

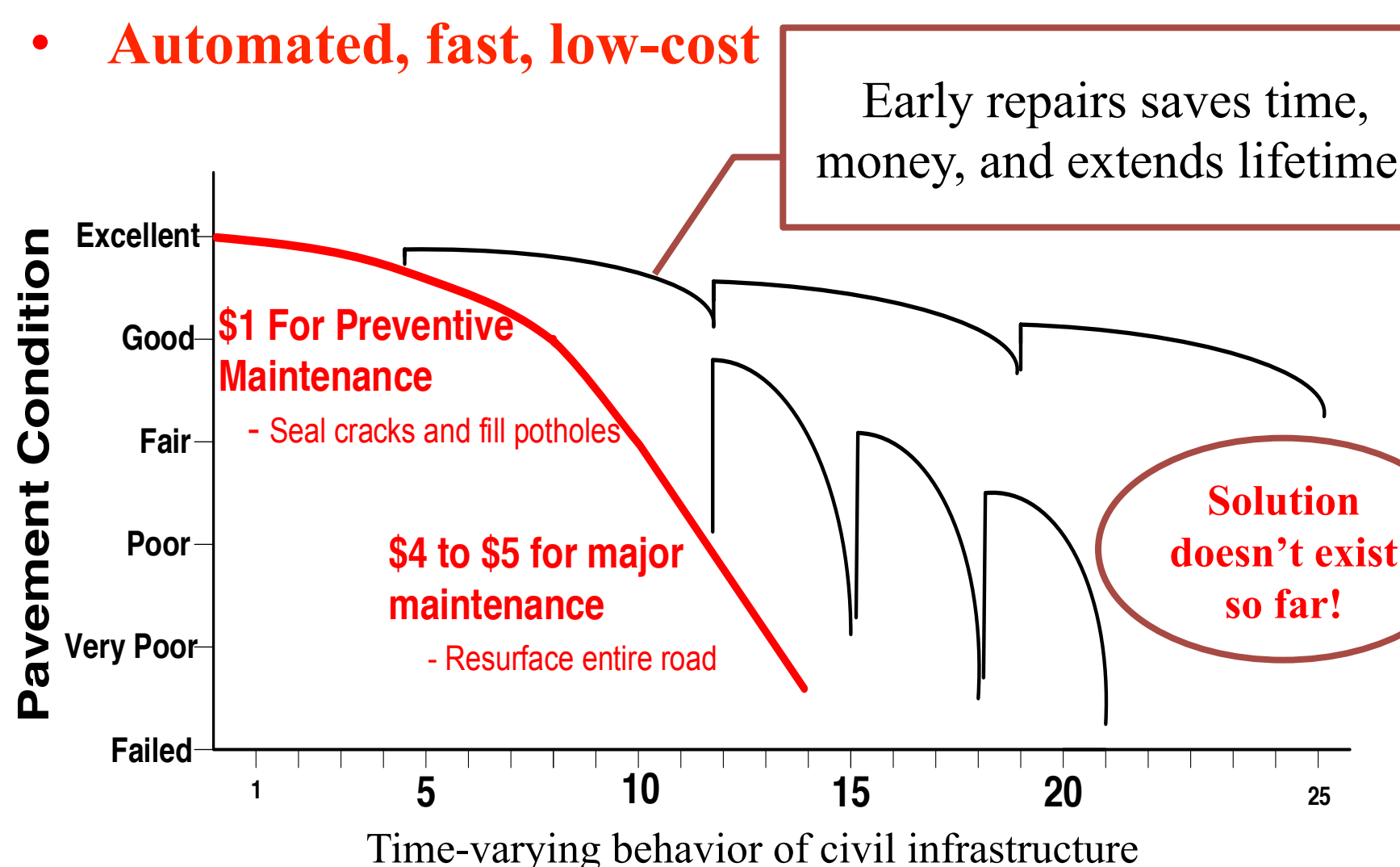
# The Next Generation Transportation Infrastructure Performance Inspection: A CPS approach

