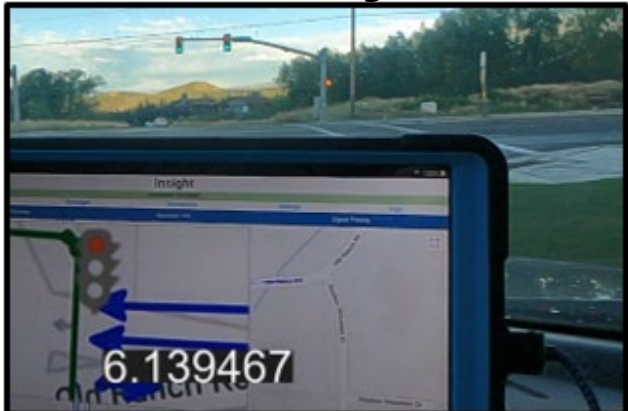
Stationary and Driving CV Data Capture



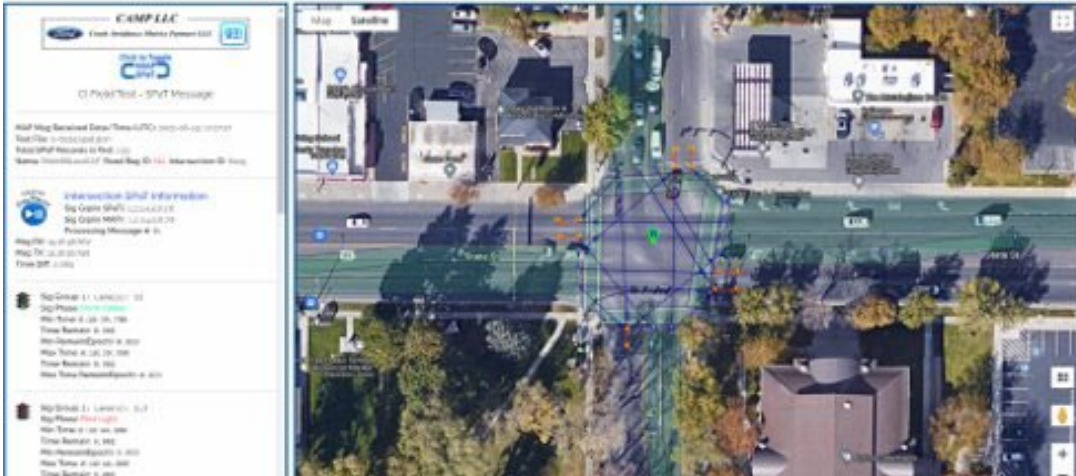
Survey

Testing – Connected Vehicles Pooled Fund Study

Analysis



6.264 - 6.139 → 125ms (30 frames)



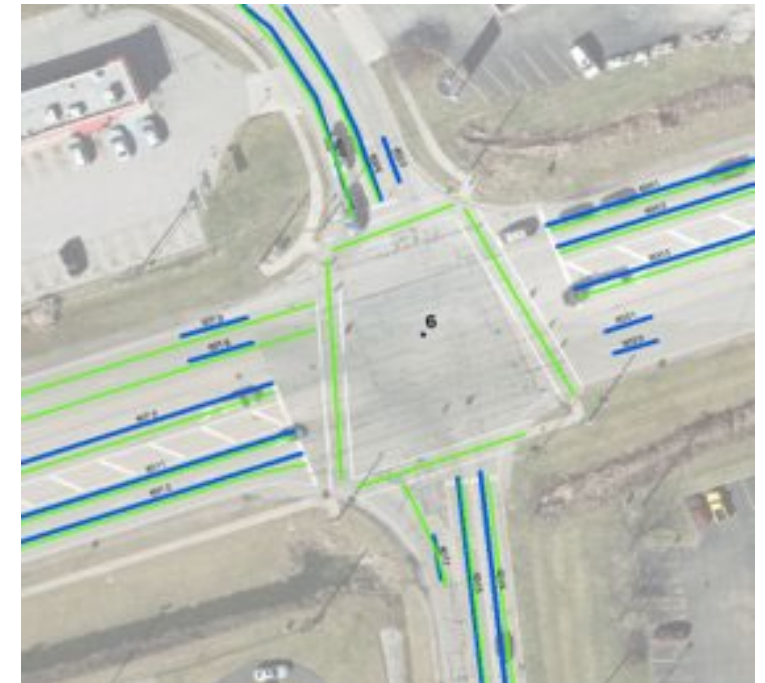
CAMP Tool

Wireshark



Testing – Connected Vehicles Pooled Fund Study

Spatial Analysis Tools



Testing – Connected Vehicles Pooled Fund Study

- 36 Requirements met at all intersections at all sites
- 26 All intersections at all sites were partial pass or did not pass
- 36 could not be tested
- 30 Mixed results between sites
 - 20 Requirements where some sites met all, and others met none
 - 10 Requirements with mixed results

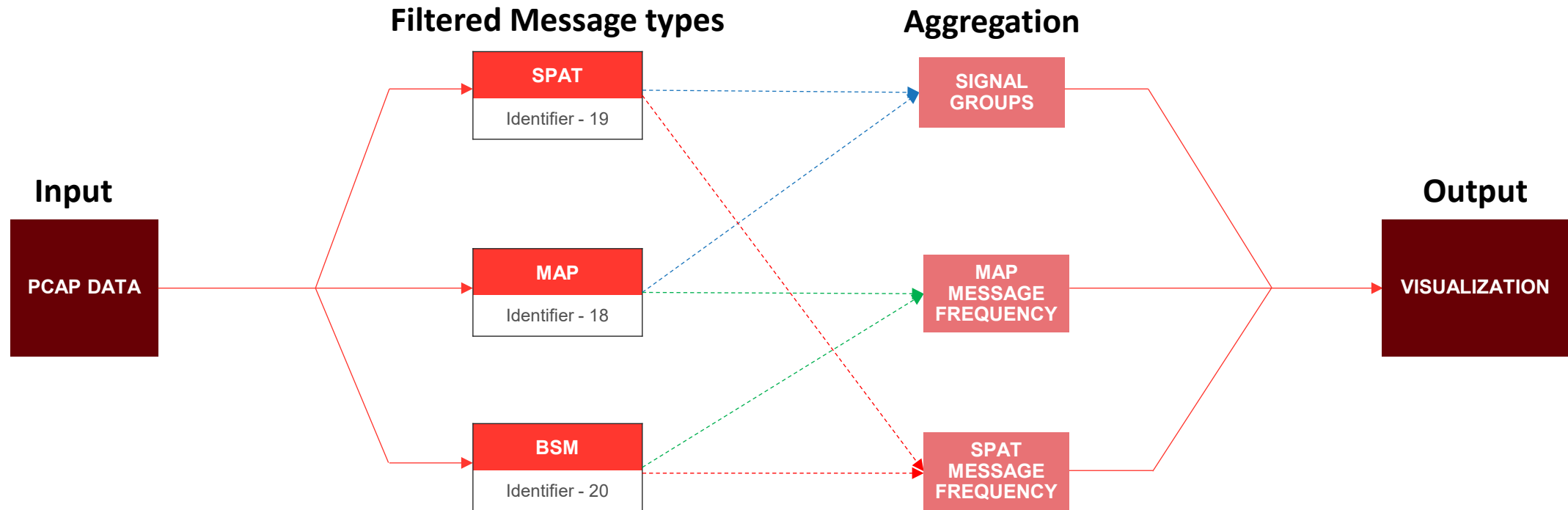
CTI 4501 Req ID	Requirement Title	All Intersections Summary (15)			
		✓	○	✖	?
3.3.3.4.1.1	Intersection Geometry Information	15	0	0	0
3.3.3.4.1.2	Intersection Geometry - Road Regulator Identifier	0	6	9	0
3.3.3.4.1.3	Intersection Geometry - Intersection Identifier	15	0	0	0
3.3.3.4.1.4.1	Intersection Reference Point - Position	15	0	0	0
3.3.3.4.1.4.2	Intersection Reference Point - Description	3	12	0	0
3.3.3.4.1.4.3	Intersection Reference Point Accuracy	15	0	0	0
3.3.3.4.1.5	Default Lane Width	15	0	0	0
3.3.3.4.1.6	Lane Identifier	15	0	0	0
3.3.3.4.1.7	Center of Vehicle Lane Geometry	13	2	0	0
3.3.3.4.1.8	Center of Crosswalk Lane Geometry	8	0	6	1
3.3.3.4.1.9	Center of Pedestrian Landings Geometry	0	0	14	1
3.3.3.4.1.10	Lane Description	15	0	0	0
3.3.3.4.1.11	First Node Point - Ingress Vehicle Lane	15	0	0	0
3.3.3.4.1.12	First Node Point - Egress Vehicle Lane	8	7	0	0
3.3.3.4.1.13	Node Offset from Intersection Reference Point	8	0	7	0
3.3.3.4.1.14	Node Elevation Offset from Intersection Reference Point	0	2	0	13
3.3.3.4.1.15	Offset from Previous Node	8	1	6	0
3.3.3.4.1.16	Elevation Offset from Previous Node	0	2	0	13

