FORCES and the SmartAmerica Challenge

Alex Bayen, Joe Butler

Gabor Karsai, Brian Peterson

Connected Corridors Systems Test Bed

SmartAmerica was the opportunity for two of the FORCES teams to integrate their respective testbeds:

* Mobile Millennium / Connected Corridors
* C2 Wind Tunnel

Outline of the presentation:

* General context of Connected Corridors (Bayen)
* Connected Corridors testbed (Butler, Peterson)
* C2 Wind Tunnel testbed (Karsai)
* SmartAmerica context, demo and movie (Reilly, Karsai)

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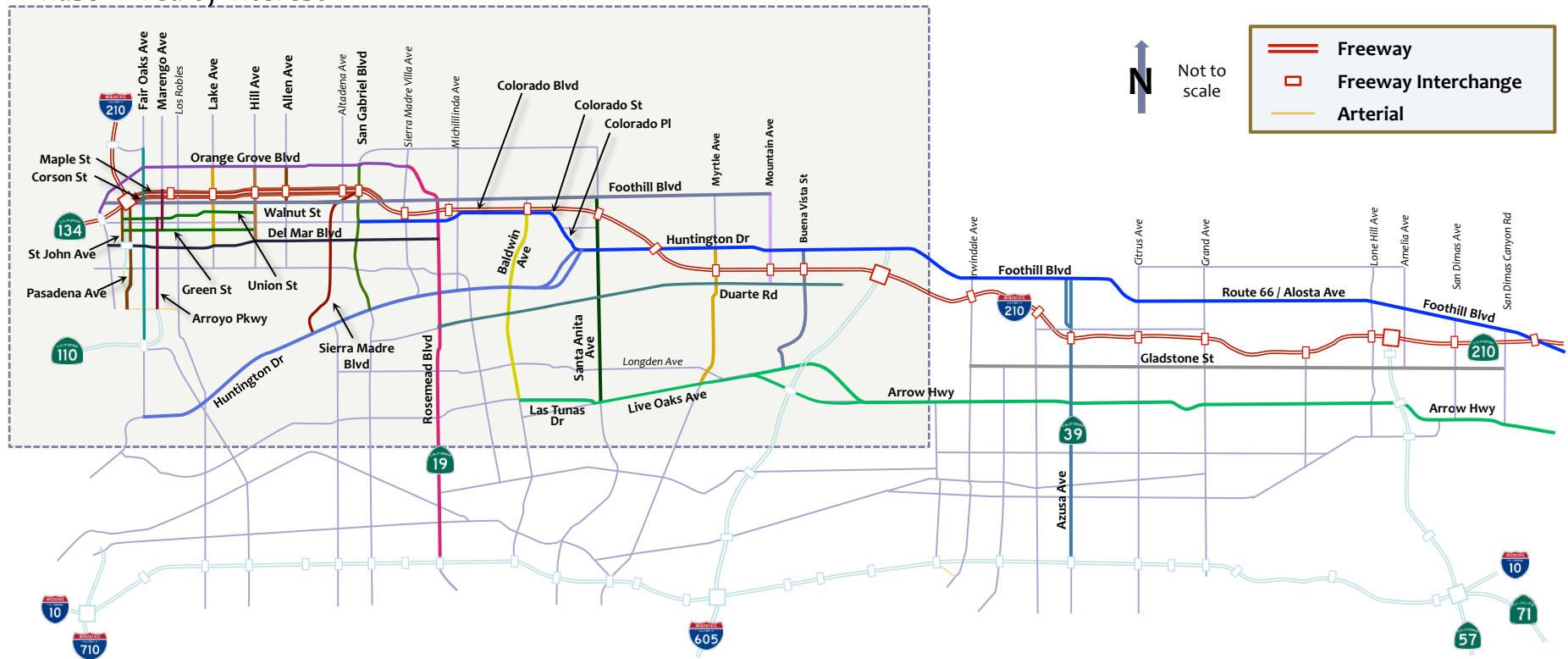
The next big transportation CPS (traffic management)

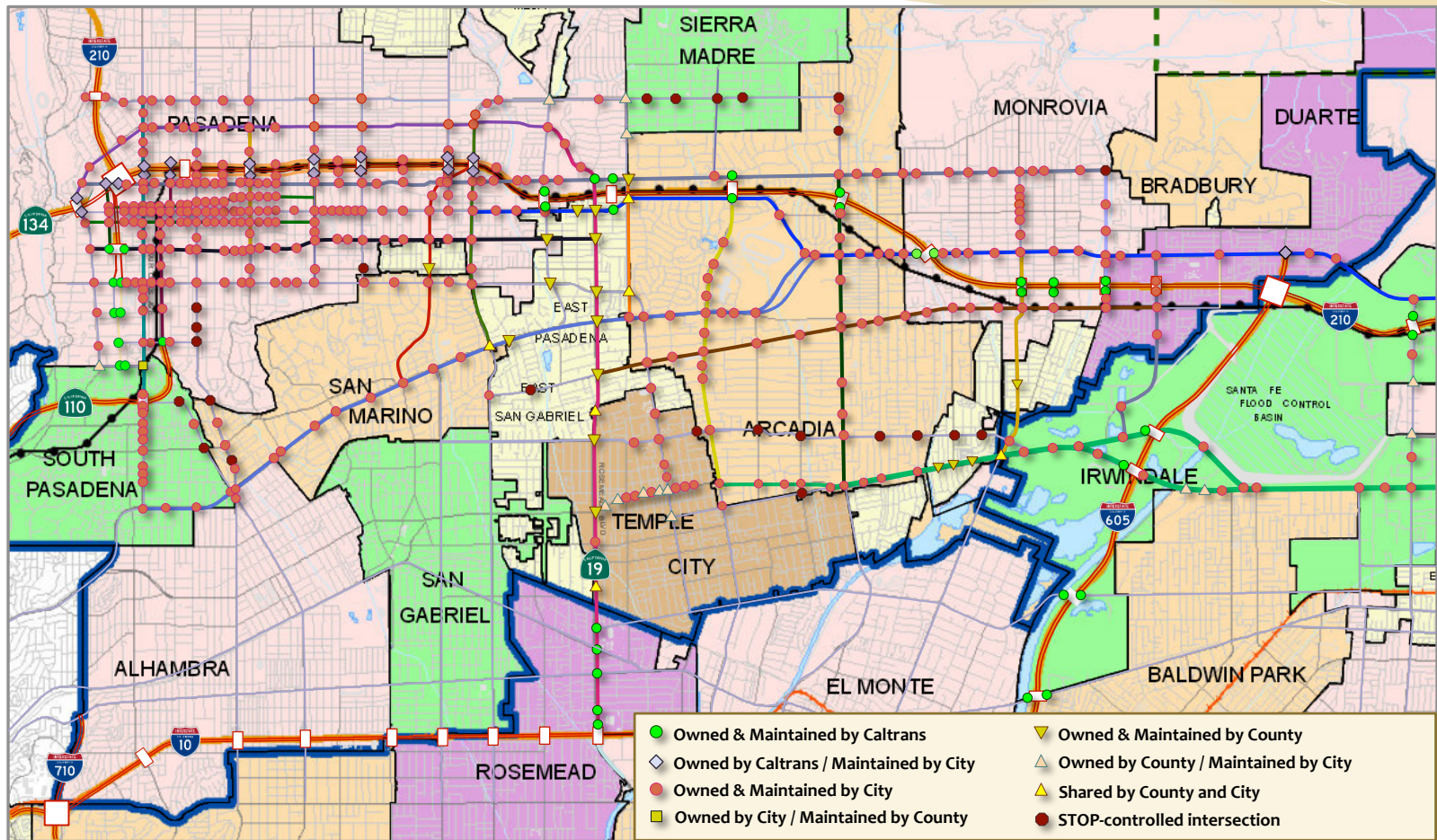# Scope of the Connected Corridor deployment