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## INTRODUCTION

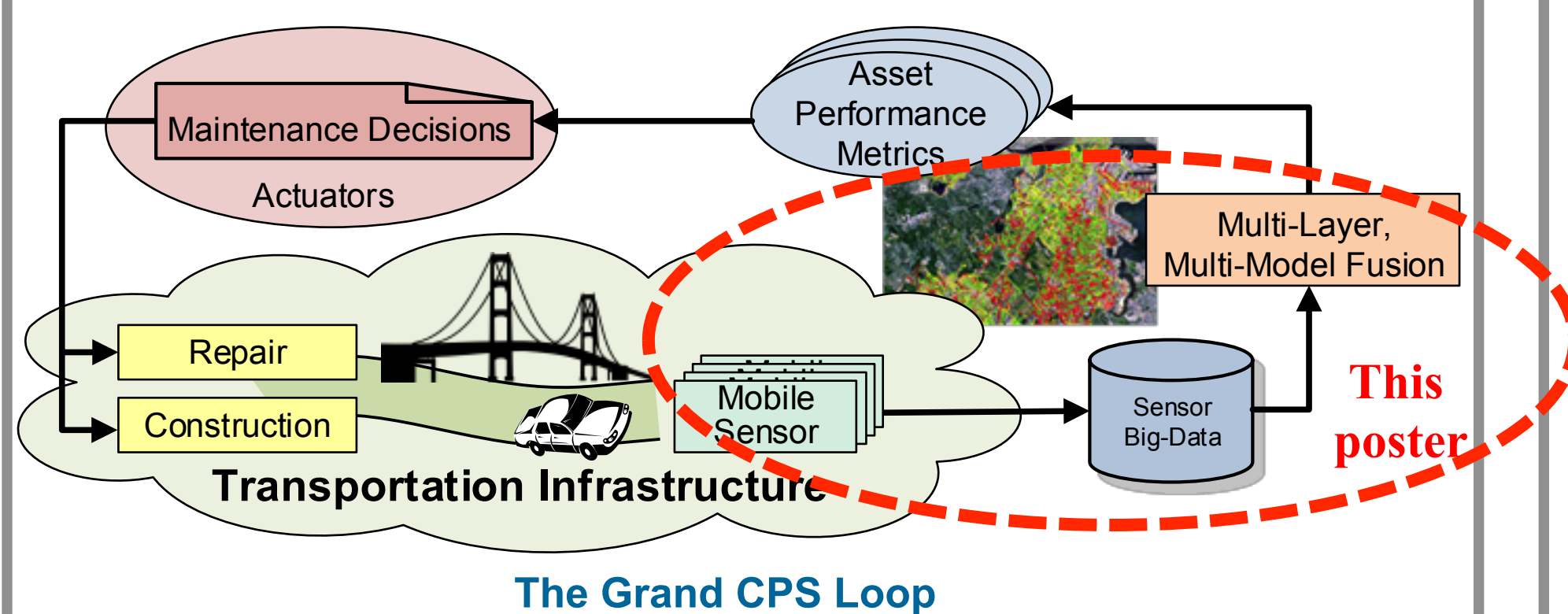
### U.S. Infrastructure Grand Challenge

- Societal need: America Infrastructure Rate: D+
- Frequent / Continuous Inspection: Data, data, data ...
- Non-intrusive: Traffic, gas, pollution, cost ...
- Sufficient coverage: Town, city, state, nation-wide
- Deployable sensors
- Deployable actuators



