CAMP LLC

Vehicle-to-Infrastructure (V2I) Consortium

V2I Safety Application Development Program
Tasks 13, 14 & 15 Final Briefing
October 30, 2019

Acknowledgement and Disclaimer

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Agenda

- Safety Application Project Extension #2
  - Task 13: Adaptation of RSZW/LC in TxDOT I-35 Construction
  - Task 14: Work Zone Mapping
  - Task 15: SPaT/RLVW Intersection Verification

Timeline of Completed V2I SA Project Tasks

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Tasks 2 through 12 – Final report submitted to FHWA on July 27, 2017

<table>
<tr><th></th><th colspan="9">2017</th><th colspan="12">2018</th><th colspan="5">2019</th><th>Safety Applications Extension #2 Tasks</th><th rowspan="2">Task Status</th></tr>
<tr><th>Task</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Deliverables</th></tr>
<tr><td>13</td><td colspan="26">Adaptation of RSZW/LC in TxDOT I-35 Construction - COMPLETED</td><td>Interim Report on WZ Deployment Guidance Document</td><td>● Task Report submitted to FHWA on June 6, 2019</td></tr>
<tr><td>14</td><td colspan="19">Work Zone Mapping / Software Toolchain / RSM Testing - COMPLETED</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Interim Report on Mapping Technique/Toolchain</td><td>● Task report submitted to FHWA on Oct. 30, 2018</td></tr>
<tr><td>15</td><td colspan="9">SPaT/RLVW Verification - COMPLETED</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Interim Report on Revised Intersection Verification Process Document</td><td>● Report Submitted to FHWA on Dec. 15, 2017</td></tr>
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V2I SA Project Tasks and Timeline

- Task 1: Technical Project Management
- Task 2: Coordination with Stakeholders
- Task 3: SA Technical Assessment
- Task 4: Develop Criteria for V2I-SA Selection
- Task 5: Application Development Plan
- Task 6: Application Development
- Task 7: Vehicle Build
- Task 8: Infrastructure Build
- Task 9: Testing
- Task 10: Map Support

- Developed V2I Safety Applications
  - Red Light Violation Warning (RLVW)
  - Curve Speed Warning (CSW)
  - Reduced Speed Zone Warning with Lane Closures (RSZW/LC)

V2I SA Project Tasks and Timeline

- SA Project Extension – 1
  - Task 11: Feasibility Study-Actuated Signal
  - Task 12: On-road Testing
- Final Report for Tasks 1 – 12 submitted to FHWA on July 27, 2017
- SA Project Extension – 2
  - Task 13: Connected Work Zone Deployment Guideline (Internal report to FHWA June 6, 2019)
  - Task 14: S/W Toolchain for Work Zone Mapping (Internal report to FHWA Oct. 30, 2018)
  - Task 15: SPaT/MAP Verification for RLVW (Internal report to FHWA Dec. 15, 2017)

Task 13

Adaptation of RSZW/LC in TxDOT I-35

Corridor Construction Project

I-35 Connected Work Zone

FHWA Final Briefing Update

October 30, 2019

In cooperation with:
Robert E. Brydia, PMP (TTI)
Jianming Ma, Ph.D., P.E. (TxDOT)

Task 13

GOAL

Deploy and test the Reduced Speed Zone Warning / Lane Closure (RSZW/LC) application

- on Real-world work zone situations
- on Interstate 35

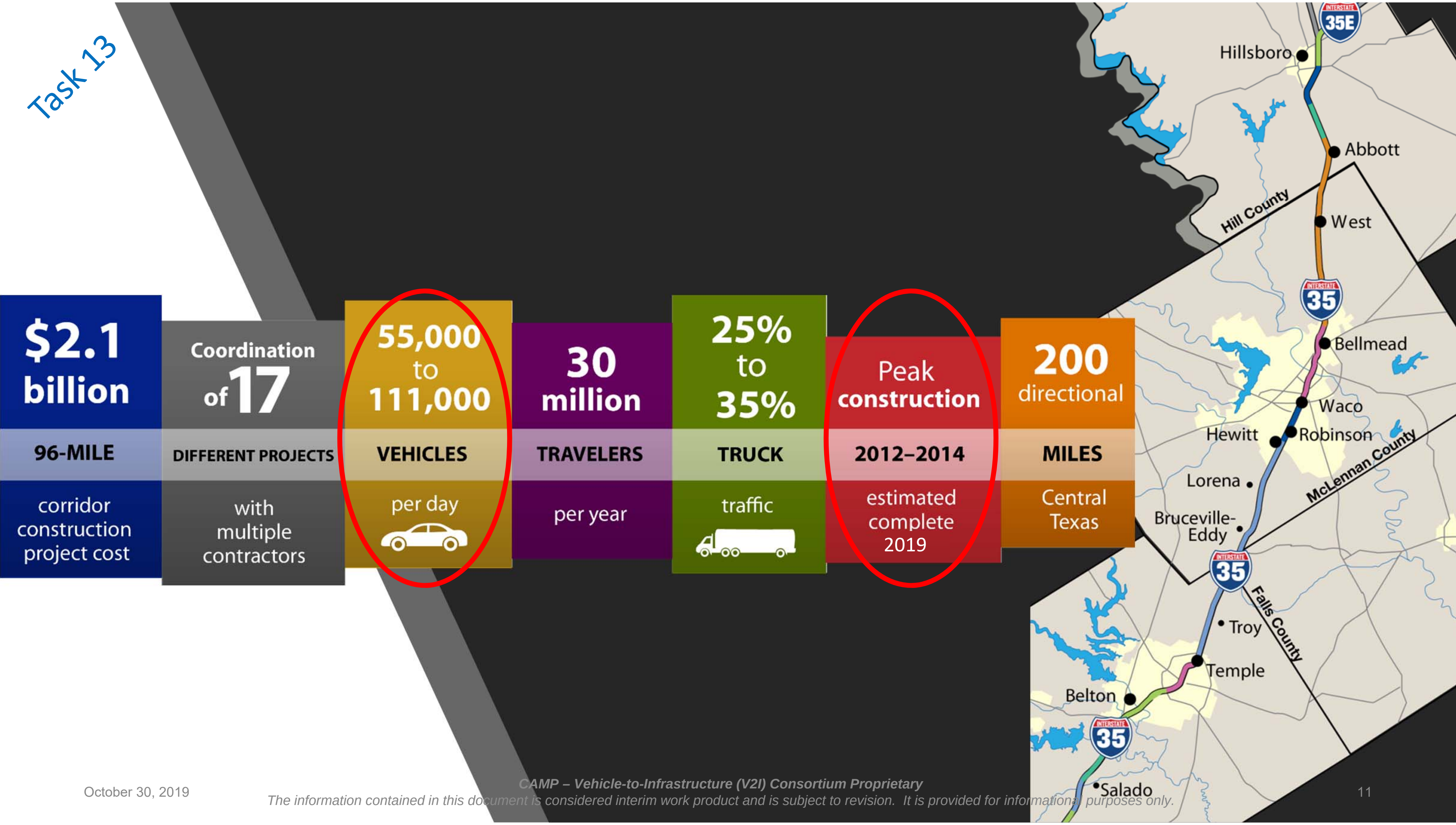
Task 13

High-level Objectives to Get to Goal

Establish methodologies to create, deliver, and test work zone information to connected vehicles

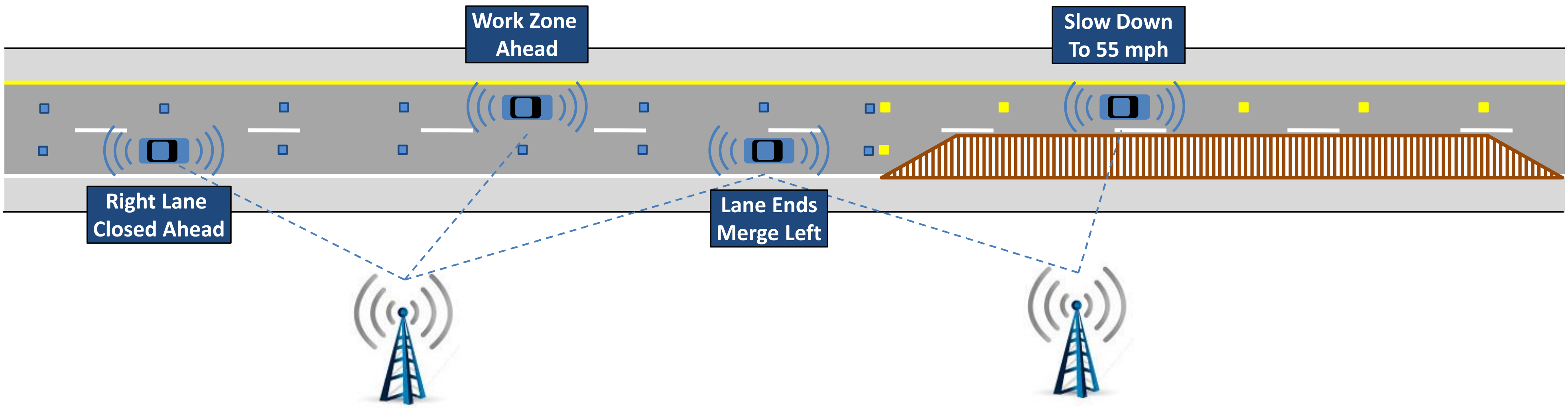
1. Utilize CAMP software base
2. Utilize existing I-35 lane closure information
3. Utilize high-fidelity and low-fidelity pathways
4. Operate RSZW/LC application / collect data / analyze
5. Provide real-world application deployment experience input for CAMP guidance document