Phase 1 Area of Interest
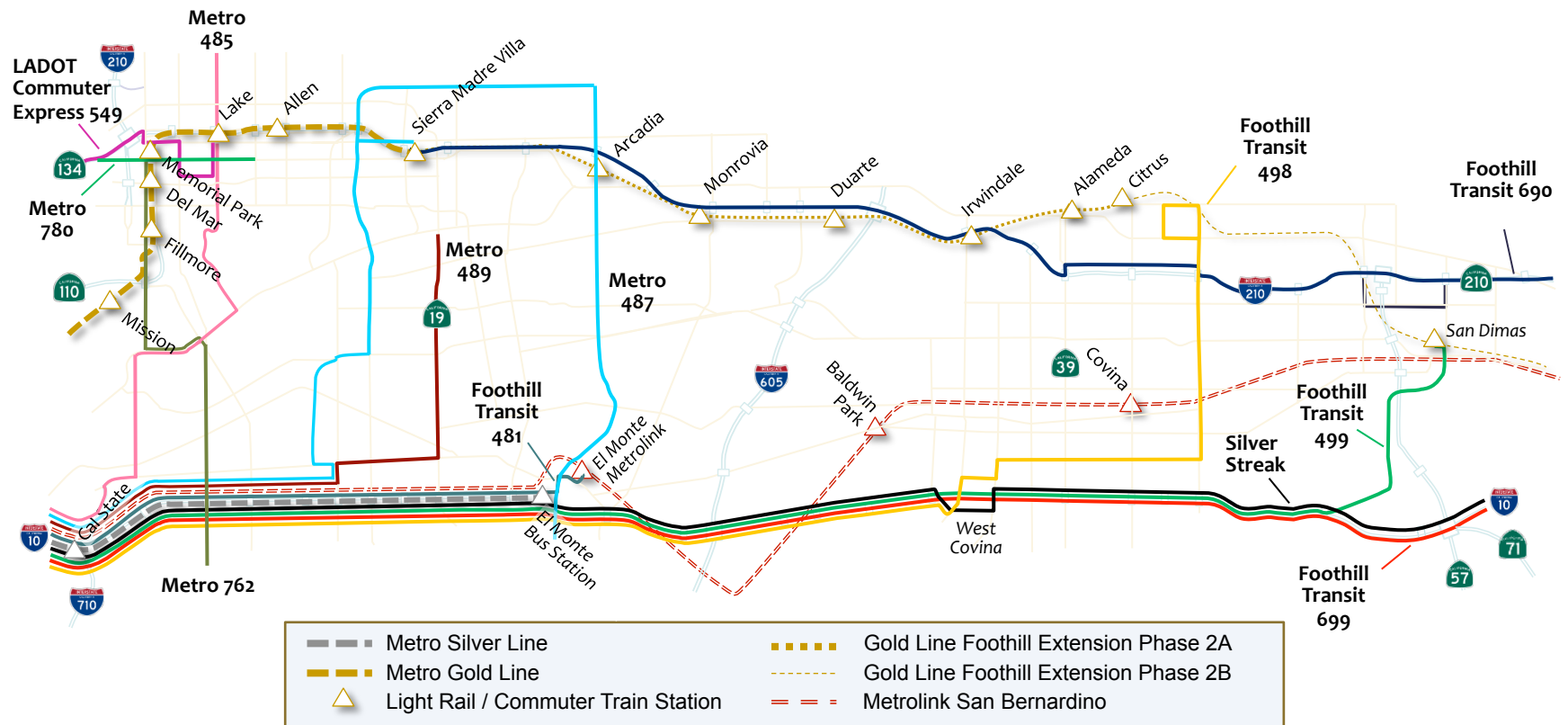
Sensing in the integrated corridor management

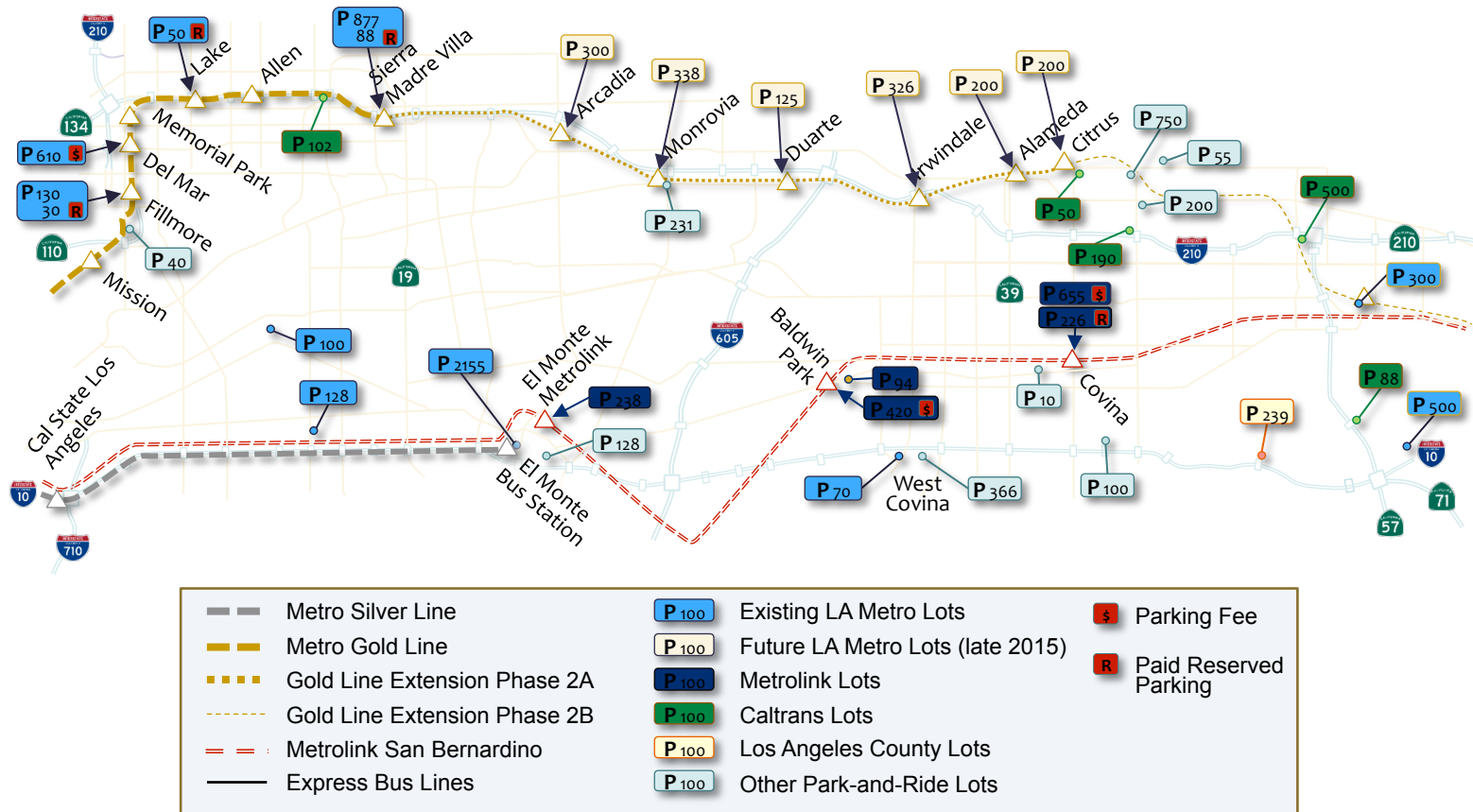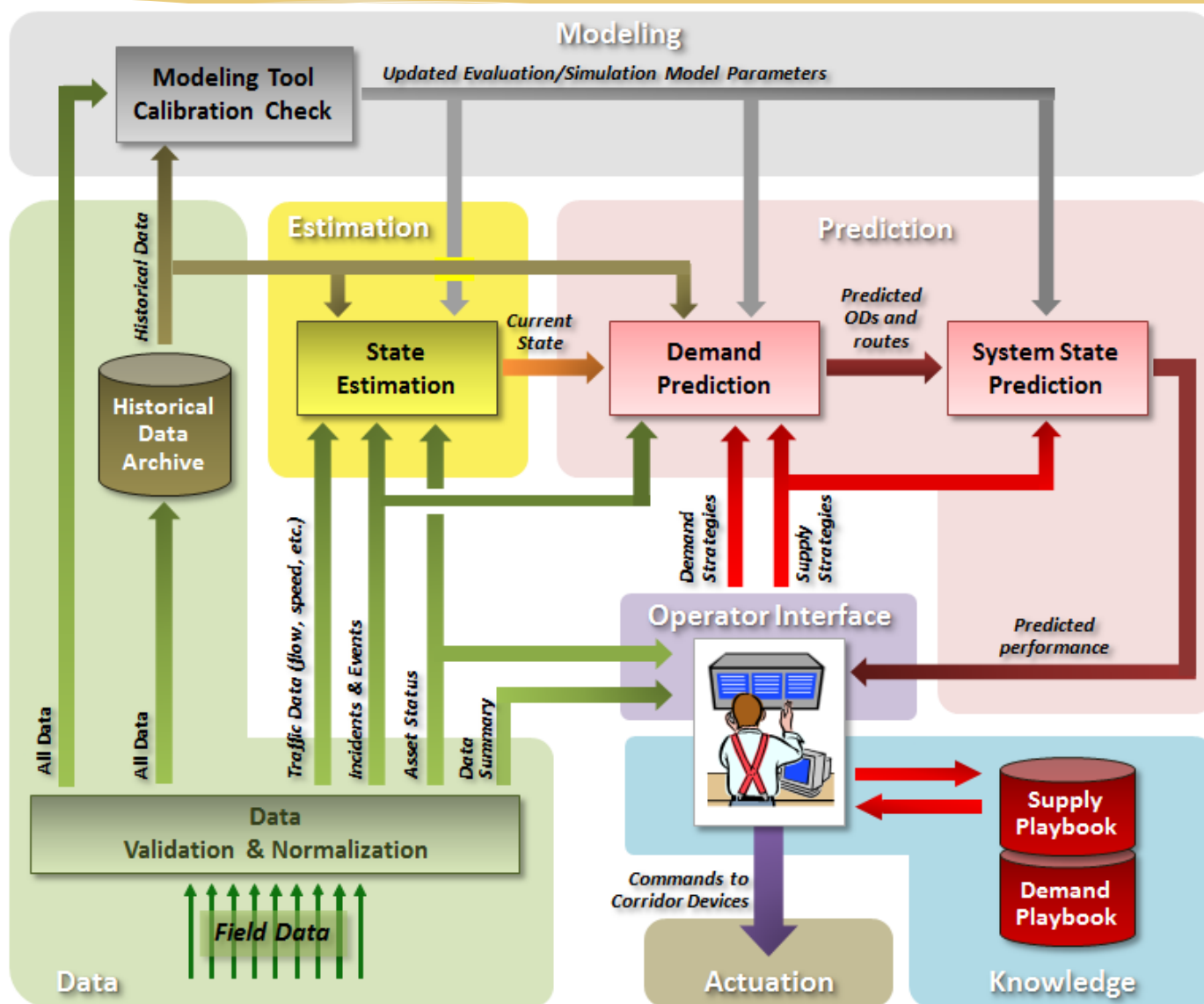# Actuation in the Connected Corridor deployment site