**Ultimate Goal:**  
Understanding, Predicting, Preventing and Maintaining the U.S Transportation Infrastructure

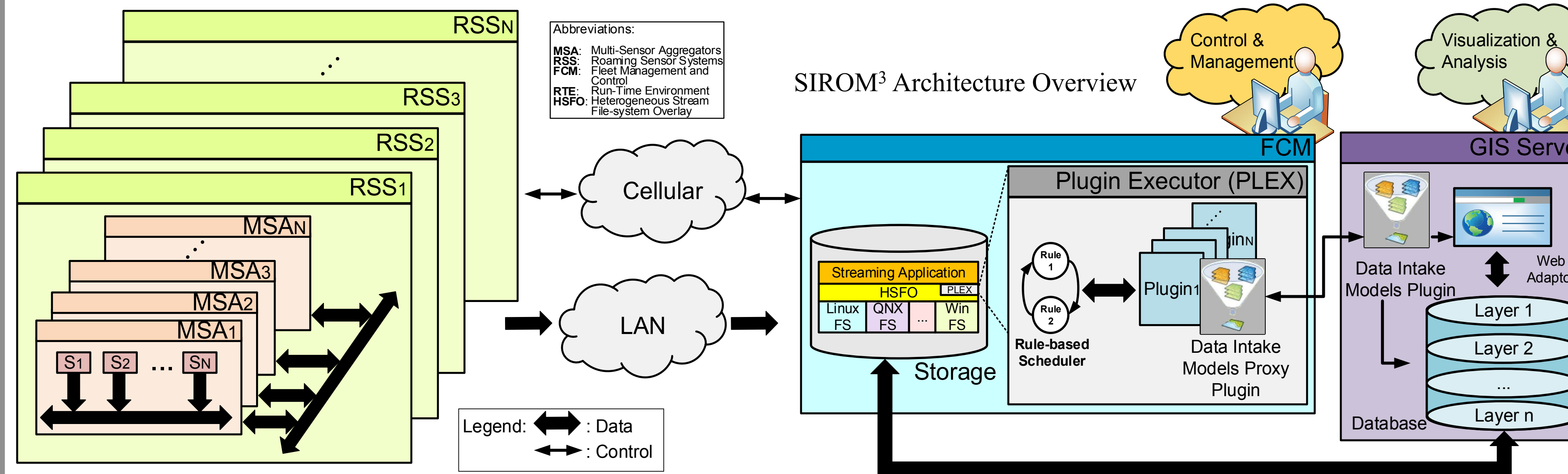
## INFRASTRUCTURE PERFORMANCE MONITORING: A CPS APPROACH



### CPS + Mobile Sensor Systems Challenges

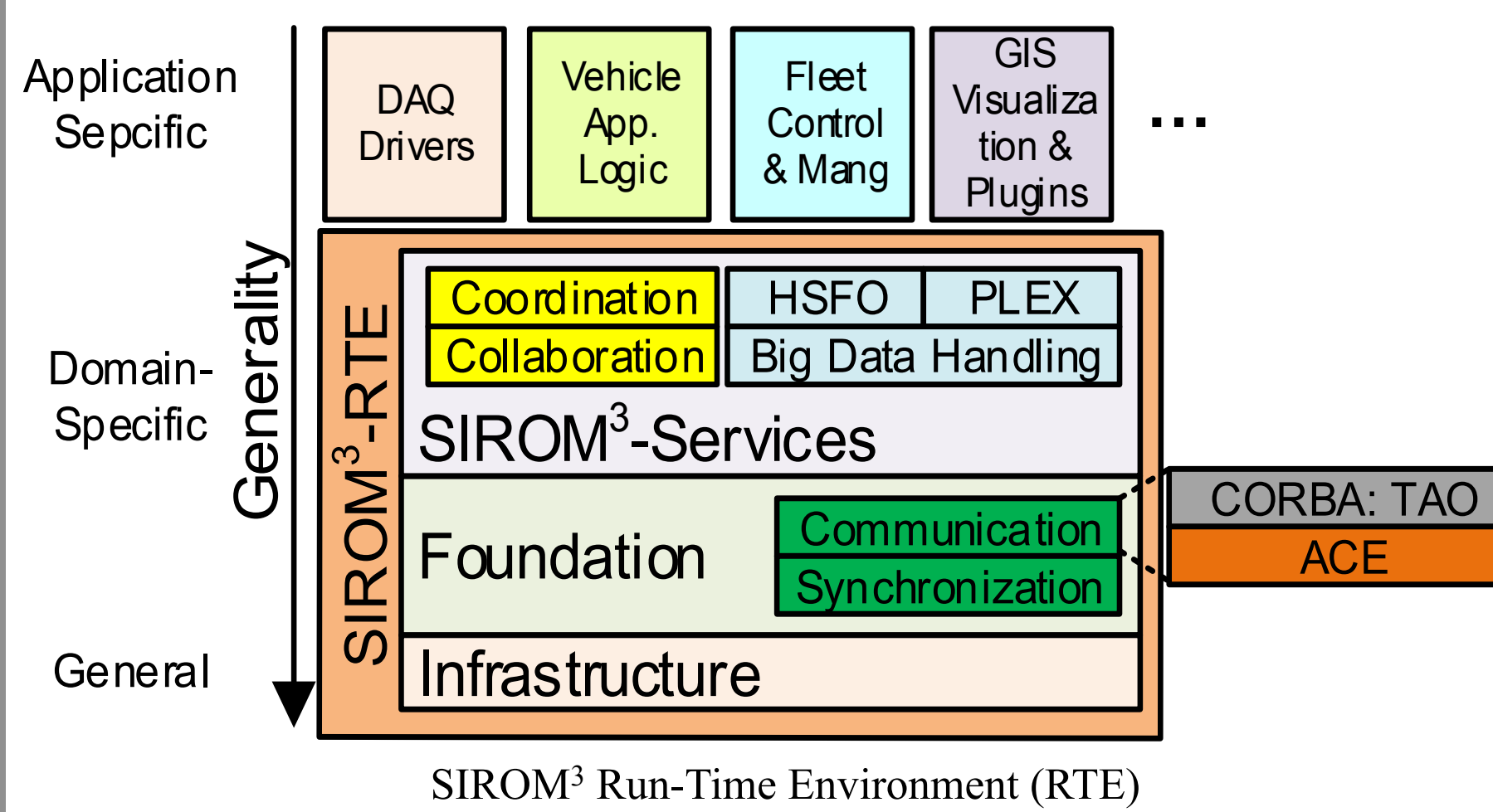
- System Performance Challenge
  - Concurrency
  - Big Data
  - Mobility
  - Real-time constraints
- System Integration Challenge
  - Temporal Correlation
  - Distributed Systems
  - Spatial Correlation
  - Automation
- System-Level Design Challenge
  - Scalability
  - Reusability
  - Expandability
  - IP-Protection