Areas of Improvement - *Operation*

- SPaT specification of protected vs. permissive movements
- MAP geometry accuracy, elevation, speed limit
- MAP crosswalks/landings
 - Geometry/Connections (MAP), signal groups (SPaT)
- MAP/SPaT use of the road regulator ID



Areas of Improvement - Process Automation



Areas of Improvement - Process Automation

	X1	X2	X3	X4	X5
1	1660753519586	S	20	{"messageId":20,"value":{"coreData":{"msgCnt":93,"id":"8cc8...	0
2	1660753519588	R	19	{"messageId":19,"value":{"timeStamp":329305,"intersections"...	0
3	1660753519595	R	19	{"messageId":19,"value":{"timeStamp":329305,"intersections"...	0
4	1660753519648	R	19	{"messageId":19,"value":{"timeStamp":329305,"intersections"...	0
5	1660753519672	S	20	{"messageId":20,"value":{"coreData":{"msgCnt":94,"id":"8cc8...	0
6	1660753519715	R	19	{"messageId":19,"value":{"timeStamp":329305,"intersections"...	0
7	1660753519771	S	20	{"messageId":20,"value":{"coreData":{"msgCnt":95,"id":"8cc8...	0
8	1660753519779	R	19	{"messageId":19,"value":{"timeStamp":329305,"intersections"...	0

PCAP

	TimeStamp	Send_Rec	Msg_type
1	1660753519588	R	19
2	1660753519595	R	19
3	1660753519648	R	19
4	1660753519715	R	19
5	1660753519779	R	19
6	1660753519840	R	19
7	1660753519913	R	19

SPAT

	TimeStamp	Send_Rec	Msg_type
1	1660753520425	R	18
2	1660753522317	R	18
3	1660753523354	R	18
4	1660753524353	R	18
5	1660753525398	R	18
6	1660753526367	R	18
7	1660753527389	R	18

MAP

	TimeStamp	Send_Rec	Msg_type	lat	long
1	1660753519586	S	20	900000001	1800000001
2	1660753519672	S	20	406925800	-1115446783
3	1660753519771	S	20	406925800	-1115446783
4	1660753519871	S	20	406925800	-1115446783
5	1660753519971	S	20	406925800	-1115446783
6	1660753520071	S	20	406925800	-1115446783
7	1660753520171	S	20	406925800	-1115446783

BSM

Areas of Improvement - Process Automation

Aggregation

▲	TimeStamp	lat	lon	nSpat	nMap
1	1.66084e+12	40.37354	-111.7829	5	1
2	1.66084e+12	40.37354	-111.7829	5	0
3	1.66084e+12	40.37354	-111.7829	7	1
4	1.66084e+12	40.37354	-111.7829	6	0
5	1.66084e+12	40.37354	-111.7829	7	1
6	1.66084e+12	40.37354	-111.7829	7	0
7	1.66084e+12	40.37354	-111.7829	9	1
8	1.66084e+12	40.37354	-111.7829	8	0