Task 13


$2.1 billion
96-MILE
corridor construction project cost
Coordination of 17
DIFFERENT PROJECTS
with multiple contractors
55,000 to 111,000
VEHICLES
per day
30 million
TRAVELERS
per year
25% to 35%
TRUCK
traffic
Peak construction
2012–2014
estimated complete 2019
200 directional
MILES
Central Texas
35E
Hillsboro
Abbott
Hill County
West
35
Bellmead
Waco
Hewitt
Robinson
McLennan County
Lorena
Bruceville-Eddy
35
Falls County
Troy
Temple
Belton
35
Salado

Task 13

I-35 Connected Work Zone



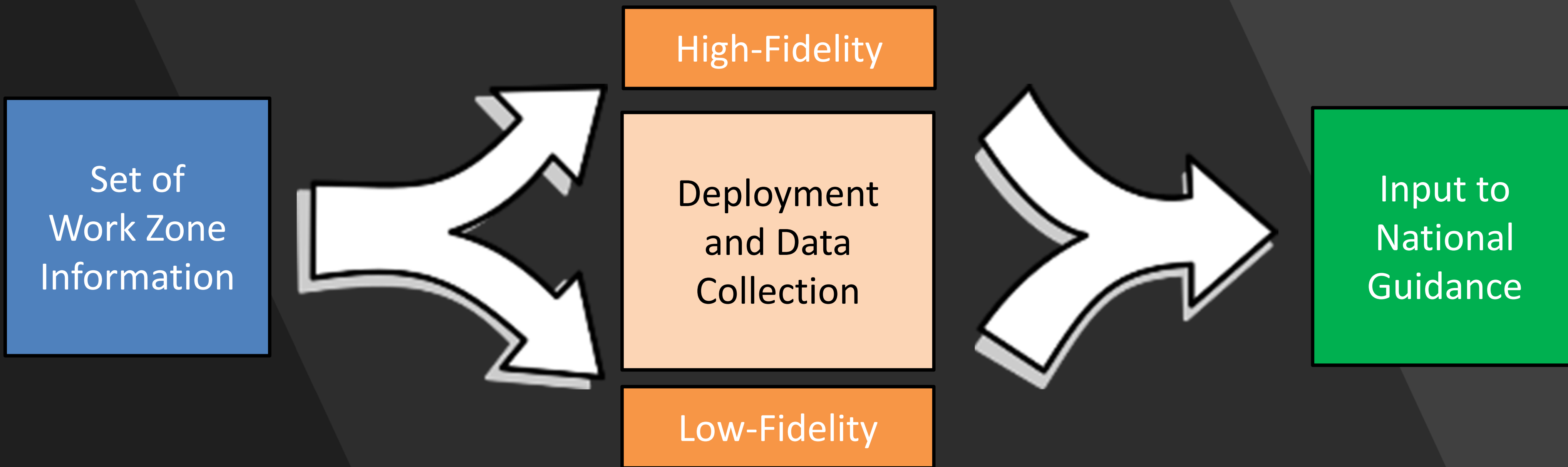
Task 13

Challenges

- Equipment assemblies are not off-the-shelf and requires specialized knowledge and parts
- Leading manufacturers and developers in this space are still shaking out
- Disparity in support, standards implementation, capabilities, ease of use, etc.
- Software solutions are developing and are not transferrable across equipment
- Different information levels (available vs. desired) exist

Task 13

The Path Forward



Task 13

Deployed and tested the Reduced Speed Zone Warning / Lane Closure (RSZW/LC) mapping and application from CAMP

1. Test work zone mapping application
2. Lonestar™ connected vehicle module
3. Integrate I-35 lane closure information
4. Built connected work zone (RSU deployment)
5. Built reference vehicle(s)
6. Conducted CWZ (using reference vehicle)
7. Operations via Lonestar™
8. Conducted test of high-fidelity RSZW/LC application
9. Developed deployment guidelines

Task 13

Field Test

RSU Deployment

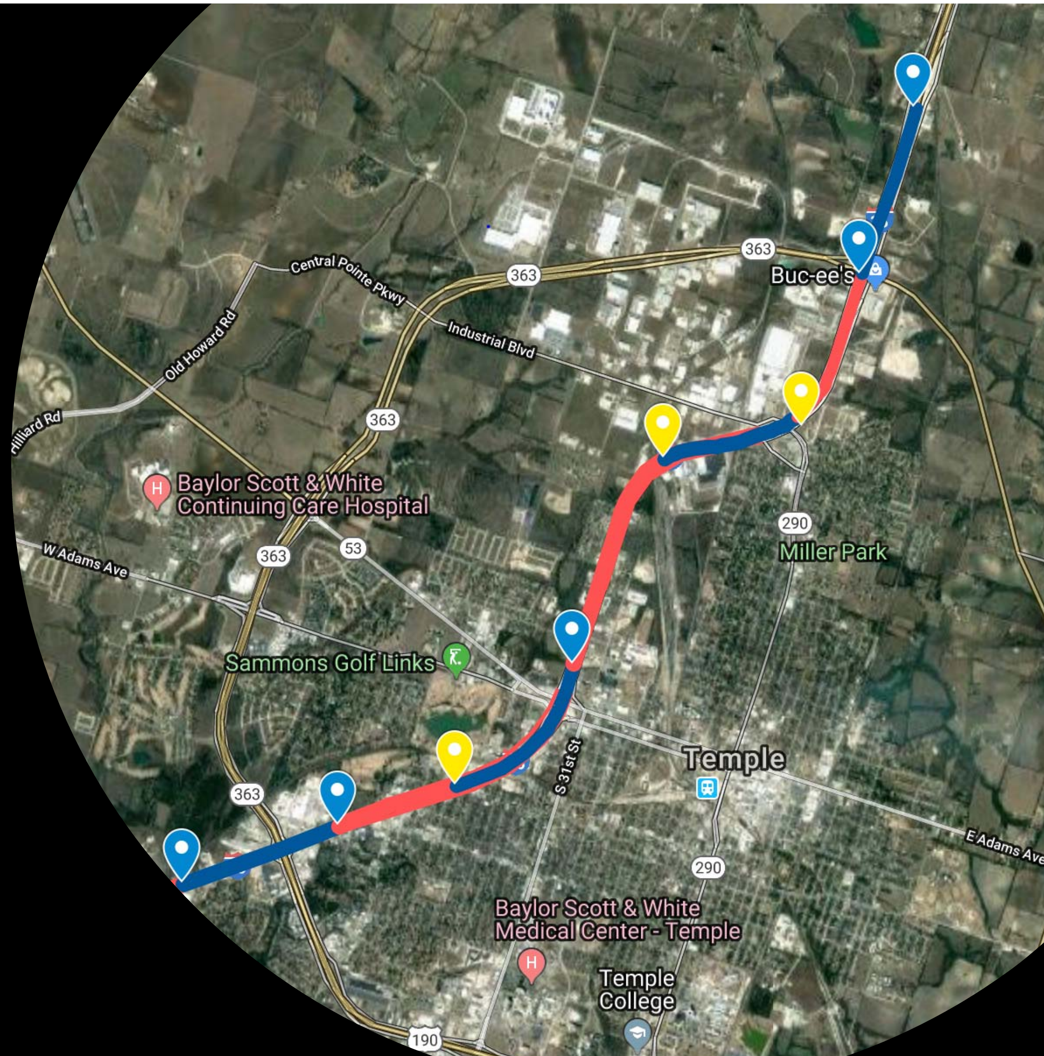
- 9 RSUs
- 8 miles of I-35 in Temple
- ~ 1 mile spacing

Closure Scenarios

- Single closure
  - Multiple lanes
- Multiple closures
  - Alternate lanes
  - Same lane

RSU Deployment

- Mapping
- High fidelity CAMP OBU Application
- Low-fidelity SwRI application



Source: Map image from Google. Used with permission.
Plotted data from Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure (V2I) Consortium

Task 13

High-Fidelity Mapped Work Zone on I-35

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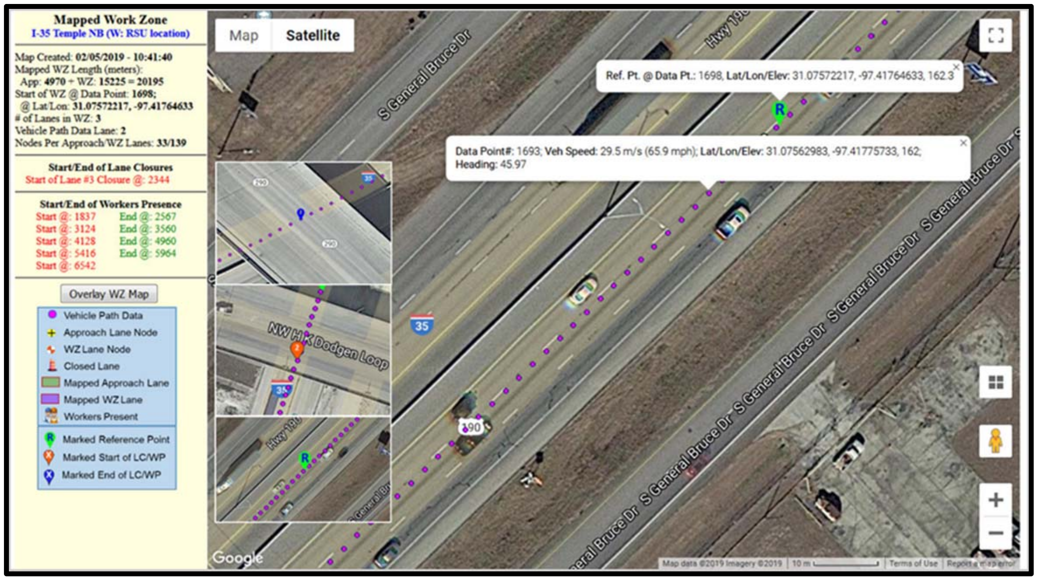