Integration with transit

Integration with other infrastructure

CPS operational decision support system

Institutional architecture for connected corridors
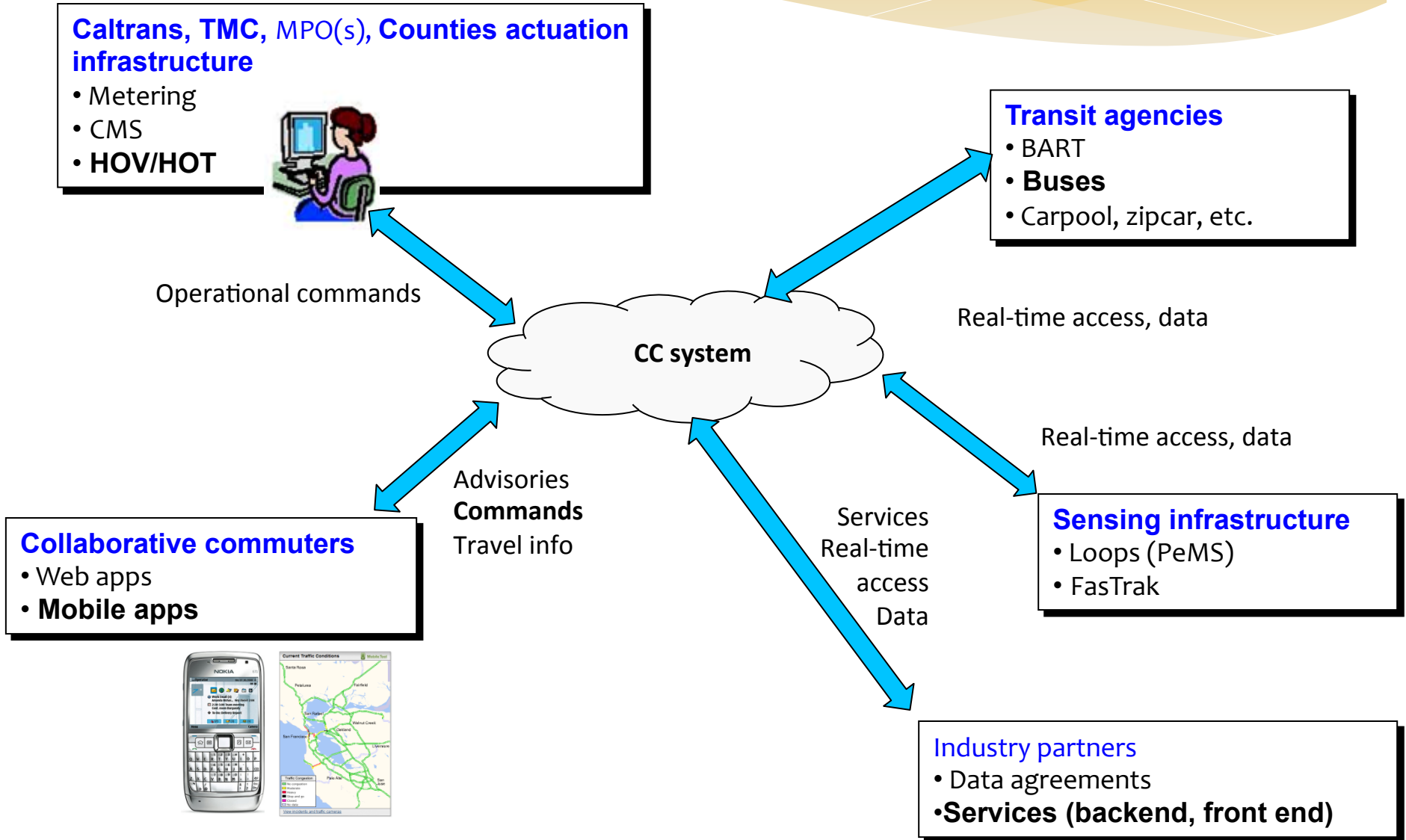
Caltrans, TMC, MPO(s)**, Counties actuation infrastructure**
- Metering
- CMS
- **HOV/HOT**

Transit agencies
- BART
- **Buses**
- Carpool, zipcar, etc.

Operational commands

CC system

Real-time access, data

Advisories
Commands
Travel info

Services
Real-time
access
Data

Real-time access, data

Collaborative commuters
- Web apps
- **Mobile apps**

Sensing infrastructure
- Loops (PeMS)
- FasTrak

Industry partners
- Data agreements
- **Services (backend, front end)**

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Connected Corridors Systems Test Bed

BRIGHT IDEAS

* In partnership with Caltrans, Berkeley is building a unique system

* Professional – scheduled for deployment on LA's 210 freeway in 2016

* Based on successful Mobile Millennium effort – real world effort with continued success at Google, Apple, Microsoft, Nokia, NAVTEQ

* Big data at high processing speeds

* Opportunity for academic and commercial partners to utilize the test bed, research, results, and the software developed in the program

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Connected Corridors Test Bed Components
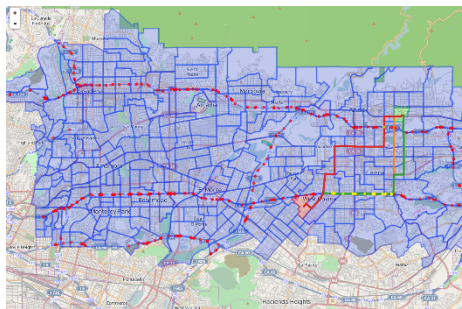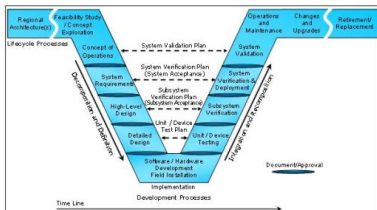
* Professional Scalable Maintainable Software

* Disaster Resistant High Performance Hardware

* Professional Staff Support

* Professional Database (Oracle)

* Commercial partnerships

* New Data Sources

* Consistency over time so that functionality continues when researchers graduate and new researchers wish to expand on previous work