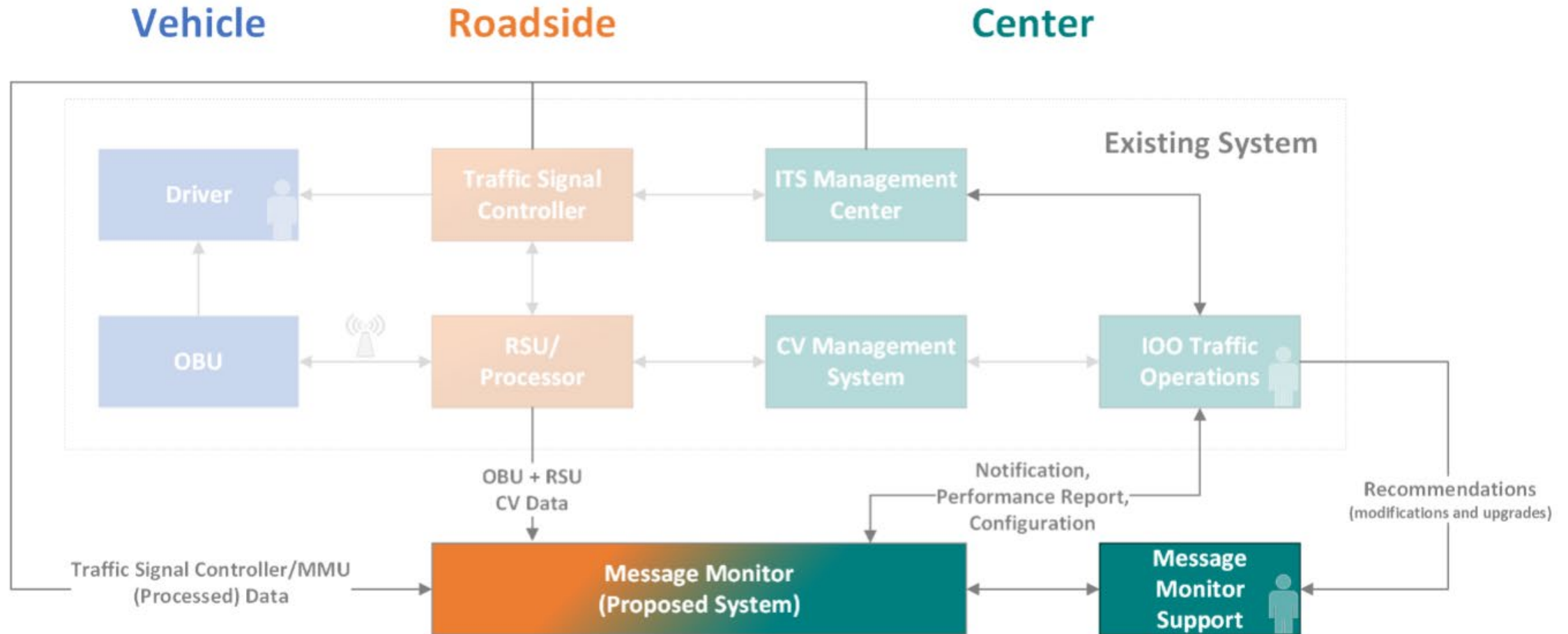
Visualization



Next Steps

- Site Updates
 - Prioritize Developments and research needs
 - Make Improvements
 - Re-Test
- CI Message Monitor
 - Framework for automated continuous evaluation – Connected Intersection Message monitoring system

Automated Continuous Evaluation



Primary Components

1) Monitor –

- Primary processing of SPaT, MAP, and BSMs
- Interfaces with the conflict monitor or traffic signal controller - a source of ground truth traffic signal data.
- Generates events related to signal states that are stored by the system

2) Interfaces

- RSU/Processor ↔ Message Monitor
- Traffic Signal Controller/ITS Management Center → Message Monitor
- Message Monitor → IOO Traffic Operations

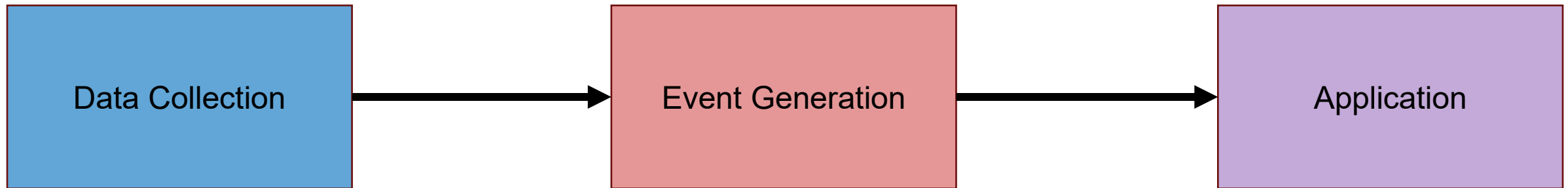
3) V2X Messages

- Signal Phase and Timing (SPaT) – Signal State
- MapData (MAP) – Intersection geometry
- Basic Safety Message (BSM) – Safety data
- Radio Technical Commission for Maritime Services (RTCM) Corrections Messages – Correction for vehicle position
- Signal Request Message (SRM) – signal preemption or signal priority requests
- Signal Status Message (SSM) – Response to the SRM