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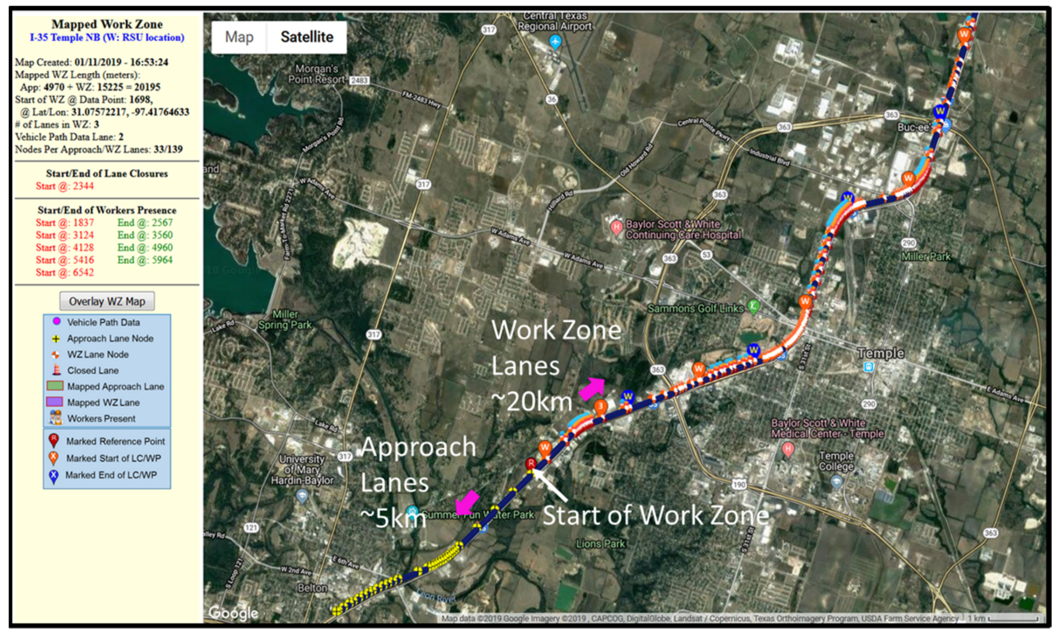

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Task 13

Findings and Lessons Learned

Task 13

The Need for Linkages

Contractor coordination for lane closure data

- Appropriate detail
- In advance
- Procedures for emergency situations

Integrate work zone mapping and closures

- Work zone mapping not yet commonplace
- Correlations of data are not automatic

Multiple systems / endpoints within the IOO

- Traveler information
- ITS
- TMC operations

IOO to roadway

- Vehicles
- Infrastructure

CAMP To IOOs

- Guidance

Task 13

Two-Tiered Solution

High-fidelity scenario

- Detailed lane-level mapping of the roadway and work zone is possible
- Reference point (beginning of lane closure taper) can be accurately defined
- Full information load for RSZW/LC application is supported

Low-fidelity scenario

- Less detailed mapping of the roadway and work zone
- Reference point is estimated
- Reduced information load for RSZW/LC application is supported

Task 13

Findings

- Work zone setup differs by state / region
- Overall, mapping and applications work
- Hardware suffers from inconsistency, specialized knowledge, and lack of standardization
- Integration of lane closure information in a systemic fashion is in early stages
- Required linkages with multi-agencies can be complex
- IOO's will have to chart an appropriate path and fidelity level

Task 13

Potential Lab-to-Market Research Areas

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- **Field Hardware Maturity, Lack of Adherence to Standards**
  - Hardware utilized in the field deployment for testing suffered from lack of maturity
  - Lack of adherence to standards vary widely between vendors of the same equipment type
    - No support for broadcasting multiple messages from RSU at a specified time interval
  - Lack of uniform easy-to-setup process for field equipment.
    - Setup process varies significantly from one vendor to another and differ from one version to another within the same vendor
- **WZ Mapping Requirements**
  - Spatial and temporal mapping requirements for high- med- low-resolution work zone maps to support
    - Different levels of fidelity
    - Quick changes to WZ map as the configuration changes
  - Consistent techniques for managing infrastructure information for:
    - Local vs backend approaches to managing data
    - Integration with other traveler information systems
      - 511 systems
      - DMS consistency
    - Manage set up / take down transitions
  - Guidelines for intended in-vehicle information / alert for drivers

Task 13

Potential Lab-to-Market Research Areas

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- **Support GPS Enabled Barrels/Arrow Board for Lane Closures**
  - Need for availability of lane closure information
    - The standardization of work zone information elements required to support the CWZ applications for broad-scale application
  - Develop uniform and consistent method to access location from GPS enabled barrels / cones / arrow boards
    - Integrate into work zone mapping
    - Integrate into Work Zone Data Initiative (WZDi)
- **RSU Placement in Field**
  - Establish guidelines for placement of RSUs in field for maximum signal coverage
    - Height and orientation of antenna for maximum coverage
    - Antenna requirements and potential signal interferences and obstructions in field

Task 14

Work Zone Mapping

Task 14

Work Zone Mapping

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Scope:

- Develop an effective dynamic mapping technique to rapidly generate work zone map for the RSZW/LC application
- Evaluate efficacy of the technique in live work zones

Outcomes:

- WZ Mapping using a reference vehicle equipped with:
  - Suitable positioning and recording capabilities
  - OBU and an on-board processing unit (Laptop) for transmitted work zone message verification
- WZ mapping and message builder “software tool chain:”
  - Rapidly construct work zone map with work zone relevant data for RSZW/LC application
  - RSZW/LC application verification
- Make the “software tool chain” and required components for building the map as part of “tool chain” available to IOOs

Task 14

Infrastructure Map for CV Applications

- Map convey many types of geographical data of the roadway
- Three levels of "Map" (region) information needed:
  - Low fidelity: only a region
    - Ex. Hurricane evacuation
  - Medium fidelity: limited road level
    - Ex. Road closures due to flooding
  - High fidelity: lane level details
    - Lane closure(s)
    - Speed limit change(s)
    - Workers present
    - …

Source: Map image from Google. Used with permission. Plotted data from Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure (V2I) Consortium

Task 14

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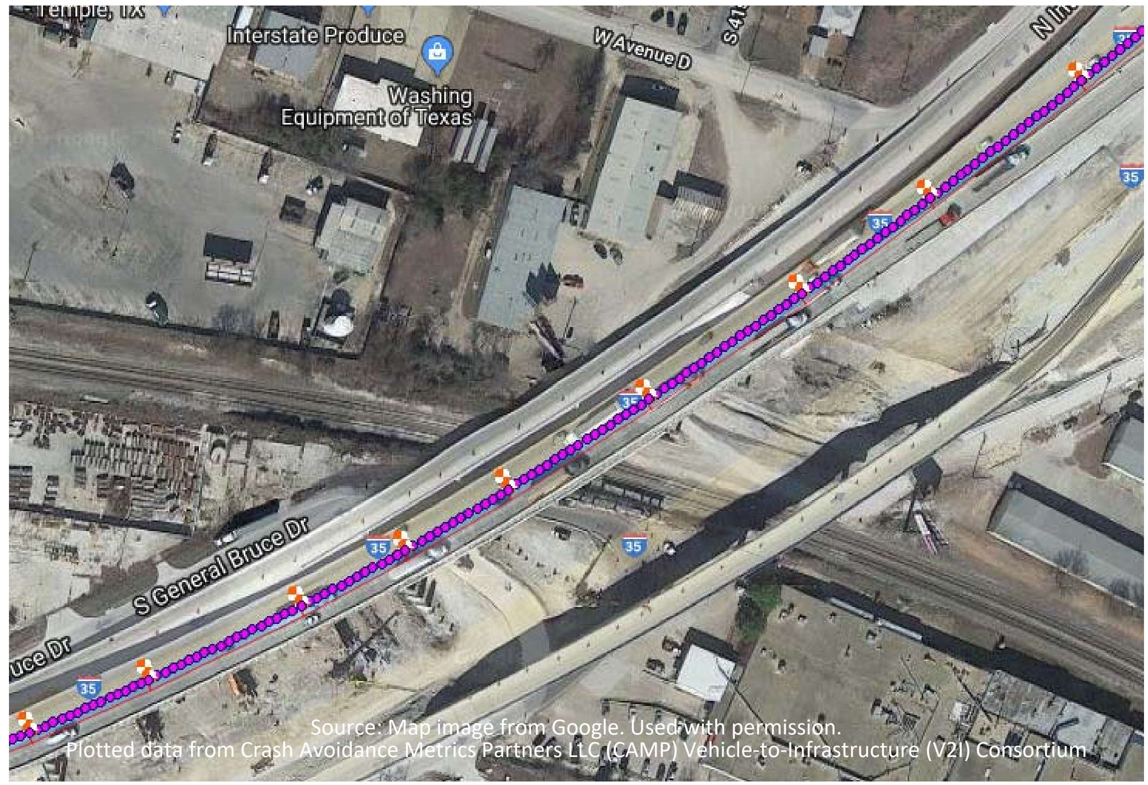
What We Need

- Proper and accurate infrastructure maps are crucial for the desired functioning of many V2I applications
- The ability to easily generate, validate and transmit accurate high-fidelity lane-level digital maps
- Wide-scale implementation using consistent mapping technology
  - to easily produce digital maps in standard format
  - for stable and dynamically changing road environment at a lane level
  - which is beneficial for both vehicle manufacturer and infrastructure owner operators (IOO)