## SIROM<sup>3</sup>: Scalable Intelligent ROaming Multi-Modal Multi-Sensor Framework



- Modular Design
- Centralized Control
- CPS Lower Loop
- Three-level Hierarchy
- Centralized Evaluation
- SW/HW Scalable and Expandable

## SIROM<sup>3</sup> Run-Time Environment



### RTE Layered Services

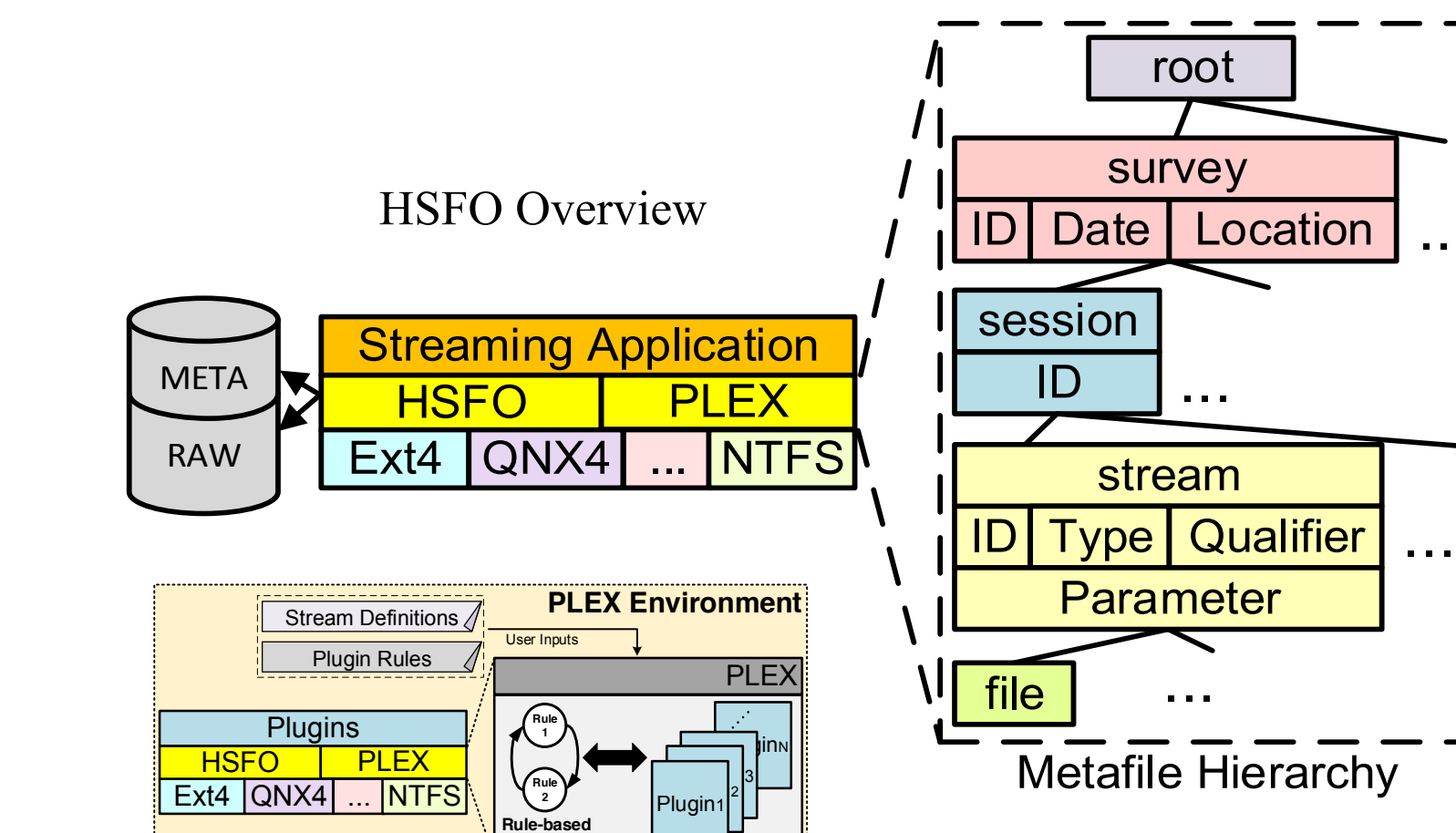
- Infrastructure layer (hardware, OS, network)
- Foundation layer
  - Time synchronization
  - Comm. messages
- Encapsulated commonalities for all SIROM<sup>3</sup> nodes (HW/SW)
- Modular design adaptive to scalability and expandability
- Easy integration of new component

## SIROM<sup>3</sup> BIG DATA HANDLING

- ### Challenges
- Large volume
  - Streaming Data
  - Heterogeneous data
  - Data/Sensor fusion
  - Automation

### HSFO (Heterogeneous Stream File System Overlay)

- Platform-independent, adaptive to system scalability
- Metafile hierarchy to organize heterogeneity
- Exposed unified APIs to plugins to ease data fusion



## IMPLEMENTATION AND RESULTS

### Realization in VOTERS (Versatile Onboard Traffic Embedded Roaming Sensors) Project

- Deployed an RSS onto a van
- Automated data processing
- Continuous data collection
- City-wide coverage: 300 miles
- Non-intrusive, traffic speed
- Driving speed: 40 mph
- Distributed resources, storage
- 1 driver only



Time/Distance triggered!

An RSS contains 5 MSAs, over 30 sensor units in total from 10 domains!

TABLE I: Data diversity and volume

Domains	Max Sensor	Min Trigger Inter.	Points/Sensor/Trigger	Size/Point [byte]	Data Rate [GB/h]
MSA1 (Positioning data)	1	0.2 s	4	4	0.0003
MSA2 (Acoustic microphones)	4	25 us	1	4	2.1
MSA2 (Dynamic Tire Pressure)	2	25 us	1	4	1.1
MSA3 (Millimeter-wave radar)	10	25 us	1	4	5.4
MSA4 (Video systems)	1	1 m	5018400	1	467.4
MSA5 (GPR systems)	16	0.01 m	1024	2	305.2
Total (Driving speed 100 km/h)					<b>781.1</b>