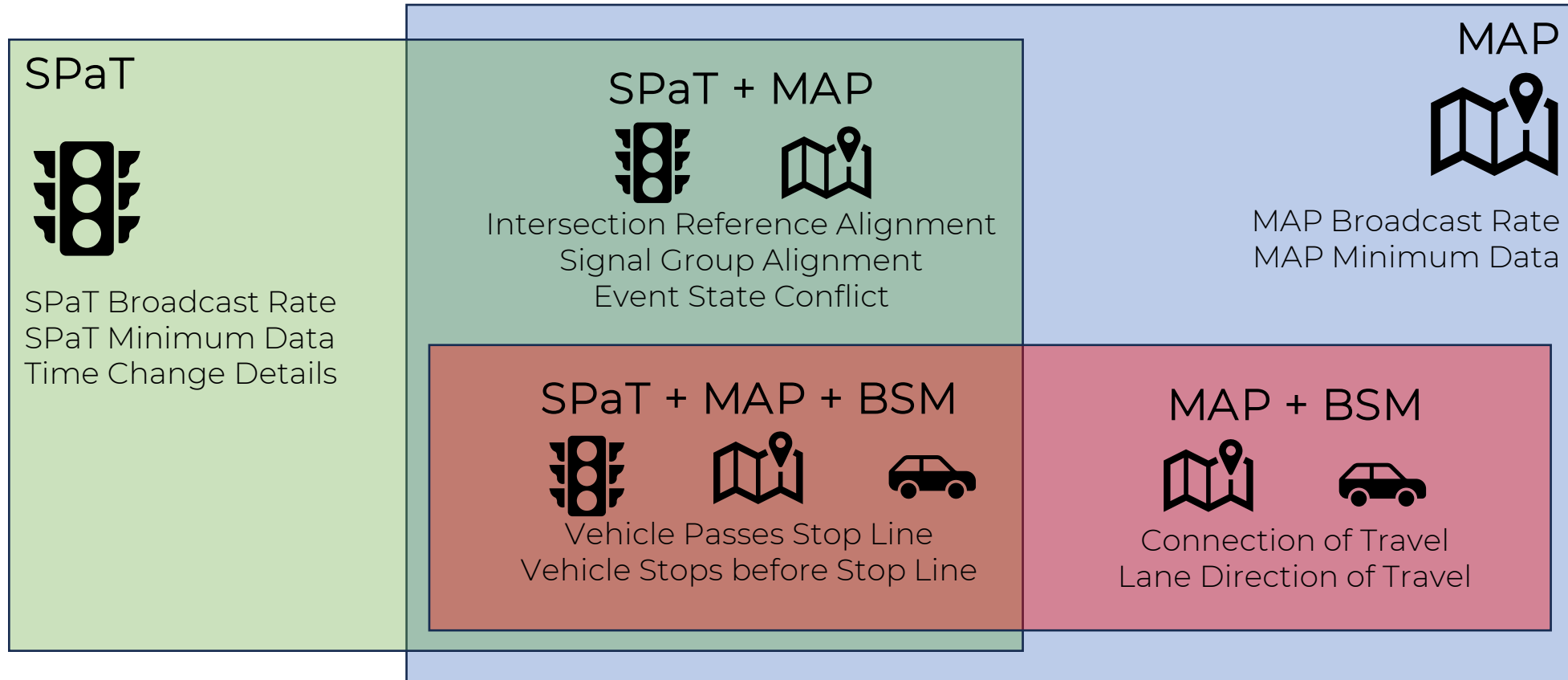
4) Security

- Protection against malicious attacks of networked devices

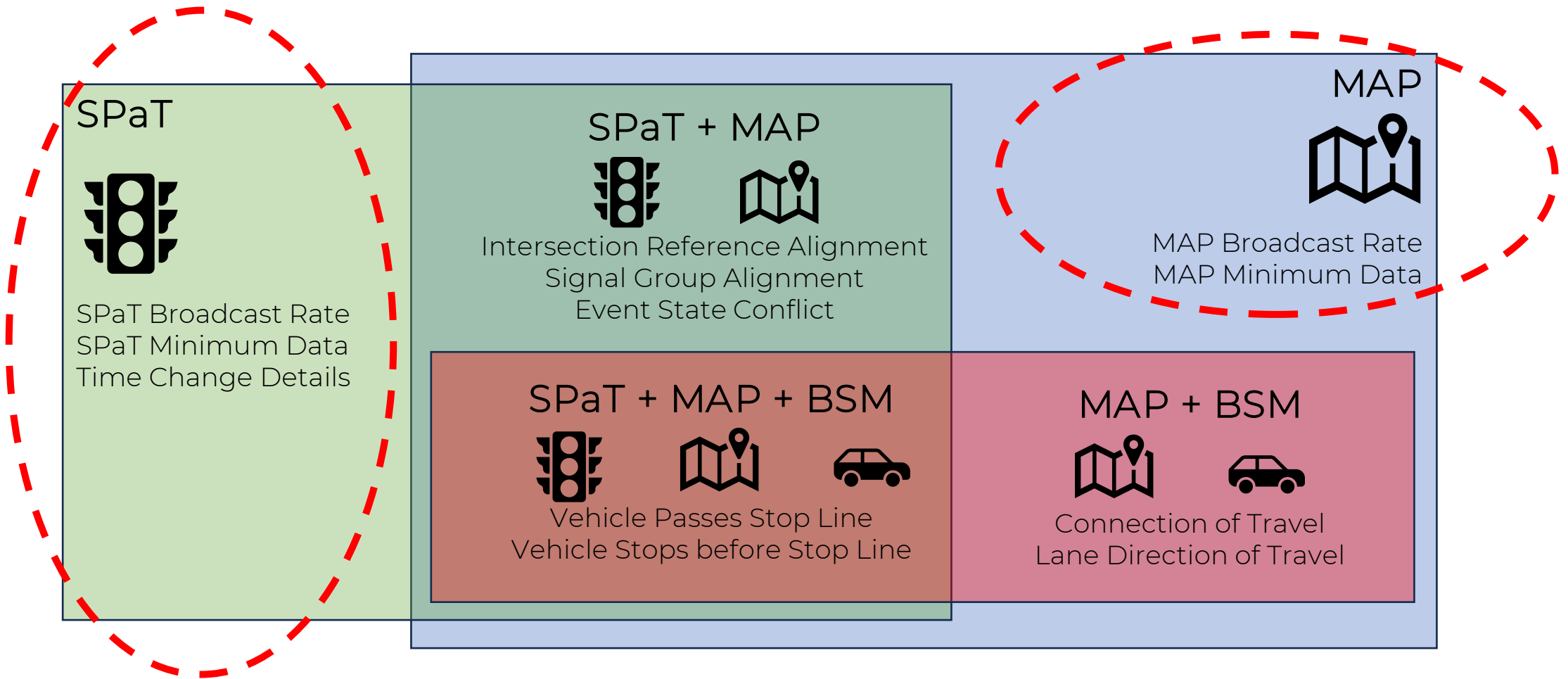
Message Monitor Algorithm



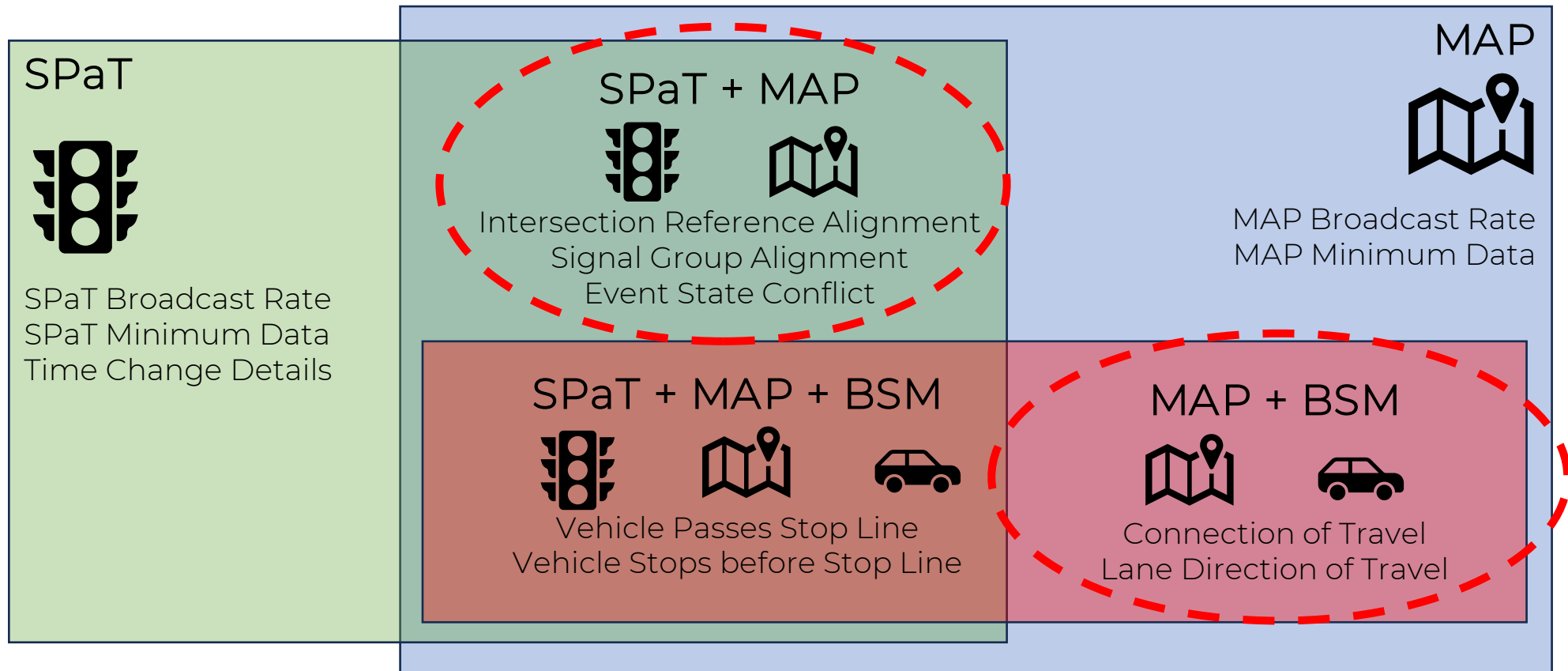
Message Monitor Algorithm



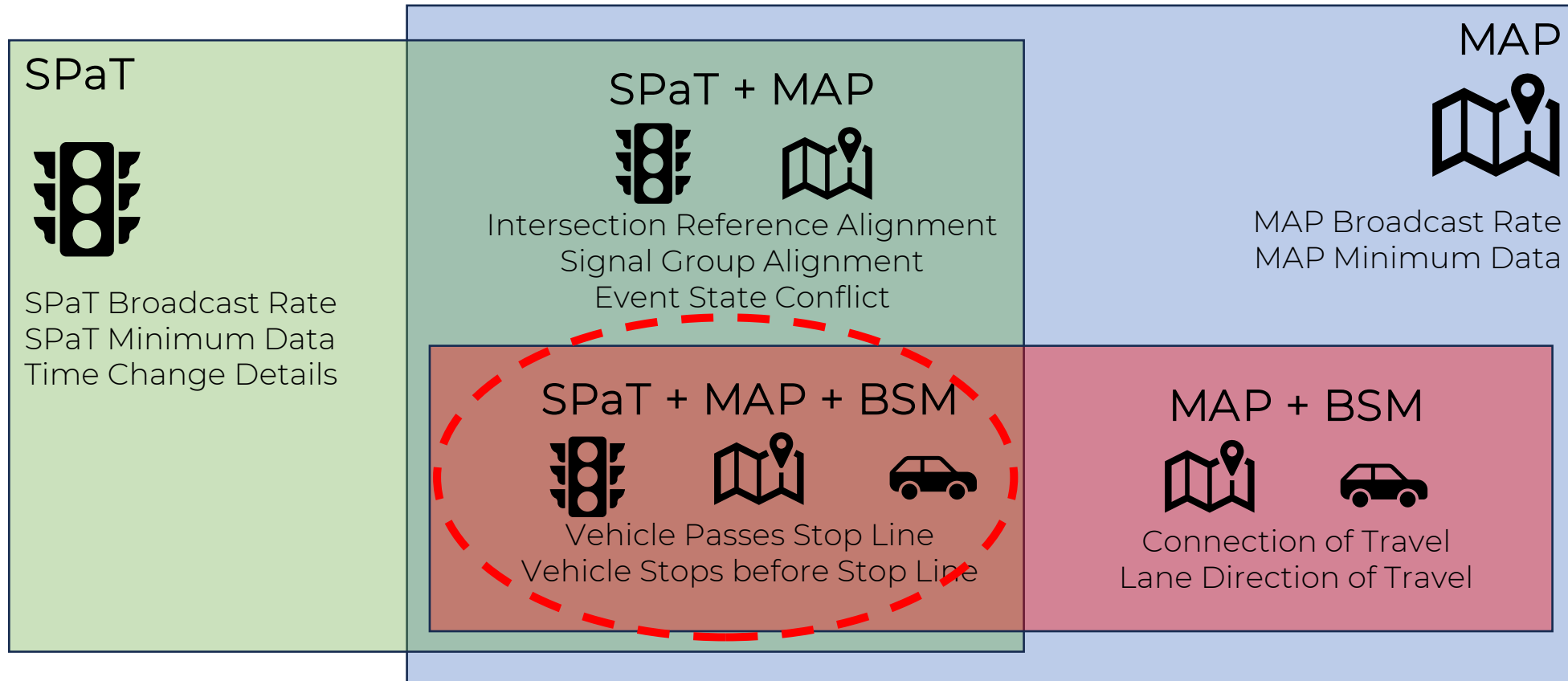
Message Monitor Algorithm



Message Monitor Algorithm



Message Monitor Algorithm



Other System Applications