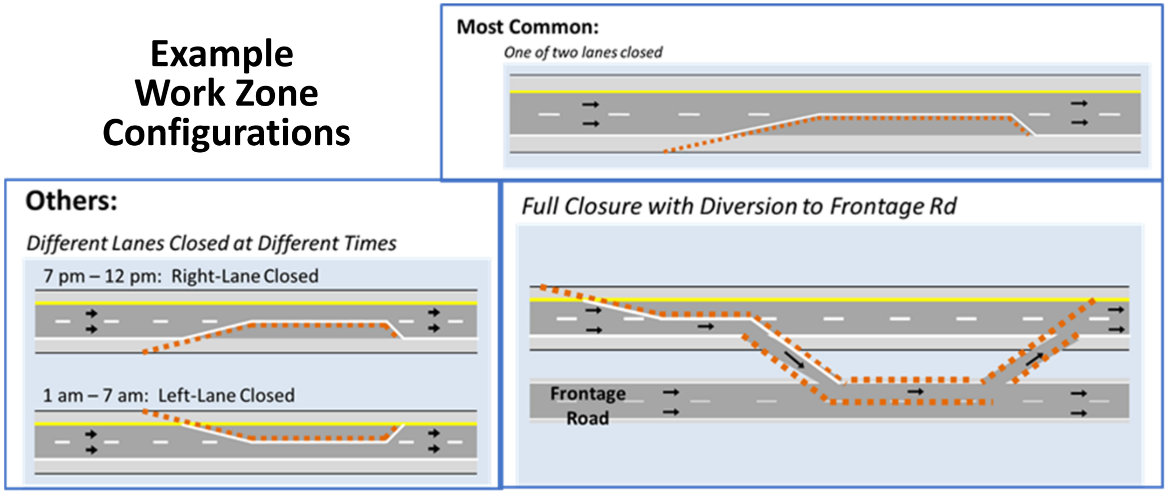
Task 14

Mapping for Connected Work Zone Applications

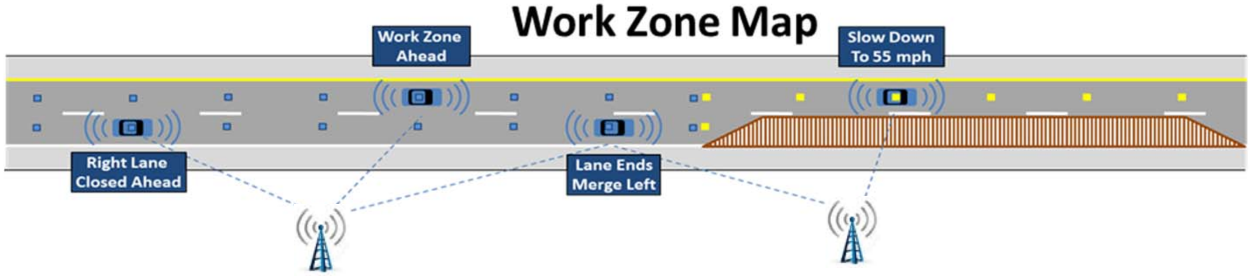
For a work zone:

- Lane geometry represented by node points that describe:
  - Start of work zone
  - Layout of each lane
    - Lane closure location(s) – Start and end of tapers
    - Workers presence zones(s) – area(s) where the workers are present
    - Posted speed limit(s)

Example Work Zone Configurations



Work Zone Map



Task 14

Lane Geometry for Determining Vehicle Lane Position

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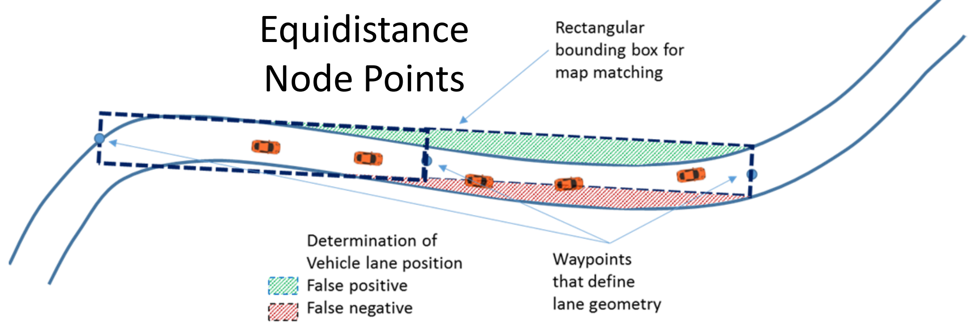
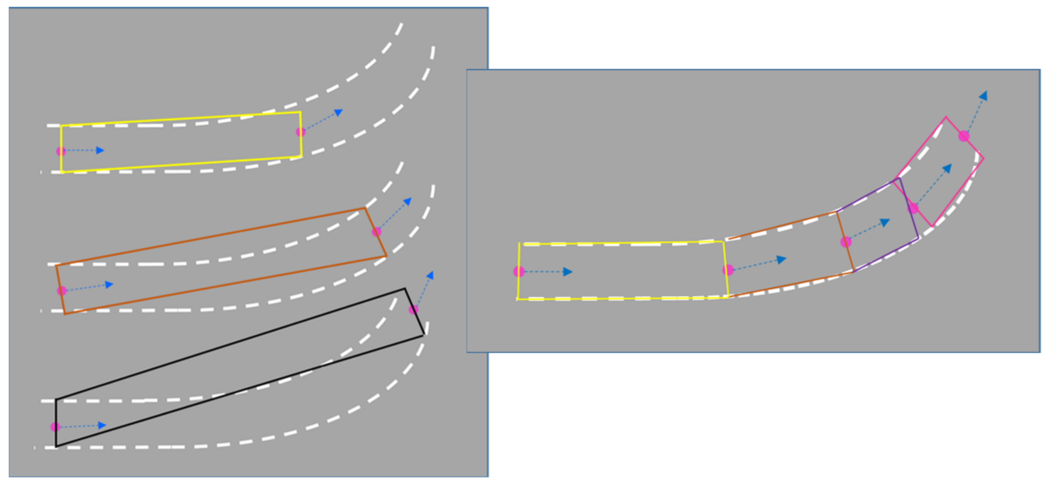
- Map can be generated by:
  - Conducting survey
    - costly and time consuming
  - Selecting node points on a map
    - manual process can be less accurate and error prone
  - Convert to specified format in a standard
- In-vehicle map matching
  - Creates a virtual bounding box equal to the lane width and two consecutive node points of the lane geometry to determine vehicle lane
  - Placement of node points for lane geometry has direct implications on the performance of the vehicle lane determination





Task 14

Software Toolchain for Work Zone Mapping and Message Building

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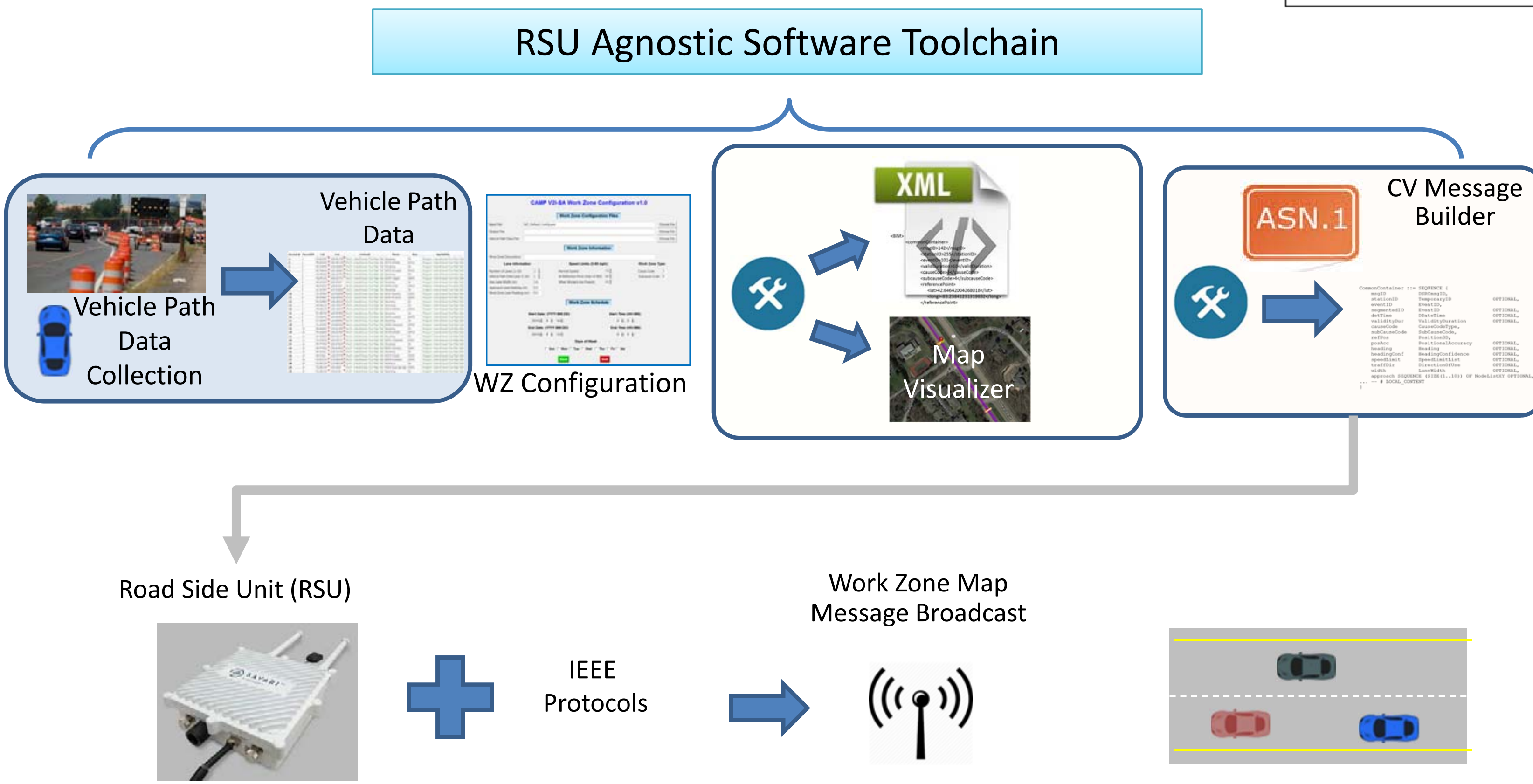