* Training researchers in team dynamics and professional engineering practices

Data and Process Integration

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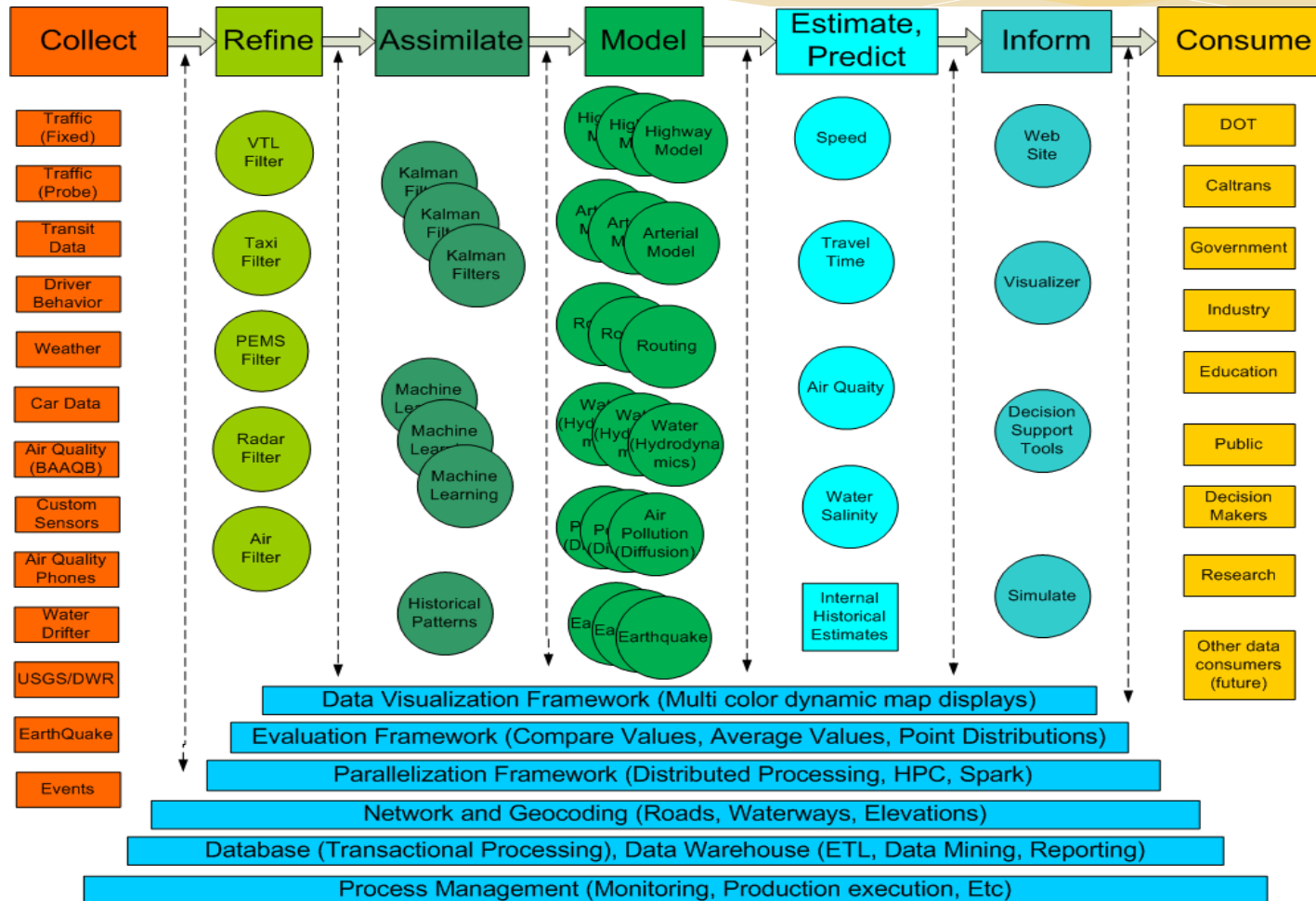
Big Data: Analytics and Control
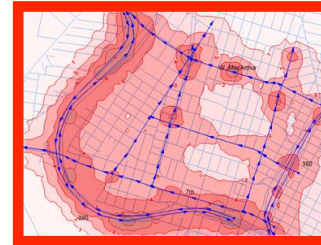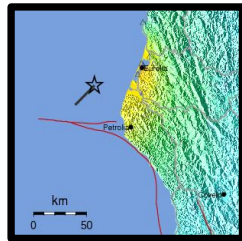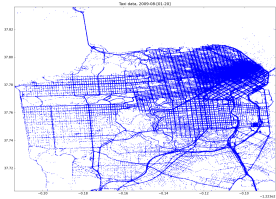
Crowdsourcing + modeling + sensing + data assimilation + HPC

* Unique partnerships with Industry and Public Data Sources for Big Data
* Relationship with NERSC for high performance parallel computing
* Access through our partners to:
    * Entire California Road Network and Points of Interest
    * Probe (GPS) data from vehicles/travelers – Every few seconds to minutes
    * Traffic sensor data – LA, San Diego, San Francisco Bay and smaller cities
    * Many types of transportation system information

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CPS meets Big Data: infrastructure

* Unique partnerships with Industry and Public Data Sources
* Oracle
* Size: Currently 7 TB
* Contains:
  * Entire California Road Network and Points of Interest
  * Traffic sensor (PeMS) data – 30 sec freq, LA, San Diego, San Francisco Bay areas
  * Probe (cell phone, GPS, bluetooth) data – position/velocity
  * Network representation of roads of interest and traffic model information (traffic demand, splits, boundary flows, behavior information)
  * Changeable Message Sign data
  * Starting Collection and Storage of Signal Plans
  * Results

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CPS meets Big Data: infrastructure

Example: one day of probe data from one of our GPS data providers

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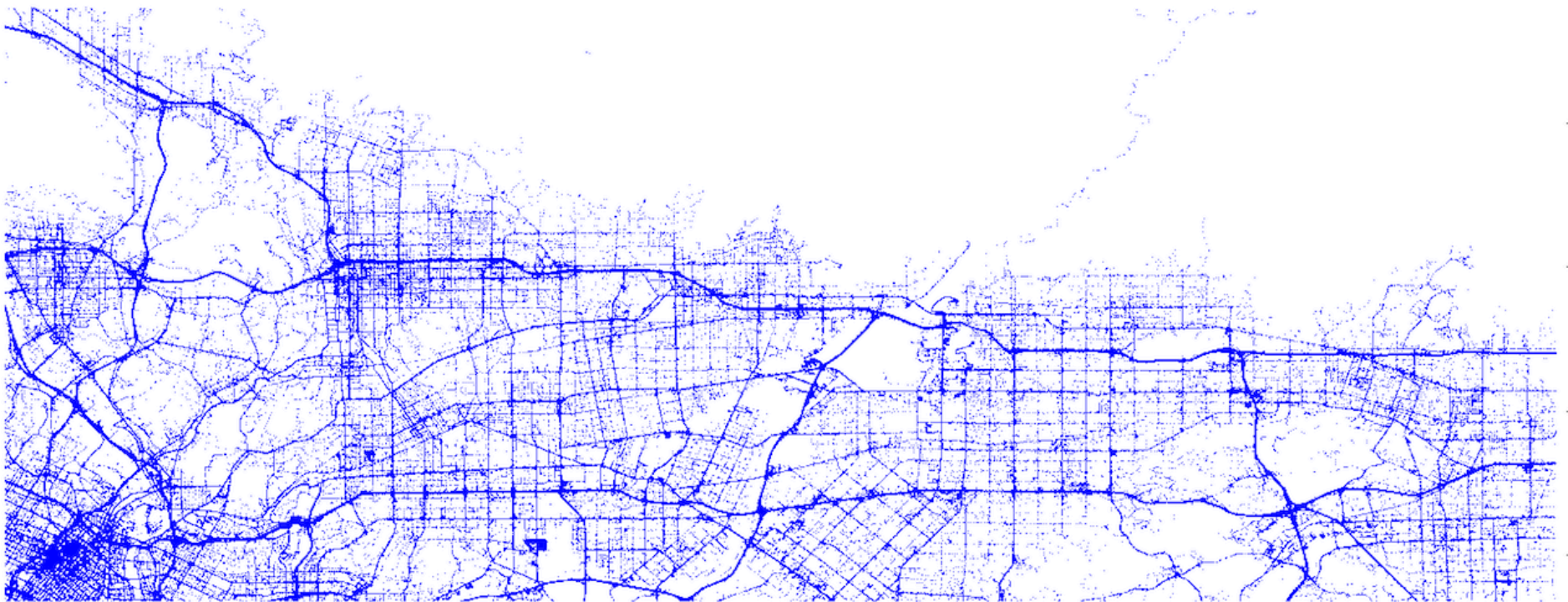
Example - Air Pollution Estimation