Road Weather Management
Aurora Pooled Fund Study

Road Weather Management

Goals

- Optimizing traffic management operations
- Improve timeliness and accuracy of information
- Efficient application of road maintenance operations
- Utilize existing infrastructure

Components

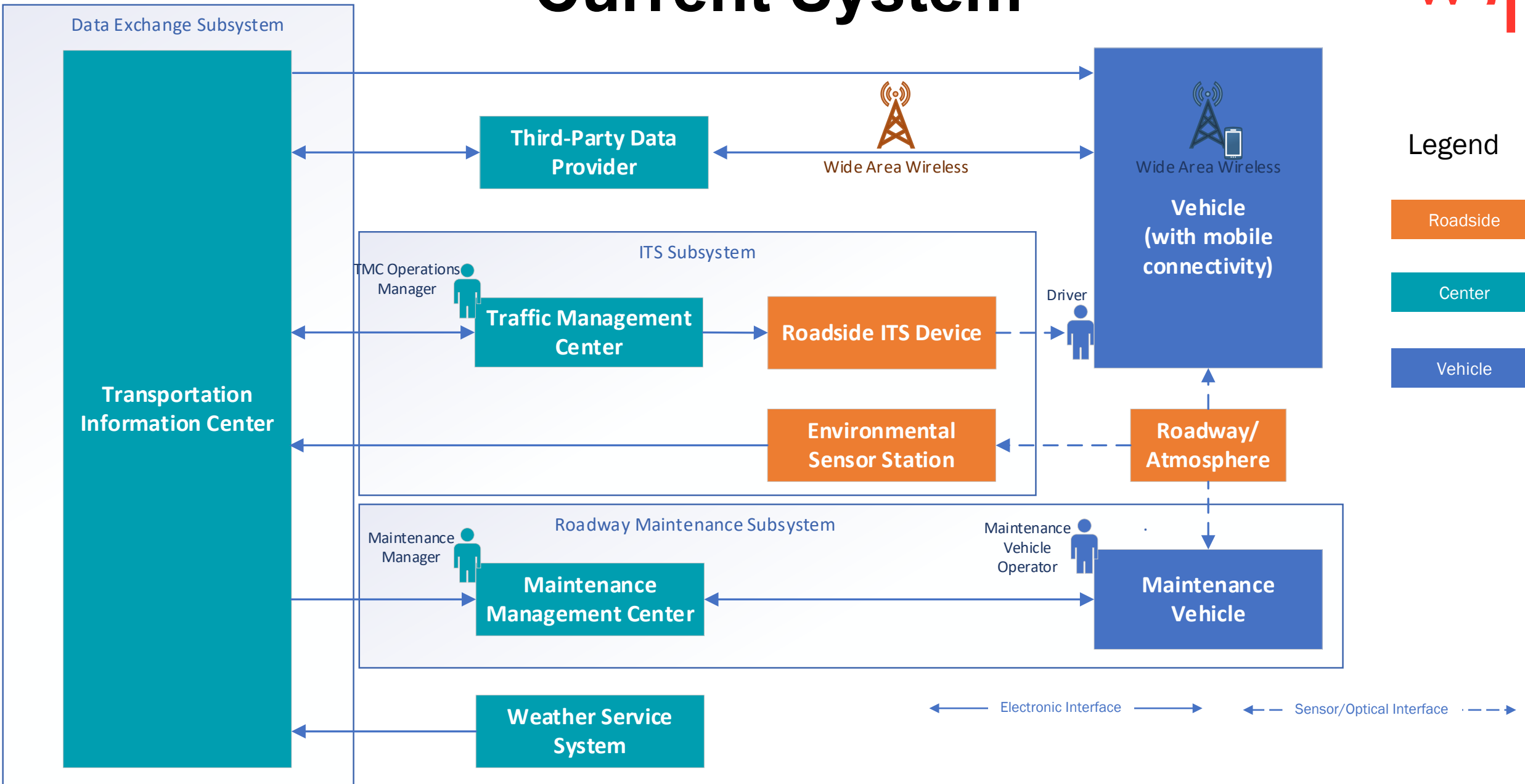
- Roadside Fixed Components
- Management Infrastructure
- Vehicles
- External Systems