Task 14

Steps for Building a Work Zone Map and Message for Transmission

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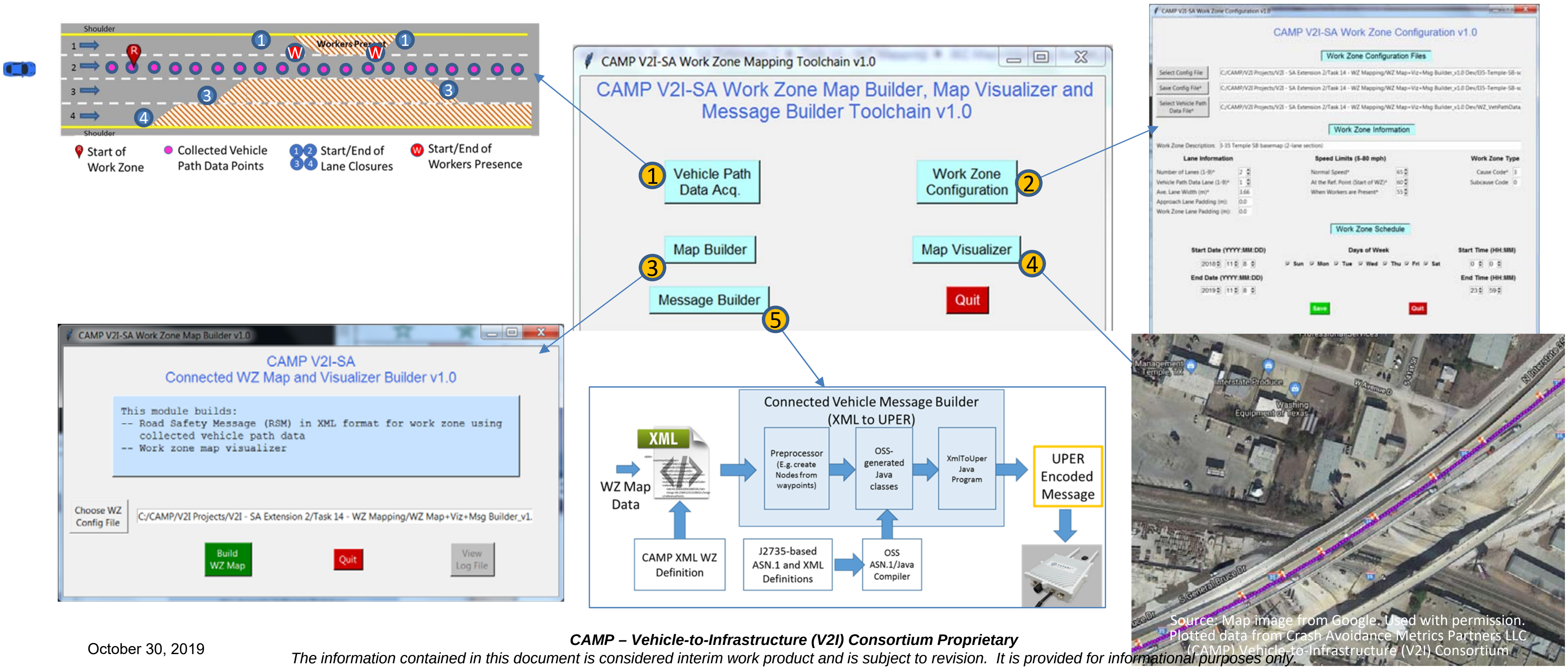

Task 14

Software Toolchain Status

- Used by TxDOT with TTI for Connected Work Zone Project on I-35 corridor in Texas
- U. of Arizona (Larry Head)
  - Used for mapping CVISN* Freight Vehicle Work Zone Project
- FHWA Saxton Transportation Operations Laboratory (STOL)
  - For integrating into a larger map making tool
- VTTI for incorporating into WZ software for use in Virginia Connected Corridor (VCC)
- In the process of:
  - Developing clickable 'free software' license to download the toolchain from CAMP websites
  - Promoting broader IOO utilization and feedback on system deployment and mapping tools through IOO/OEM forum

CVISN - Commercial Vehicle Information Systems and Networks

Task 15
SPaT/RLVW Intersection Verification

Task 15

Verification of SPaT/MAP for RLVW

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Scope:

- Conduct verification of selected signalized intersections in SE Michigan to confirm DSRC messages (SAE J2735-201603) transmitted by the RSE will support the RLVW application
- Develop SPaT/MAP verification process and refine as needed based on SPaT Challenge

Outcome:

- Develop SPaT/MAP verification process document

Deliverable:

- Updated verification process document including satellite-based position correction as task interim report

Findings from Tested Intersections for RLVW

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- SPaT and MAP messages contain different intersection IDs
  - Failed association between SPaT and MAP
- Incomplete MAP (map data) of an intersection
  - Map of only right 2 out of 4 SB lanes in the MAP message
- In some cases, intersection map contained absolute GPS coordinates and other offset from previous node for mapped node points
- Pedestrian cross walk phase and time used in SPaT for signal phase and time
  - Incorrect red phase time
  - Very high (random) *minEndTime* in SPaT message until crosswalk button is pressed or "don't walk" timer is activated
- Inconsistencies in time remaining in current phase in SPaT message for actuated signalized intersections

Task 15

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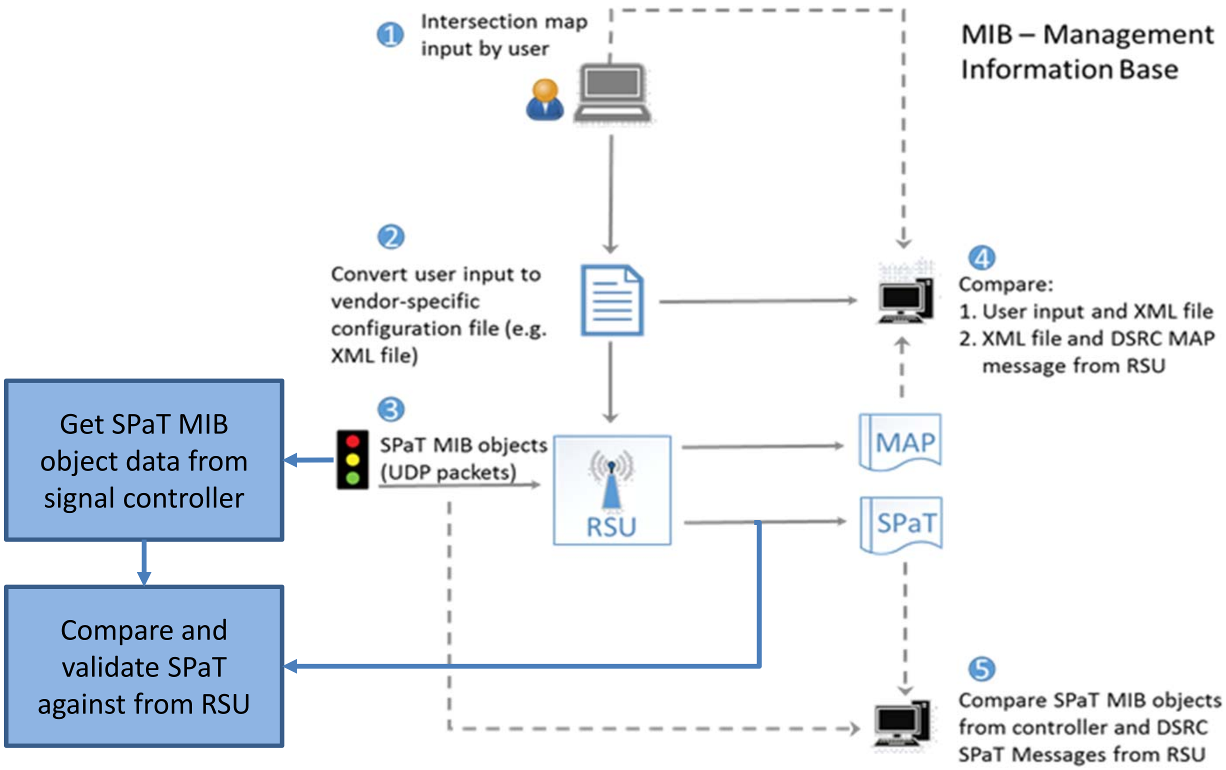
Steps for SPaT/MAP Verification



Task 15

Satellite-based Positioning System Error
and
Techniques for Correction

Task 15

Position Correction Study

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- In addition to SPaT / MAP verification, FHWA suggested to include study for vehicle position correction for:
  - Do all intersections are required to equip with RTCM correction for RLVW application?
  - NYC pilot experienced significant position errors in urban canyon areas
  - Suggest recommendations

Task 15

Need for Position Accuracy

- For the vehicle to accurately identify the approach and associate with signal phase using the MAP/SPaT message, it is critical that the location of the vehicle (determined by the on-board GPS) is within required accuracy
- Satellites broadcast their signals in space with a certain accuracy, but what is received depends on additional factors
- This can be accomplished by a broadcast of position correction information