* Requires Feeds
  * Static Traffic
  * Probe Traffic
  * Weather
  * Altitude
  * Static Pollution Sensors
  * Probe Pollution Sensors
* Multiple Models
  * Traffic Models
  * Pollution Models
  * Diffusion Models
  * Assimilation Models
* Models feed models
  * Highway → Air Pollution
  * Air Pollution → Diffusion
* Multiple Visualizations
  * Segment
  * Tiles
  * Cell Phones
* Multiple Outputs
  * Cell Phones
  * Web Sites
  * Data Feeds

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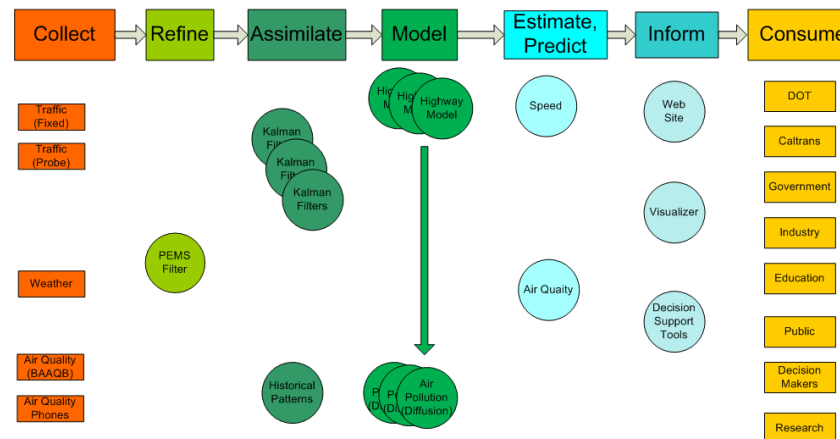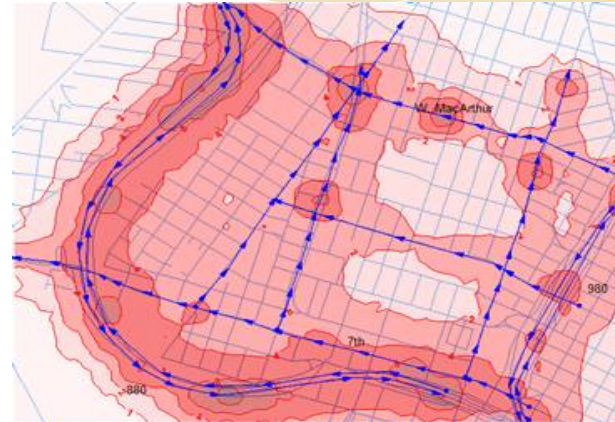
Connected Corridors/C2 WT Integration

* First generation
  * Take Berkeley's ccFramework – integrate with Vanderbilt's C2 Wind Tunnel
  * Simulate real world traffic, add traffic control optimization, demonstrate C2 integration

Traffic Control & Optimization

Command & Control

Real World Traffic

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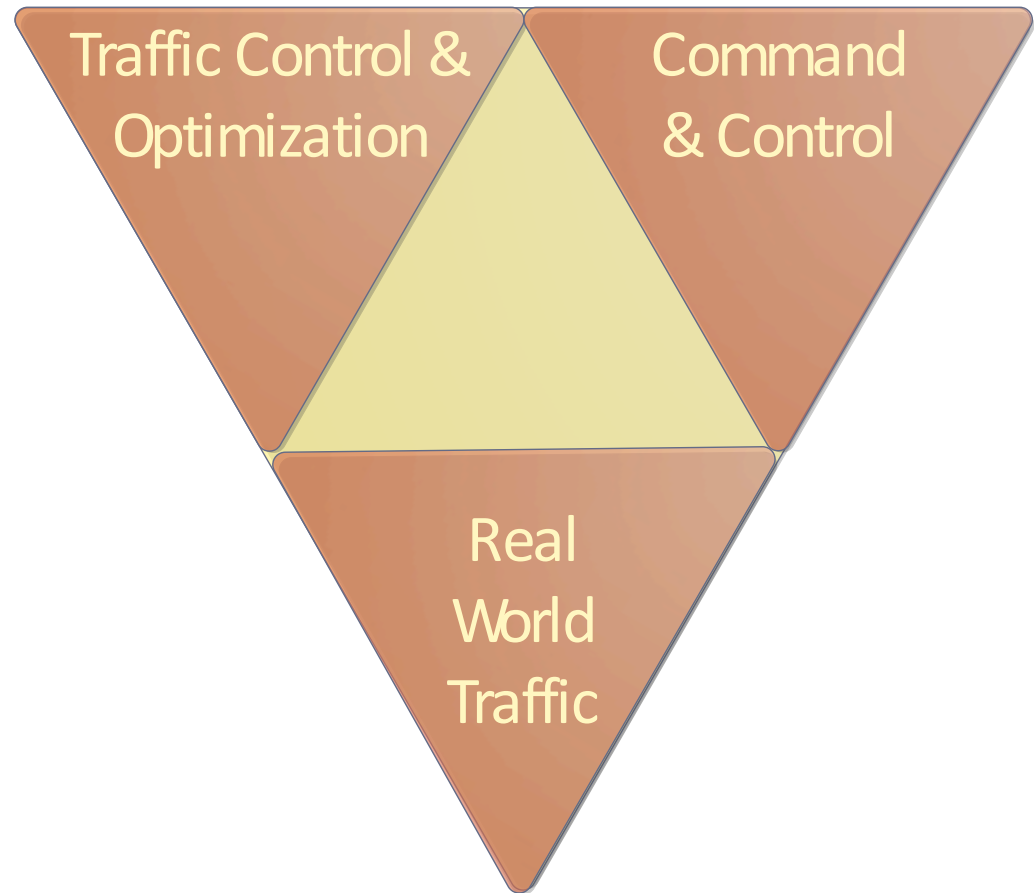
Connected Corridors/C2 WT Integration