Current System



Legend

- Roadside
- Center
- Vehicle

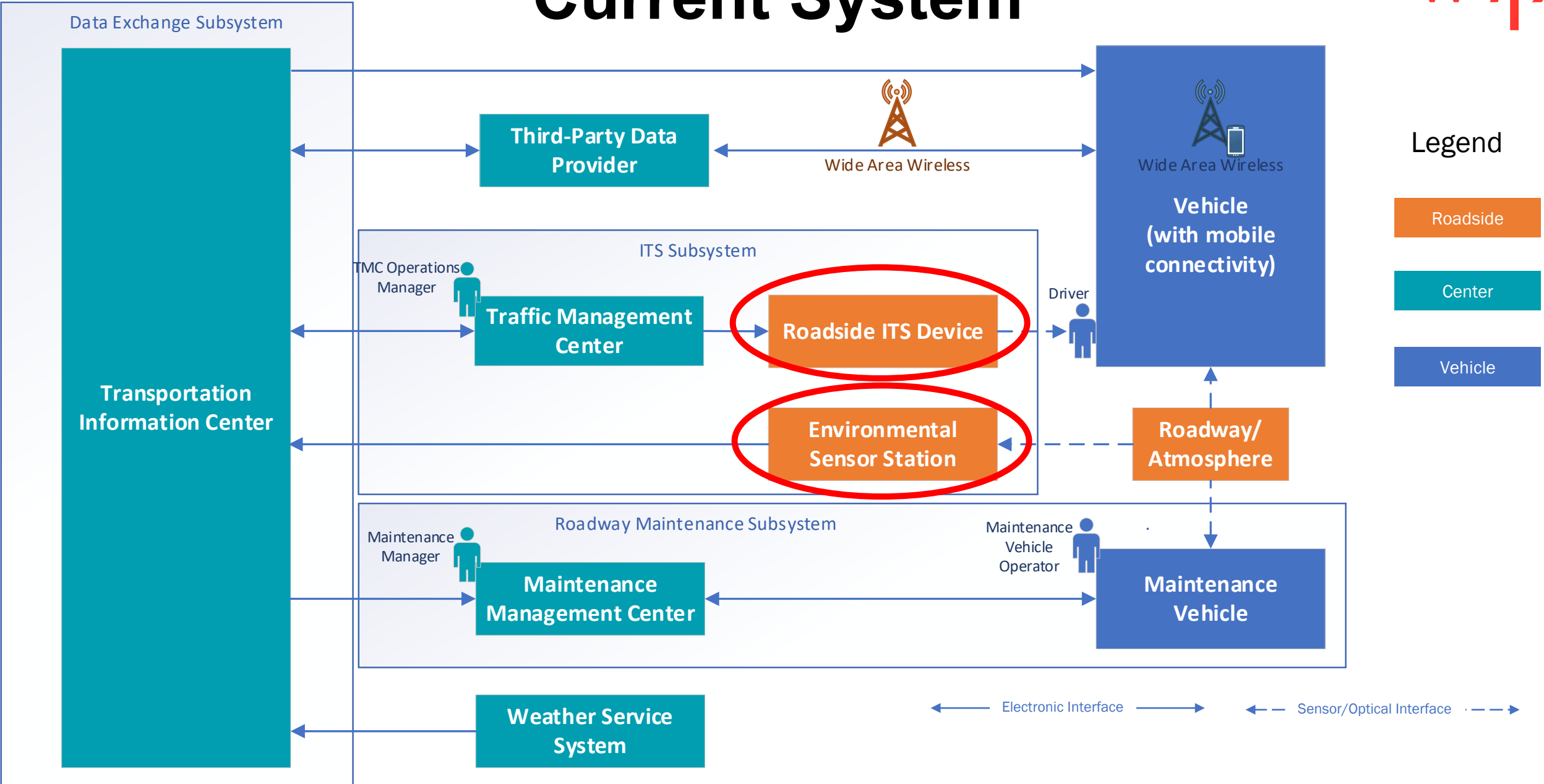


Current System

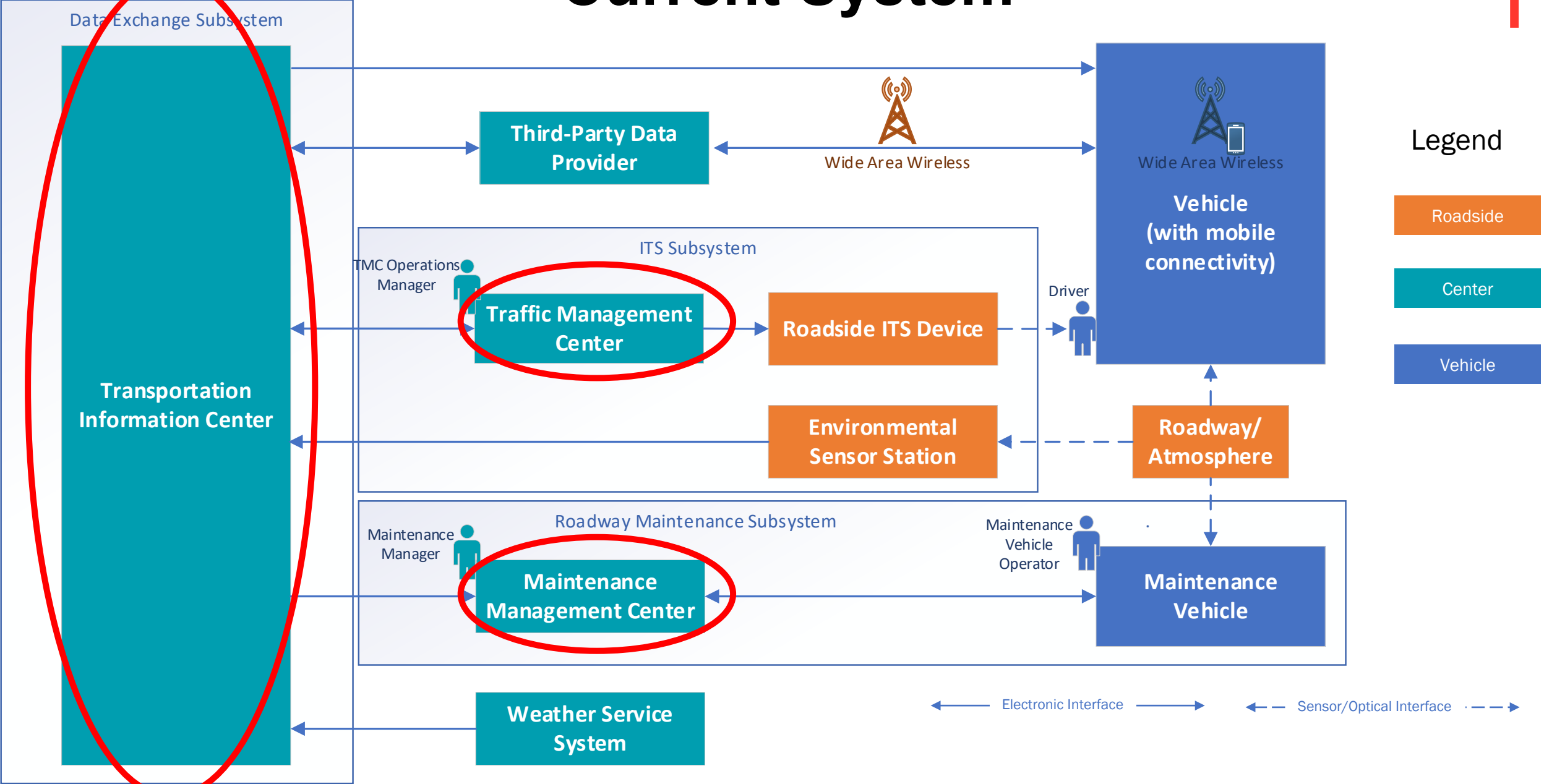


Legend

- Roadside
- Center
- Vehicle



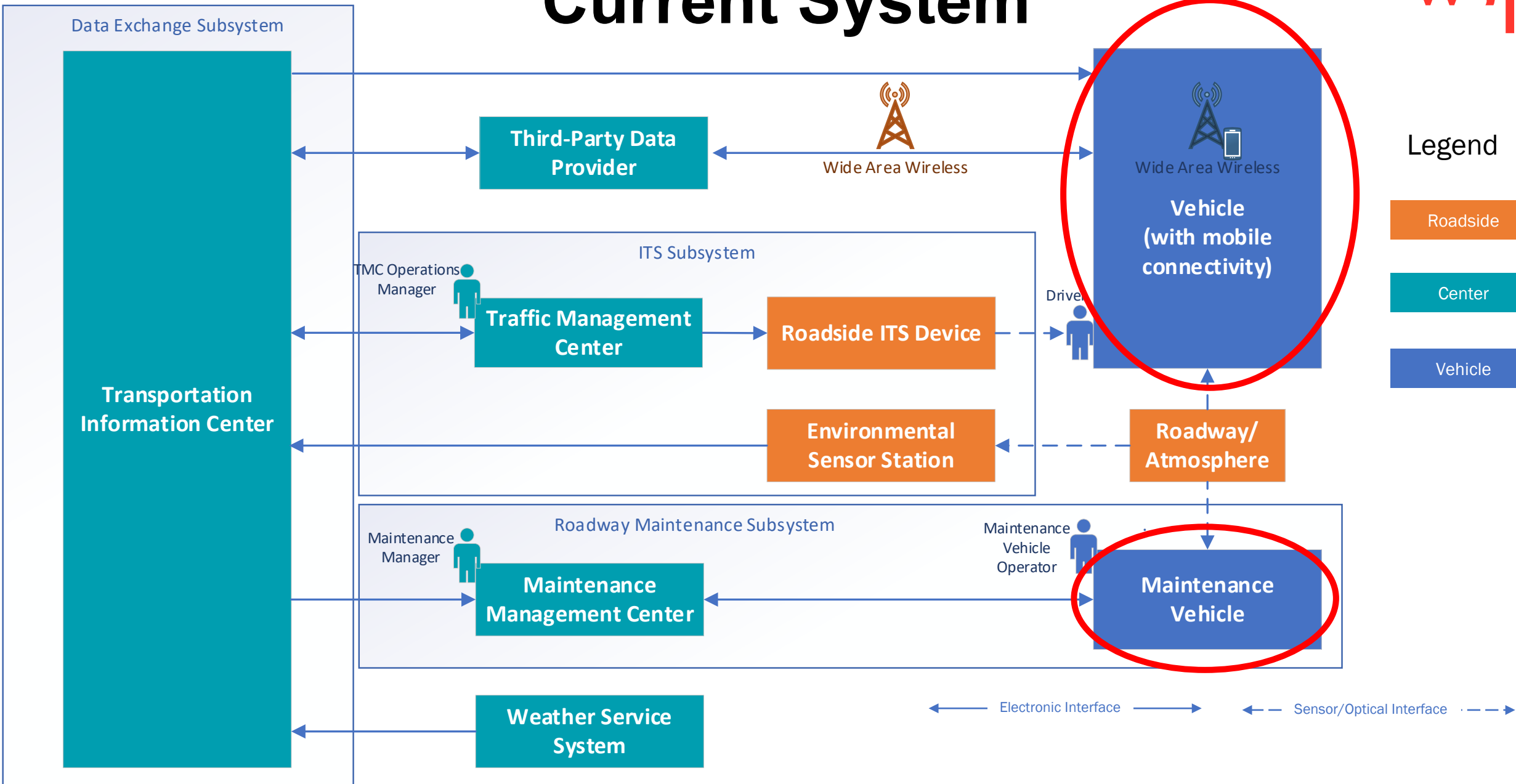
Current System



Current System



Legend

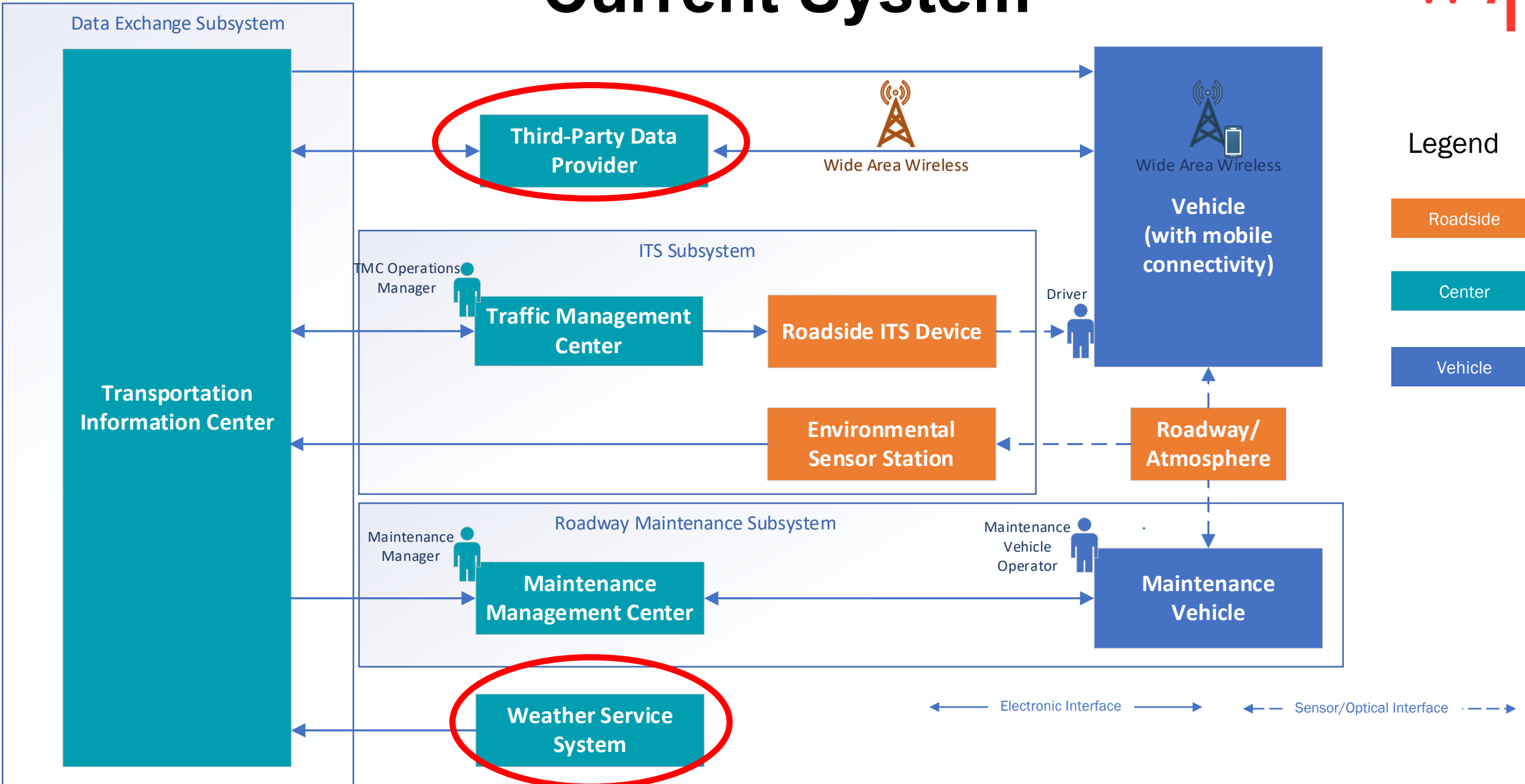


Current System



Legend

- Roadside
- Center
- Vehicle

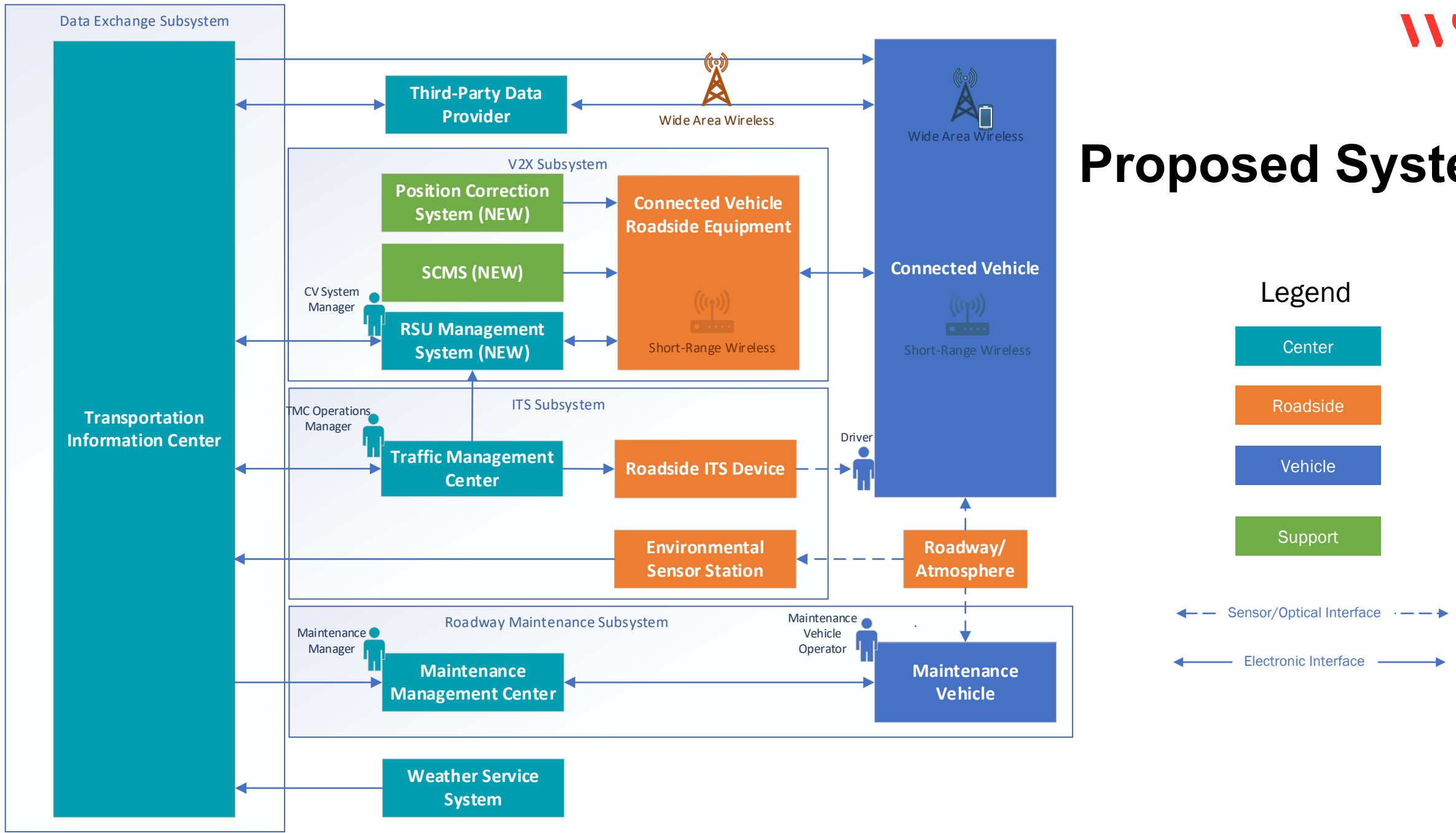


User Needs



User	Need	Application
TMC Operations Staff Needs	<ul style="list-style-type: none"> • More complete and local Road Weather Information to provide other users • Implement Traffic Management Strategies • Provide National Weather Service Alerts to Road Users. 	<ul style="list-style-type: none"> • evaluate the safest rerouting options. • ensure the most effective traffic operations during a weather event • ensure road users don't use unsafe roads. • provide road users with relevant weather information
Maintenance Manager Needs	Identify precise areas for mitigation	<ul style="list-style-type: none"> • preserve the safety of road users
Maintenance Vehicle Operator Needs	<ul style="list-style-type: none"> • Faster critical weather response • Prompt treatments 	<ul style="list-style-type: none"> • Faster return to safe roadway and normal traffic operations conditions
Driver Needs	<ul style="list-style-type: none"> • Avoid Extreme Weather Instances with Real-time Weather Watches and Warnings • Safer Route Planning • Awareness of Low Visibility Conditions • Awareness of Road Surface Conditions • Awareness of Road Closures • Information relevancy 	<ul style="list-style-type: none"> • make the safest route choice and avoid driving through extreme weather events • make rerouting decisions in advance • avoid crashing into other vehicles or roadside objects. • avoid losing control of the vehicle • focus on relevant information for decision making.

Proposed System



Key Takeaways

- Growing deployments
- Need for Interoperability
- Need for systems to manage the scalability
- Multiple benefits





QUESTIONS?



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