Task 15

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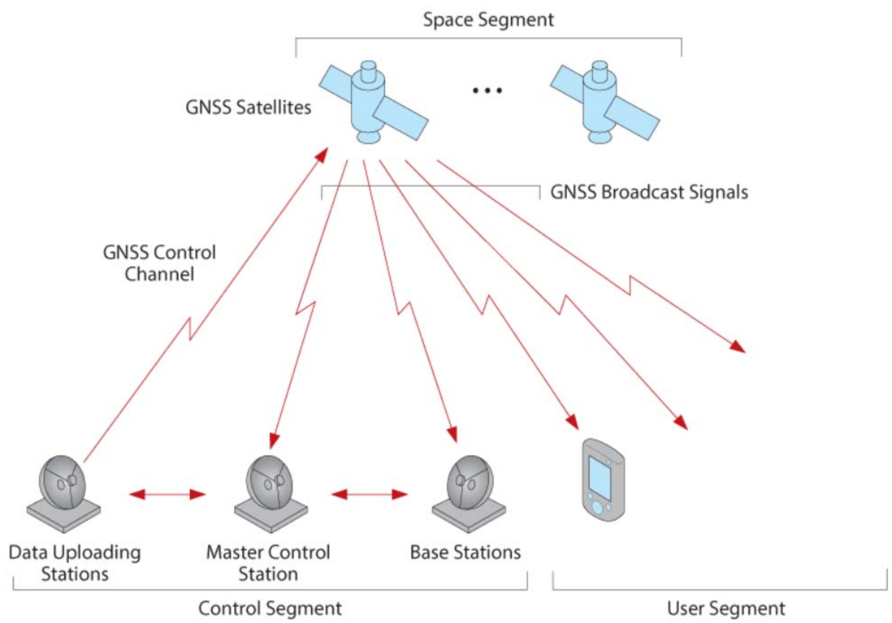
GNSS Systems

- "GNSS" (Global Navigation Satellite System) describes the collection of satellite positioning systems
  - GPS (United States)
  - Galileo (European Union)
  - QZSS (Japan)
  - GLONASS (Russia)
  - BeiDou (China)
  - IRNSS (India)
- GNSS satellite systems consist of three major components or "segments:"
  - space segment
  - control segment
  - user segment



Source: https://www.novatel.com

Task 15

User Equivalent Range Error (UERE)

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- Error *components* in the distance from a satellite to the receiver
  - Signal arrival time measurement
  - Atmospheric effects (changes slowly)
    - Ionosphere - affects speed of the signal as they pass through earth's atmosphere
      - Effects are smaller when satellite is directly overhead and greater for satellites near horizon
    - Troposphere - humidity also causes a variable delay
      - Effects are localized and changes quickly
      - Atmospheric pressure - affects signal reception delay
  - Ephemeris and clock errors
  - Receiver Noise
  - Multipath
  - Geometric dilution of precision
    - Satellites have smaller angular separation (close together) in the sky – DOP value is high
    - Satellites have wider angular separation – DOP is low, better positional accuracy

Contributing Source	Error Range
Satellite Clocks	~ ± 2m
Orbit Errors	~ ± 2.5m
Ionospheric Delays	~ ± 5m
Tropospheric Delays	~ ± 0.5m
Receiver Noise	~ ± 0.3m
Multipath	~ ± 1m

Source: https://en.wikipedia.org/wiki/Error_analysis_for_the_Global_Positioning_System
Source: http://www.gps.gov

Task 15

Resolving Errors

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- Many techniques are used to resolve errors
  1. Averaging of repeated observations at the same location (the least efficient method)
  2. Modeling of the phenomenon that is causing the error and predicting the correction values
  3. Differential Corrections
- What is the ideal technique for error correction?
  - There really is no "best way," it all depends on the positioning performance required for the application
- There are trade-offs between the different methods of removing errors

Task 15

GNSS Measurement Code Phase Vs. Carrier Phase

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- Code-phase measurement
  - Compares the *pseudo random code* with an identical code in the signal from the satellite
  - A wide pseudo random code is used
  - Measurement can be off by 3 to 6 meters
  - Results in positioning accuracies of a few meters
- Carrier-phase measurement
  - a measure of the range between a satellite and receiver in units of cycles of the *carrier frequency*
  - Real-time Kinematic (RTK)
  - Precise Point Positioning (PPP)

Task 15

Differential GNSS

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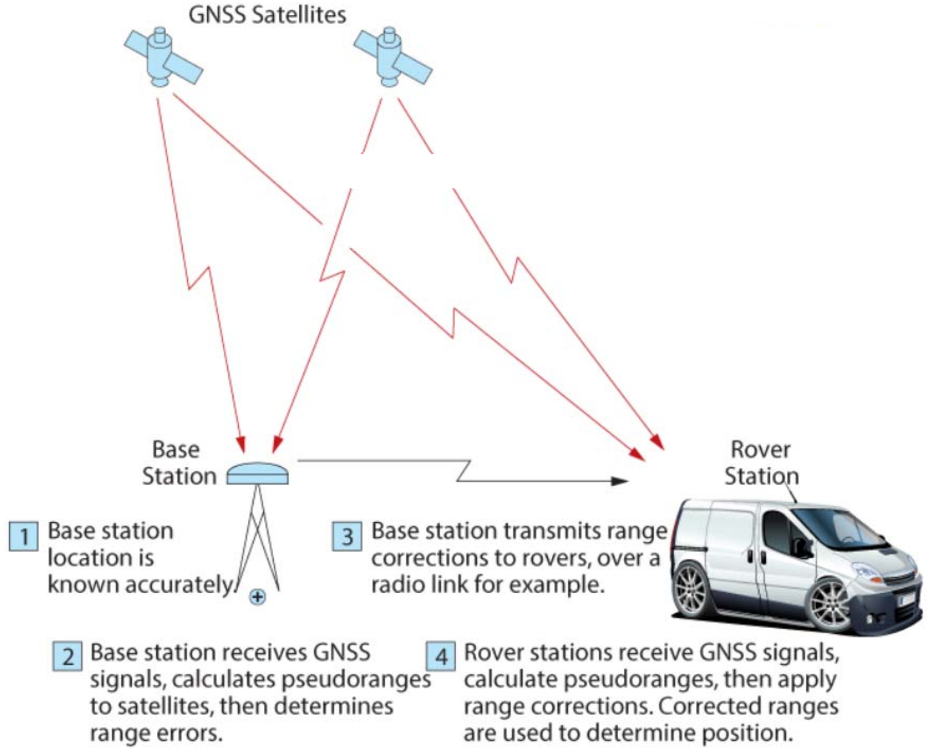
- A commonly used code-based technique for improving GNSS performance

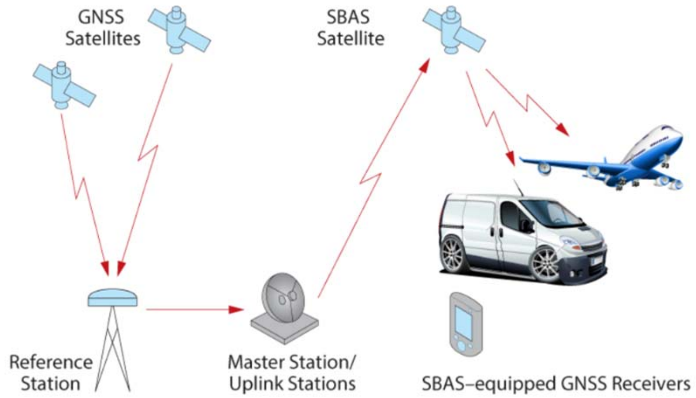


Source: https://www.novatel.com

Task 15

"SBAS" – Satellite Based Augmentation System

- For applications where the rover stations are spread over a large area
- Include reference stations, master stations, uplink stations and geosynchronous satellites
- Corrections are uplinked to the satellite then broadcast to GNSS/GPS receivers
- User equipment receives the corrections for range calculations



Source: https://www.novatel.com

WAAS Positioning Accuracy

- 15 m: Typical GPS position accuracy without selective availability
- 3-5 m: Typical differential (DGPS) position accuracy
- < 3 m: Typical WAAS position accuracy

Task 15

"RTK" Real-time Kinematic

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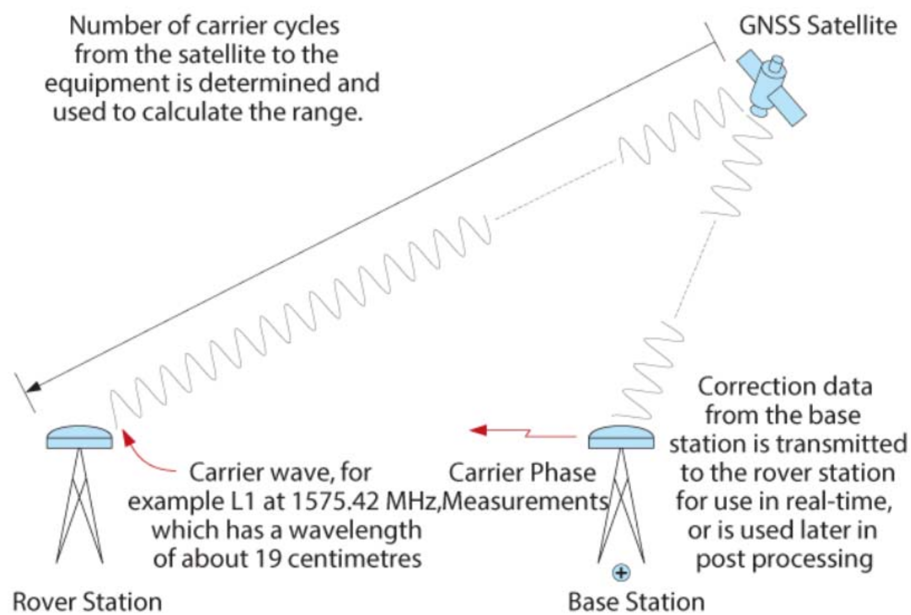
- Carrier-phase ranging technique
  - More precise than code-phase positioning
  - The concept reduces and removes errors common to a base station and rover pair
  - Provides centimeter-level positioning