* Trio
  * ccFramework – Optimization
  * C2 WT – Command and Control
  * TSS Aimsun – simulated real world
* Server component:
  * Control of simulation
  * Intercept ramp meter control
  * Simulate attack and recovery
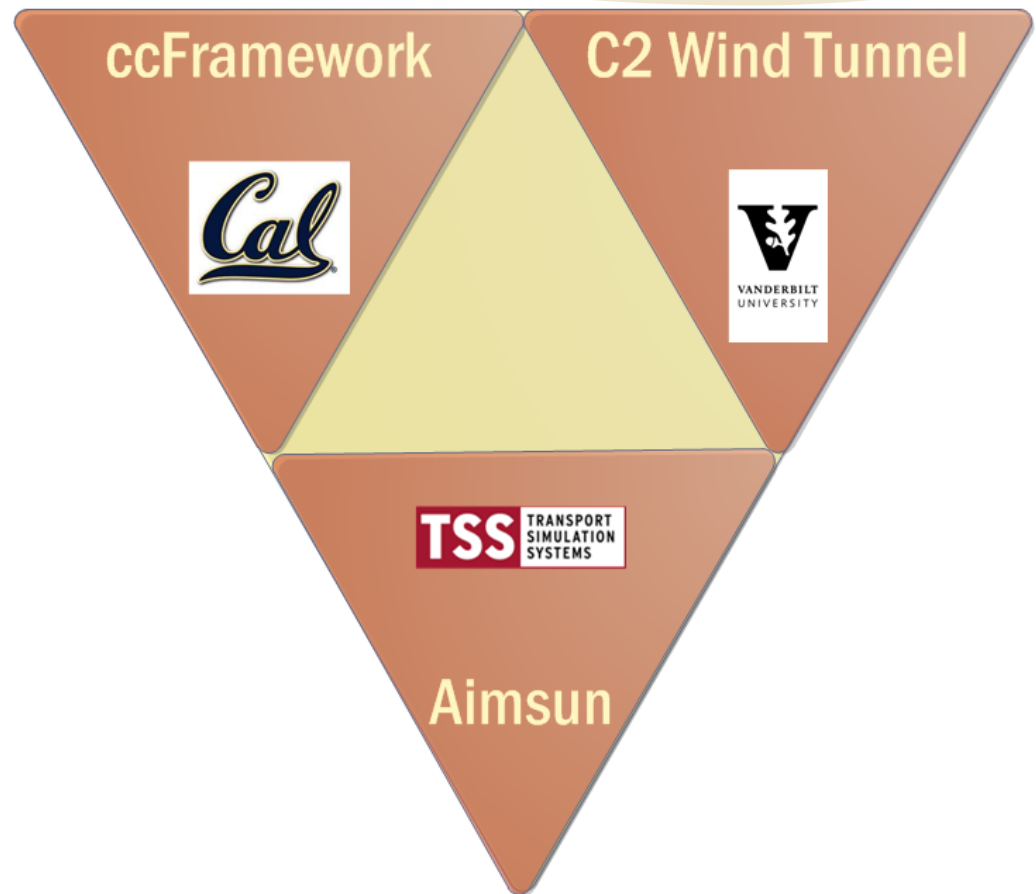
ccFramework
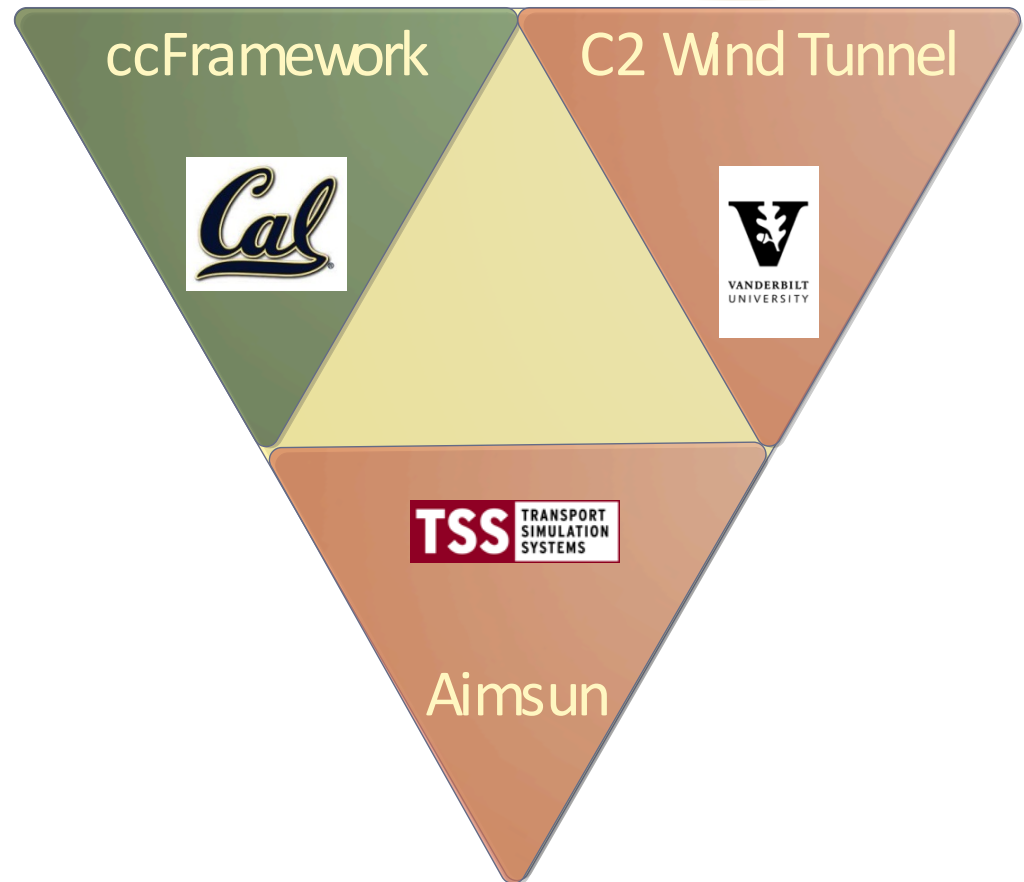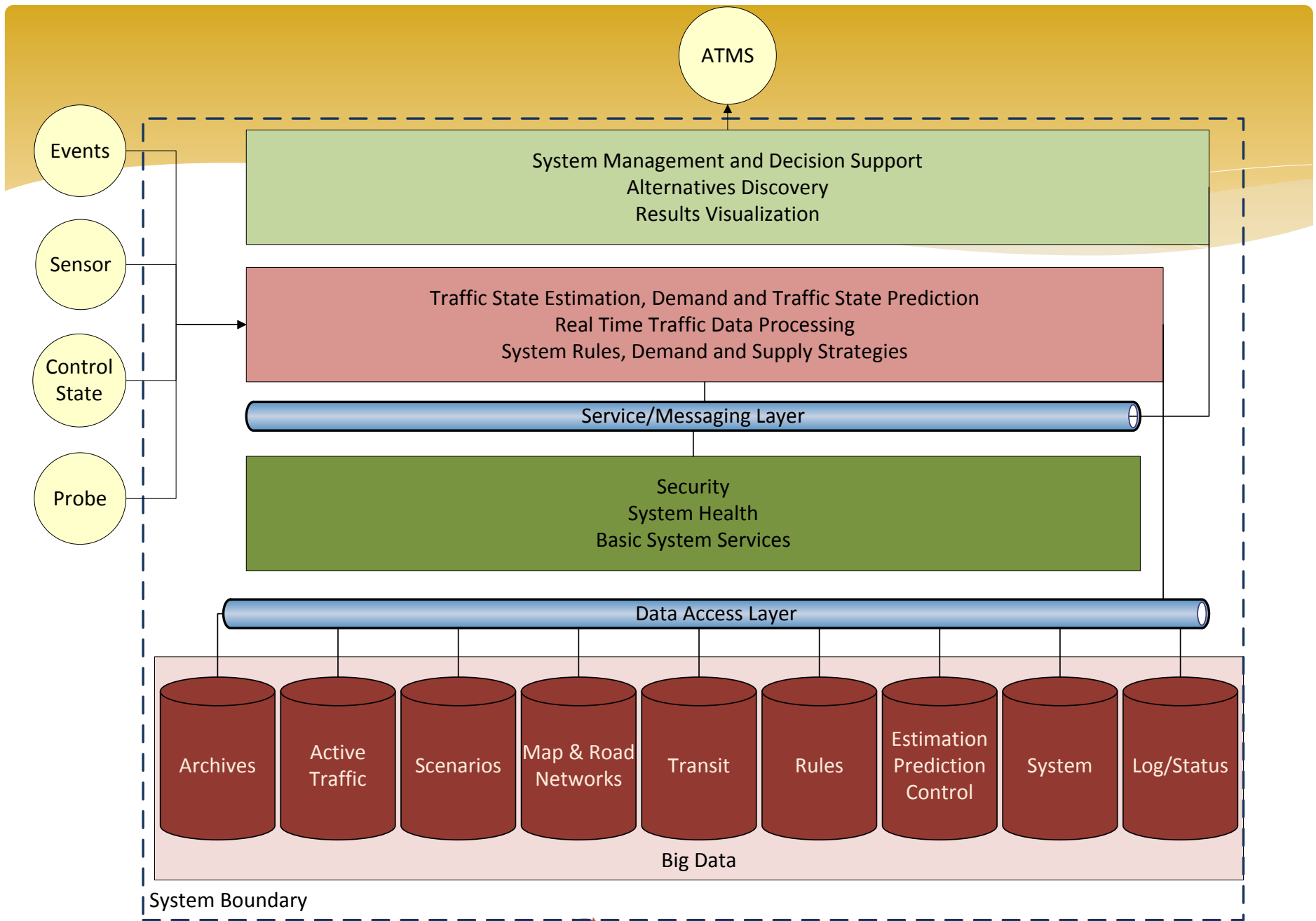
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ATMS

Events

Sensor

Control State

Probe

System Management and Decision Support
Alternatives Discovery
Results Visualization

Traffic State Estimation, Demand and Traffic State Prediction
Real Time Traffic Data Processing
System Rules, Demand and Supply Strategies

Service/Messaging Layer

Security
System Health
Basic System Services

Data Access Layer

| Archives | Active Traffic | Scenarios | Map & Road Networks | Transit | Rules | Estimation Prediction Control | System | Log/Status |

Big Data

System Boundary

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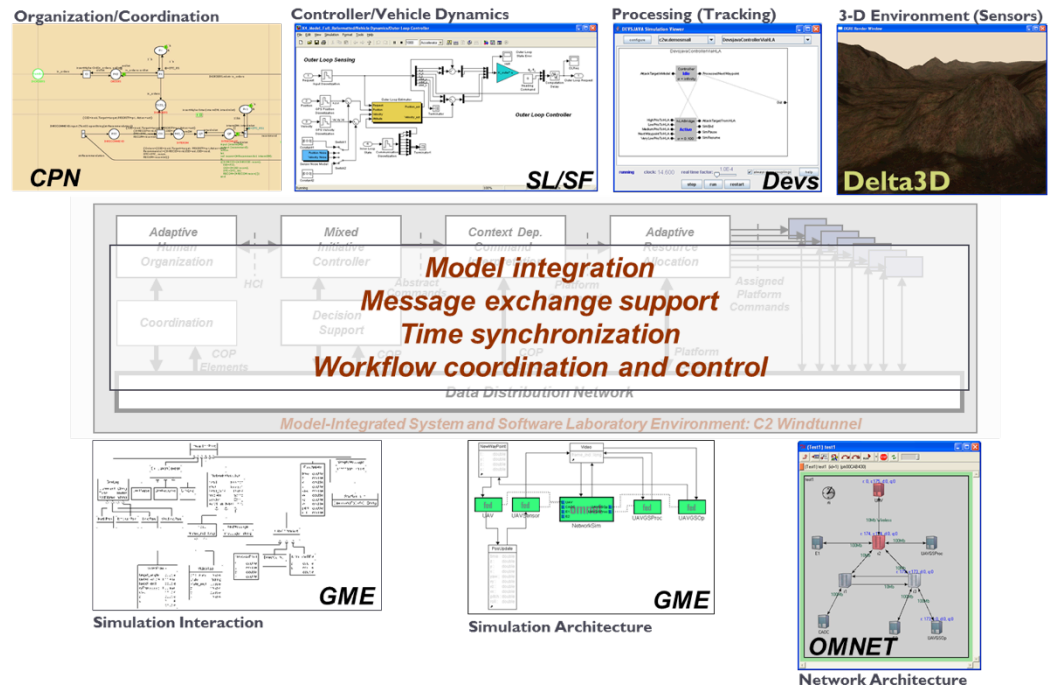CYBER-PHYSICAL SYSTEMS

Command and Control Wind Tunnel

∗ **Vanderbilt's** Command and Control (C2) Wind Tunnel is a virtual laboratory for experimentation with simulated worlds that include both *physical* and *cyber* elements that are tightly coupled and interact. It has been used to evaluate C2 systems for the military, and to experiment with cyber defenses in industrial control (SCADA) systems. The tool is open source and is used in various research projects and in the industry.

Simulators:
∗ Matlab/Simulink
∗ CPN Tools
∗ DEVS
∗ Omnet++
∗ …

Services:
∗ Message exchange
∗ Time synchronization
∗ Message translations

Organization/Coordination · Controller/Vehicle Dynamics · Processing (Tracking) · 3-D Environment (Sensors)

CPN · SL/SF · Devs · Delta3D

Model integration
Message exchange support
Time synchronization
Workflow coordination and control

Model-Integrated System and Software Laboratory Environment: C2 Windtunnel

Simulation Interaction — GME
Simulation Architecture — GME
OMNET — Network Architecture

Omnet++ - Cyber effects

* **Simulated cyber effects:**
  * Disable network: block network
  * Disable node: block node
  * Replay: capture packets and replay them
  * Out of order packets: scramble packet order
  * Sniffer: capture packets in flight
  * Modify route
  * Delay node – slow down specific host
  * Network filter – block specific packets going through a node
* **Other effects** (work in progress):
  * DNS Poisoning
  * Packet modification
  * Masquerading (as another node)
  * Data injection (inject bogus packets)
  * Disable link (disable specific link)
  * Delay path (slow down a specific path)
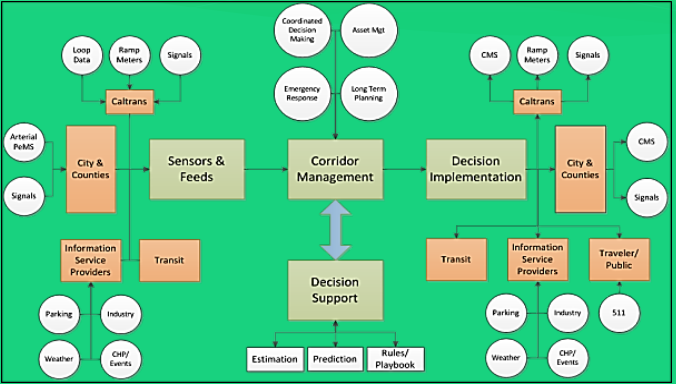
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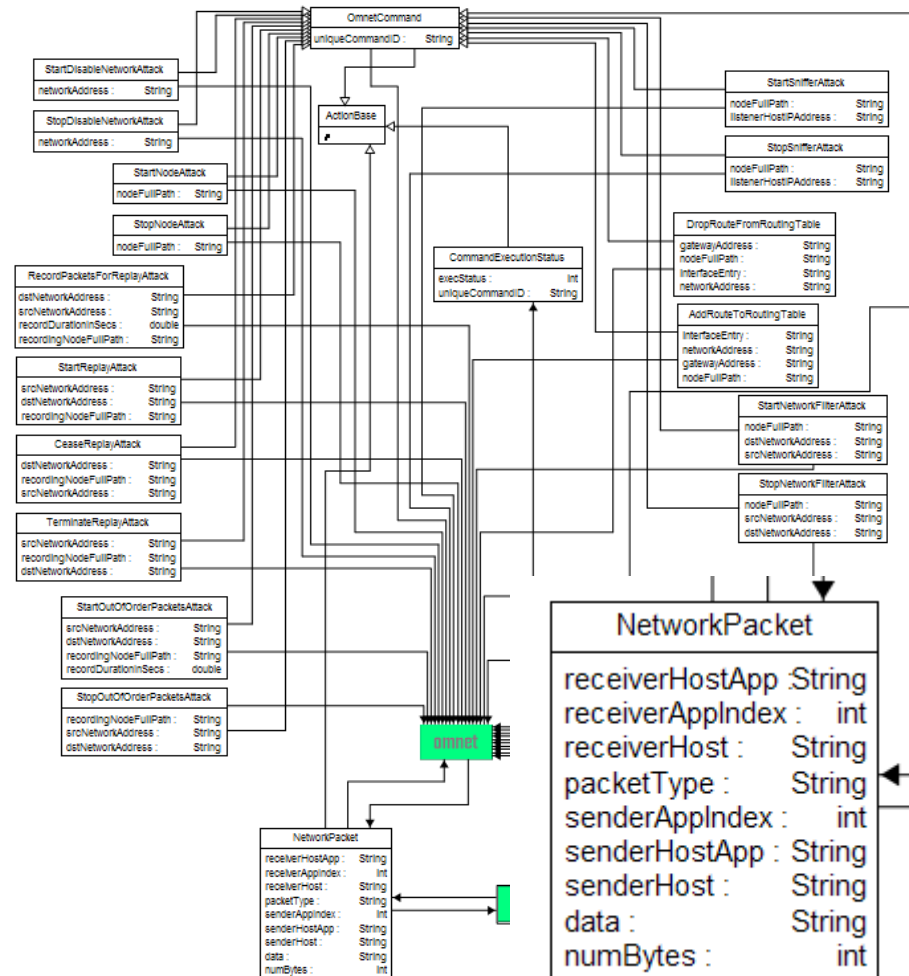
Integrated CPS Testbed

Our Solution:

Connected Corridors (CC)

+

High-fidelity simulation software (C2WT)
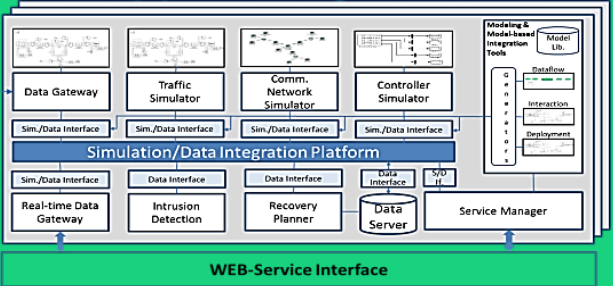
Well-managed and resilient traffic flows

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CPS Testbed

* The CPS testbed / system integrates **advanced control algorithms** and high-fidelity **simulation software** with real-time data to *predict* and *manage* traffic flows, to support resilience to cyber attacks.