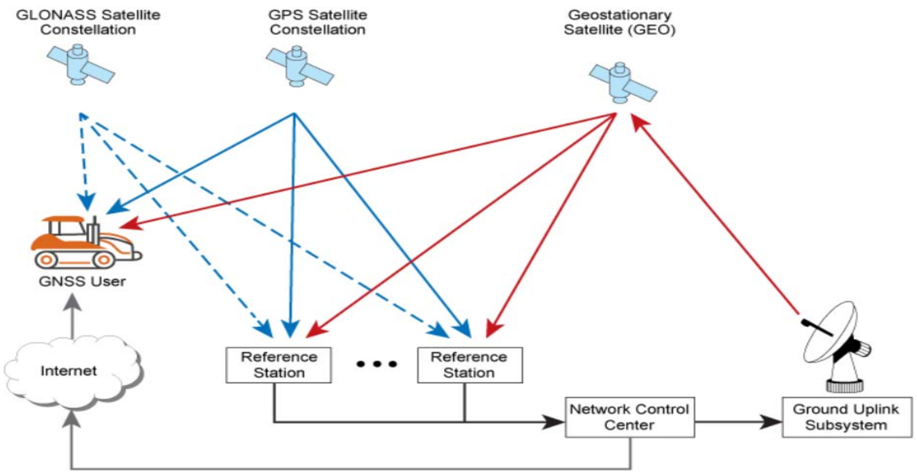


Source: https://www.novatel.com

Task 15

"PPP" Precise Point Positioning

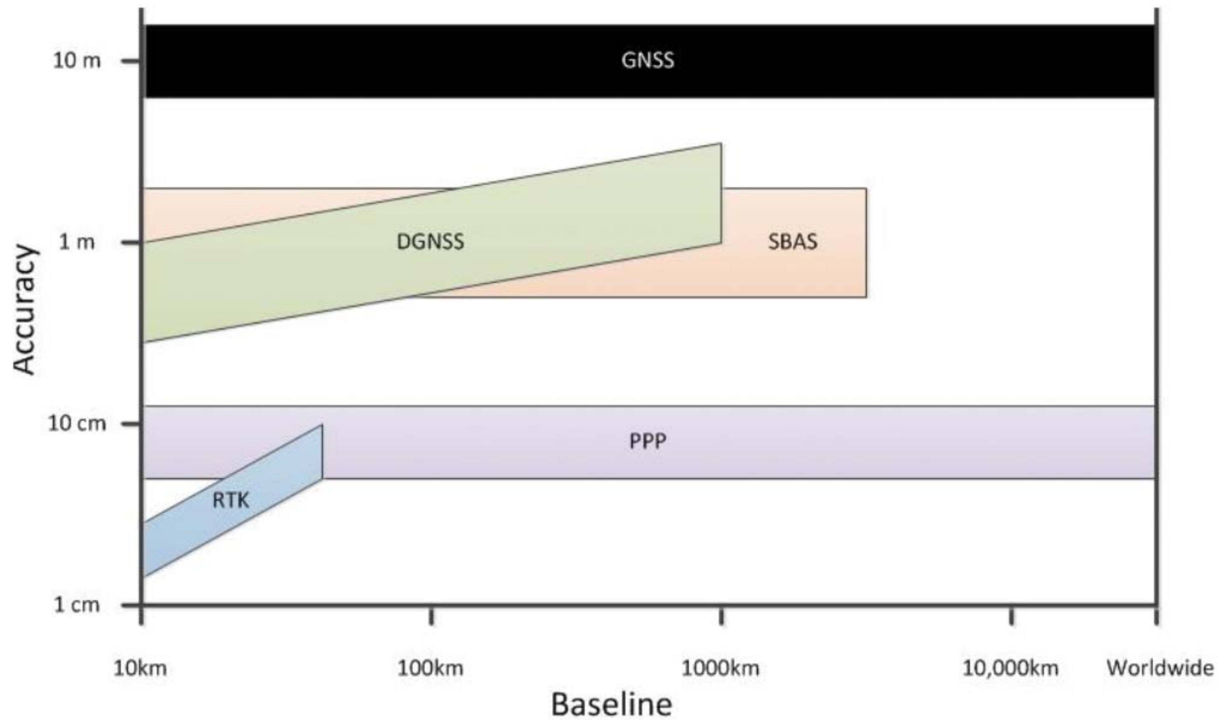
- Removes GNSS system errors to provide a high level of position accuracy
- Solution depends on GNSS satellite clock and orbit corrections generated from a network of global reference stations
  - Does not require base station
  - Corrections are delivered via satellite or over the Internet
  - A typical PPP solution requires time to converge to high accuracy in order to resolve any local biases
- Generally a fee to access base service from the providers



Source: https://www.novatel.com

Task 15

Which Correction Method?



A comparison of the accuracy and practical range of use for each of the method

Task 15

Comparison of Various Position Correction Techniques

	Base Station	Rover Station	Positioning Technique	Cost	Correction Source	Coverage	Accuracy
DGNSS	Receiver at known location	Requires one or more Constellations	Code-phase	Less expensive than RTK $	Receive correction from base station	~ 10s of Km	± 1m
SBAS	Reference station and Master station	User: SBAS capable receiver and a GNSS antenna	Code-phase	Free	Receive corrections from satellites.	Wide area or regional augmentation	± 2m
PPP	Network of global reference stations	User: • PPP compatible receiver • Antenna capable of receiving GNSS and L-Band frequencies	Carrier-phase	Subscription based $$	Receive corrections from satellites	Worldwide	± 3cm Long convergence time, ~ 20–30 min
RTK	Receiver at known location	Requires two or more constellations	Carrier-phase	Subscription based $$	Receive correction from base station	~ 50 Km	+/- 2cm or so Available immediately

Task 15

Radio ***T***echnical ***C***ommission for ***M***aritime for Position Correction

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- What is RTCM?
  - Message standard and data format for GNSS
  - **RTCM Special Committee 104** was formed to draft a standard format for the correction messages to ensure an open real-time DGPS system
  - The format is generally known as **RTCM SC 104**
  - RTCM is not instrument specific

Task 15

RTCM SC-104 Versions

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- RTCM - 2.0 (Code correction -> DGPS)
- RTCM - 2.1 (Code + Phase correction -> RTK)
- RTCM - 2.2 (…+ GLONASS)
- RTCM - 2.3 (….+ GPS Antenna Definition)
- RTCM - 3.0 (….+ Network RTK & GNSS)
  - Message type 1001 – GPS L1 observations at 5 Hz
  - Message type 1005 – Antenna Reference Point (ARP) coordinates at 2 Hz

Task 15

Position Correction for Different Intersection Configurations

Open Sky Clear Visibility Satellite Intersections

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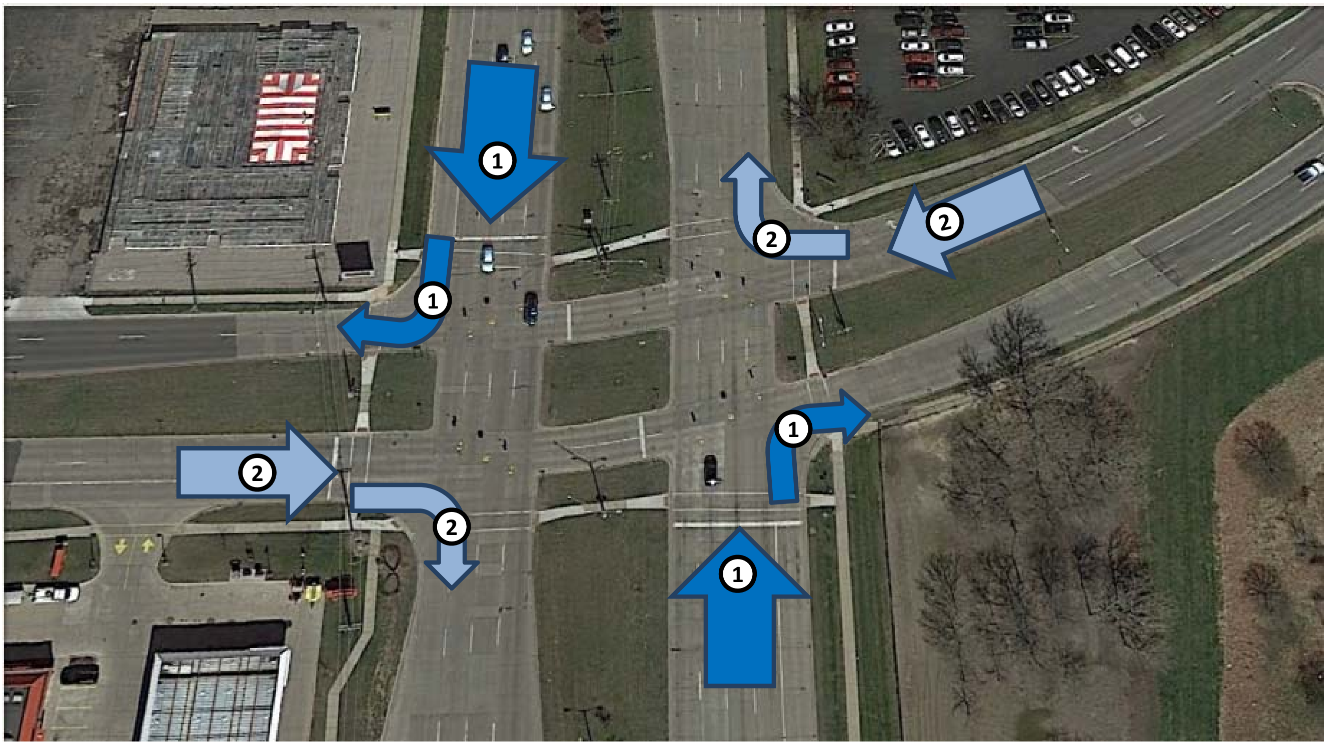

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Plotted data from Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure (V2I) Consortium

Intersection Configuration:

- Multiple lanes in each direction
- Near-far traffic lights in all direction

Complexity - Low:

- Simple – Straight through and right turn
- Maximum 2 signal phase associations – Straight and right turn movements
- Positioning challenge - Low