▸ Use cases

Off-line

  ▸ High-fidelity simulation of road traffic, based on real data
  ▸ Development and evaluation of novel control algorithms – before they are applied
  ▸ Study of cyber effects on the networks and on the system
  ▸ Training of system operators in preparation for emergencies

On-line

  ▸ Real-time monitoring of traffic and predictive simulation
  ▸ Real-time control of traffic by ramp metering
  ▸ Real-time situational awareness about the status of the network

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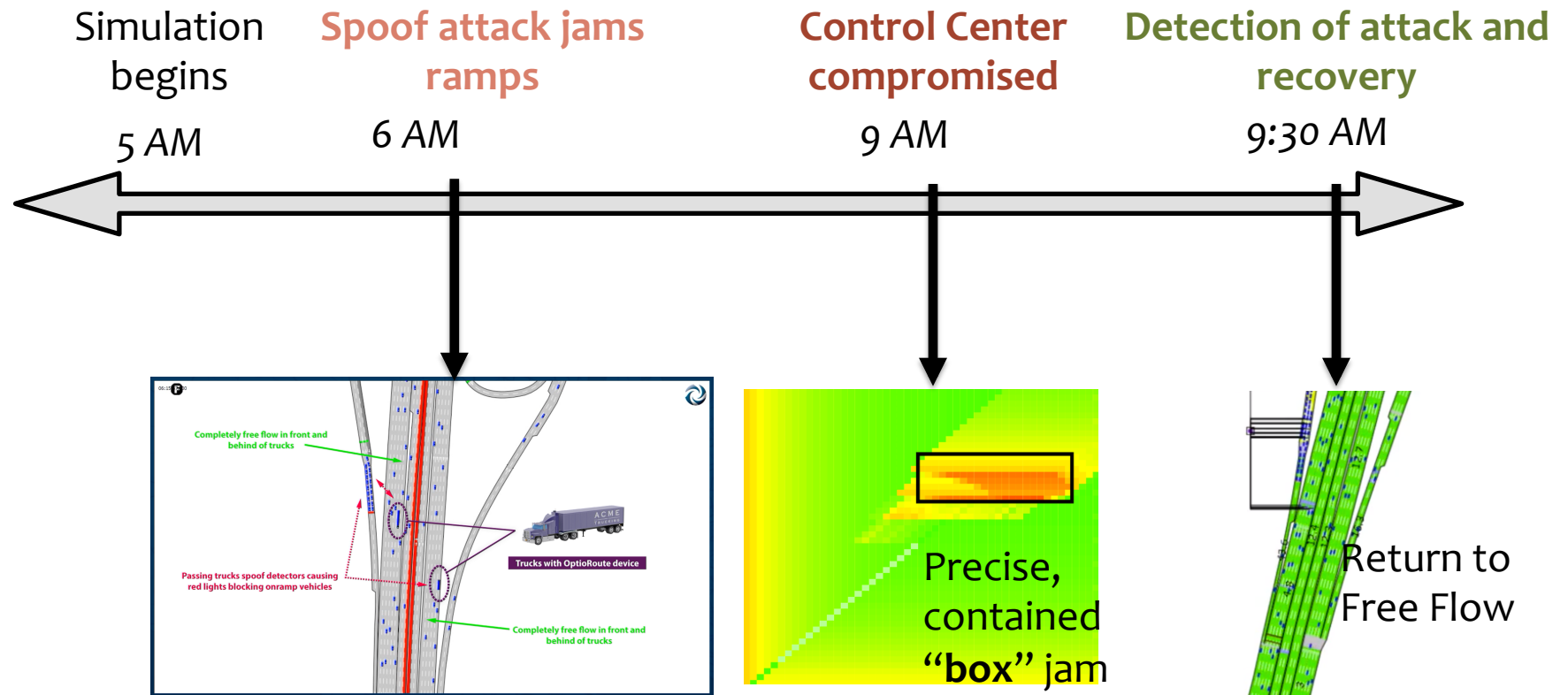
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The SmartAmerica Challenge: scenarios

Scenario Timeline

Simulation begins	Spoof attack jams ramps	Control Center compromised	Detection of attack and recovery
5 AM	6 AM	9 AM	9:30 AM

Completely free flow in front and behind of trucks

Passing trucks spoof detectors causing red lights blocking onramp vehicles

Trucks with OptioRoute device

Completely free flow in front and behind of trucks

Precise, contained "**box**" jam

Return to Free Flow

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Movie preview: the attack shown in the movie is real: FORCES is already able to replicate it
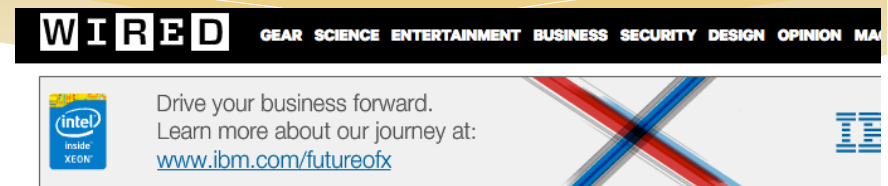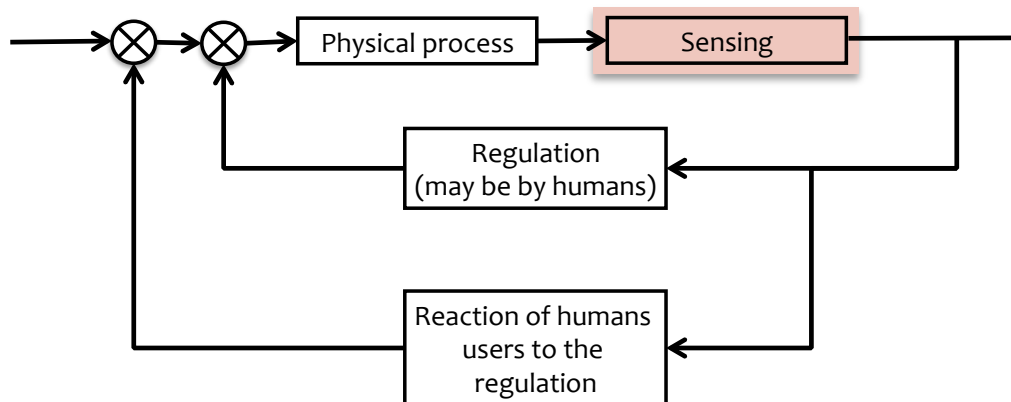
The *Italian Job* (2003)

The "real" *Italian Job* (2007)

NC DOT signs hacked (2014)

Snail operations (2014)

Waze / Google hacked (2014)

Sensys Attack (2014)

WIRED — GEAR SCIENCE ENTERTAINMENT BUSINESS SECURITY DESIGN OPINION MA

THREAT LEVEL — cybersecurity — hack and cracks

Hackers Can Mess With Traffic Lights to Jam Roads and Reroute Cars

BY KIM ZETTER 04.30.14 | 6:30 AM | PERMALINK

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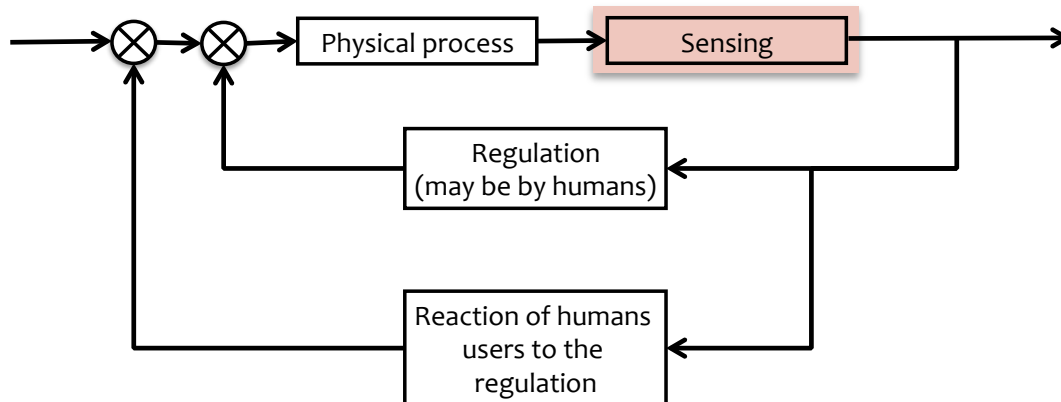
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Cesar Cerrudo in downtown New York City, conducting field test of vulnerable traffic sensors. Photo: Courtesy of Cesar Cerrudo

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Hacking Traffic Signal Data from a Drone

Hacking Traffic Signal Data from a Drone

Select and shot
Fake traffic

Physical process → Sensing

Regulation (may be by humans)

Reaction of humans users to the regulation

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