Position correction may not add significant benefit

- Limited lane-level map matching is required

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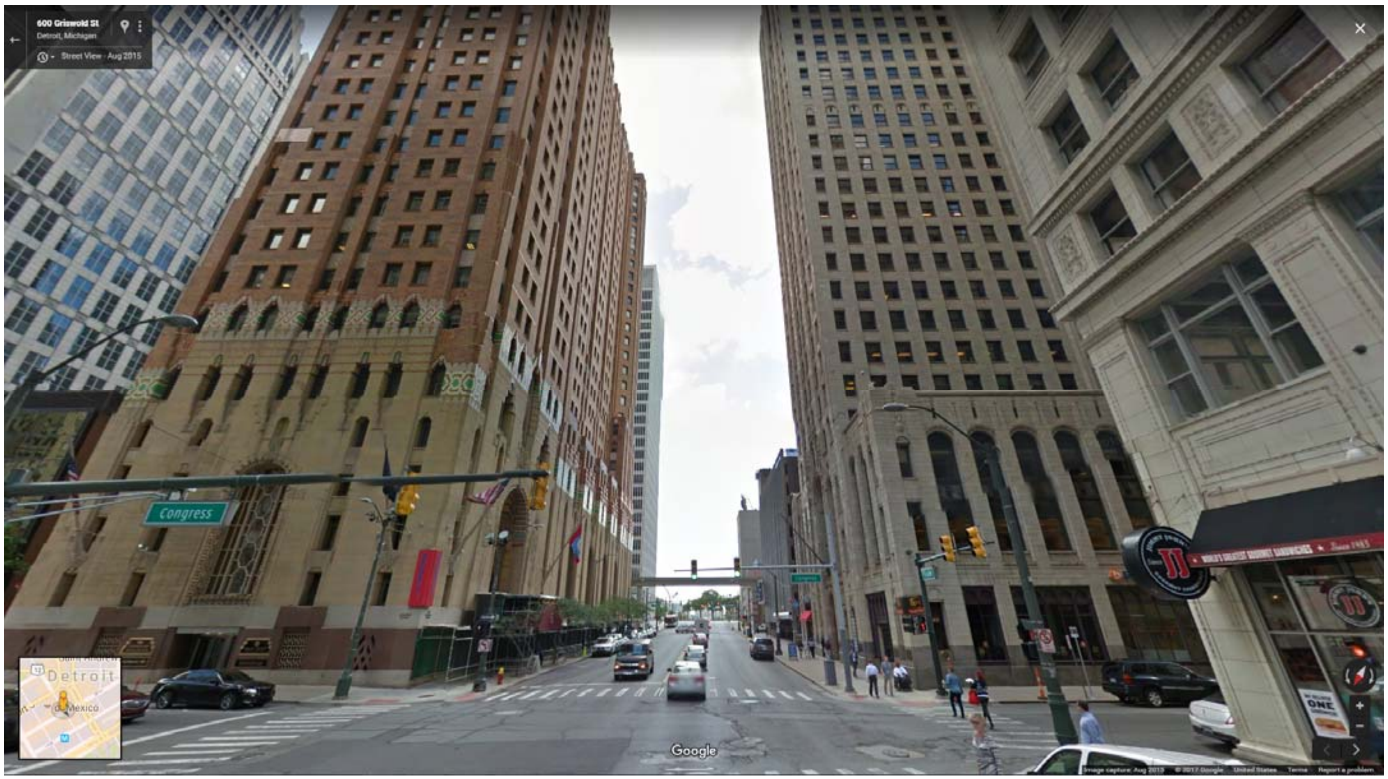
Low/Poor Satellite Visibility Intersections



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Intersection Configuration:

- Typical no Near-far traffic lights

Complexity - High:

- Multiple lanes in each direction
- Multiple signal phases in each direction
- Urban canyon, obstructed satellite visibility, makes it difficult to use correction
- Positioning challenge - High

Position correction would not provide required benefits

Task 15

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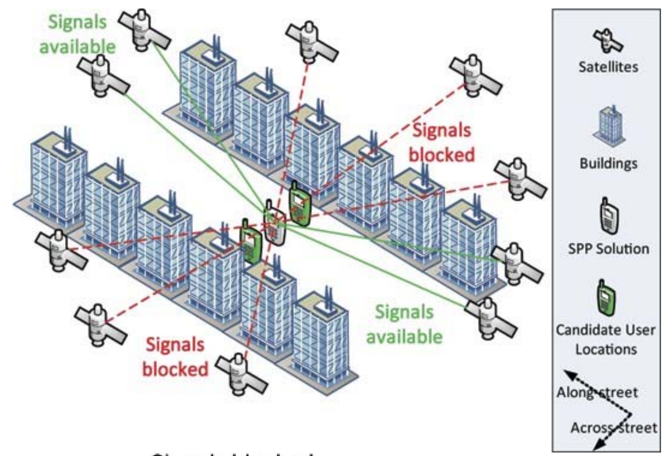
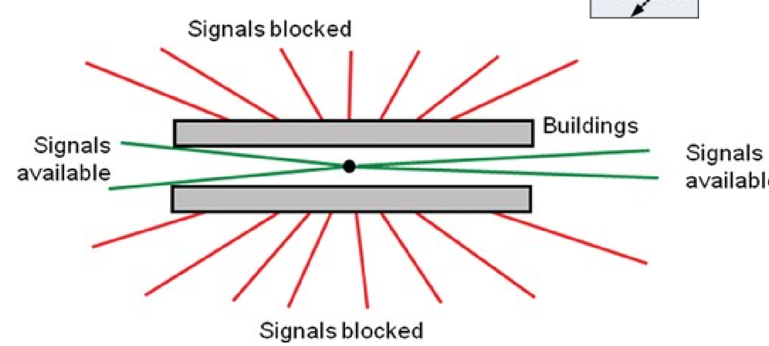
Positioning Challenge in Urban Canyon

- Lack of direct line-of-sight (LOS) signals from GNSS satellite constellations
- Forced to use signals that have multipath in them
- Surrounded by buildings that are parallel to the street,
  - which means that it is more likely to receive LOS signals from satellites that are along the street than across the street





Source: THE JOURNAL OF NAVIGATION (2011),64, 417–430.fThe Royal Institute of Navigationdoi:10.1017/S0373463311000087

Task 15

Open Sky Clear Visibility Satellite Intersections Complex SPaT/MAP

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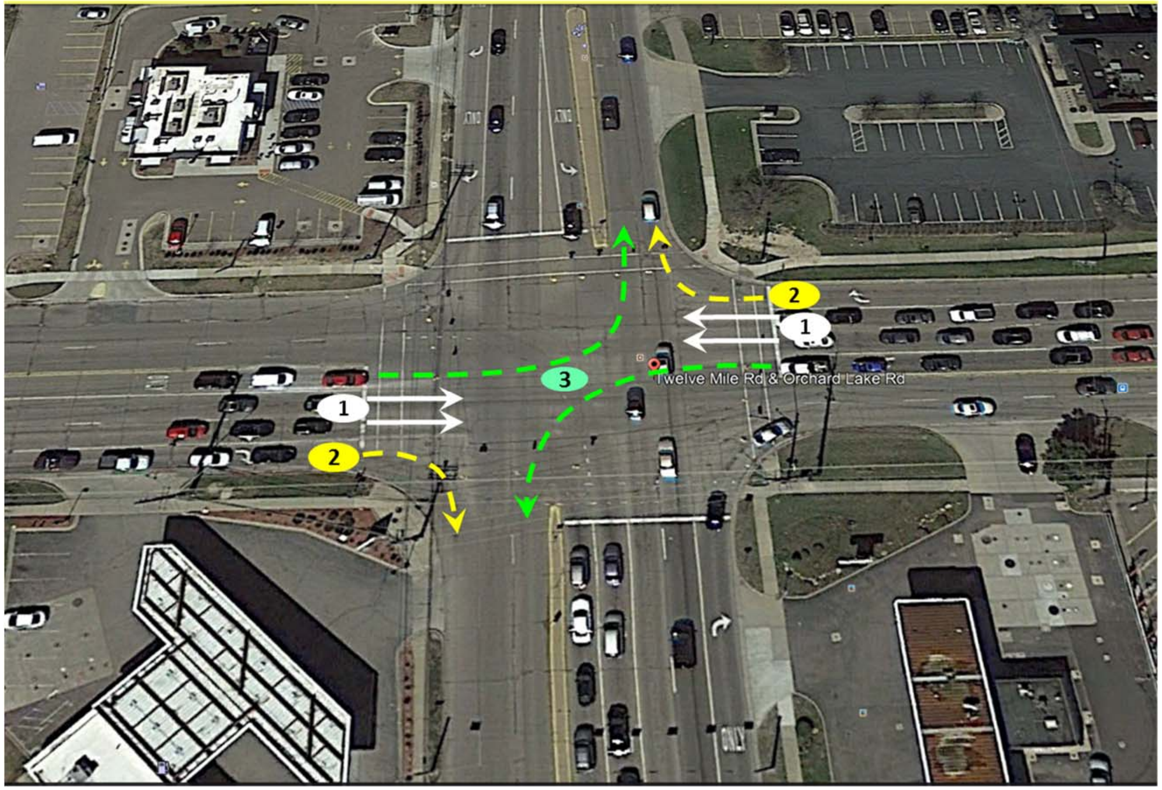

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Intersection Configuration:

- Typical, no near-far traffic lights

Complexity - High:

- Multiple lanes and multiple signals phases in each direction
- Lane-level positioning is required

Position correction would certainly provide required benefits

Task 15

Benefits from Position Correction

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HONDA NISSAN HYUNDAI Ford SUBARU GM VOLKSWAGEN mazda VOLVO

Benefits from Position Correction		
Satellite Visibility → / Intersection Configuration ↓	**Open Sky High Satellite Visibility**	**Obstructed Satellite Visibility**
Combination of Less Complex SPaT/MAP Configuration	Some benefit can be achieved	May not achieve desired benefit
Combination of Highly Complex SPaT/MAP Configuration	**Most benefit can be achieved**	Cannot achieve desired benefit

Questions / Discussion

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