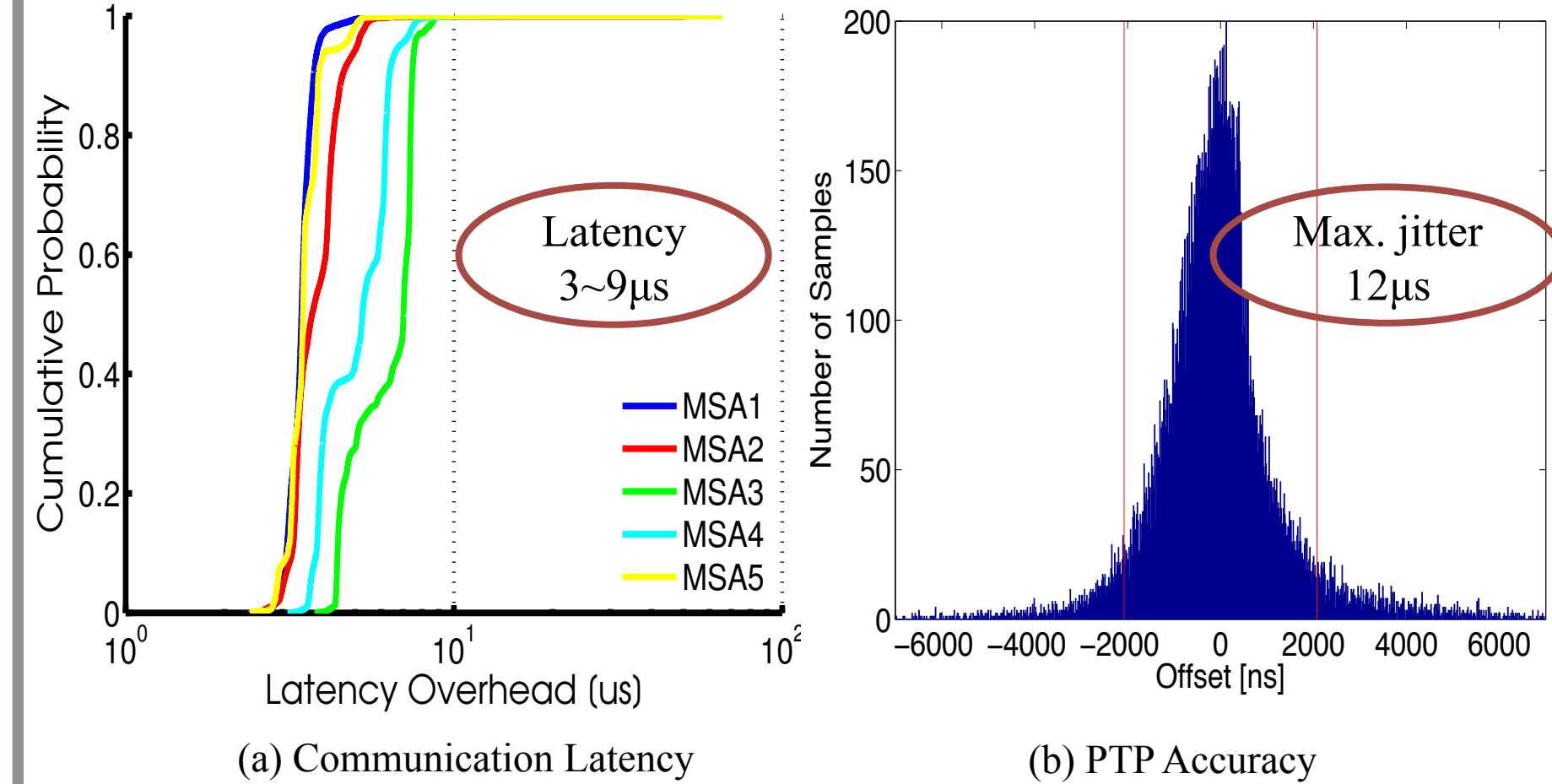
## Performance Analysis

TABLE II: MSA Performance Results

Systems	CPU [%]	Memory [MB]	Network load [KBps]	Avg. Comm. Latency [us]	Total Code [%]	Intg. Code [%]
MSA1	0.04	7.9484	216.392	3.7149	3.8	3.8
MSA2	2.69	6.8237	82.06	4.2916	6.5	1.1
MSA3	3.25	10.4202	800.97	6.3283	6.3	0.13
MSA4	3.21	10.5188	842.98	5.5105	2.9	0.09
MSA5	52.6	95.6133	122.68	4.2325	3.6	0.09
MSA5 (DAQ)	45.4	93.2933	NA	NA	NA	NA

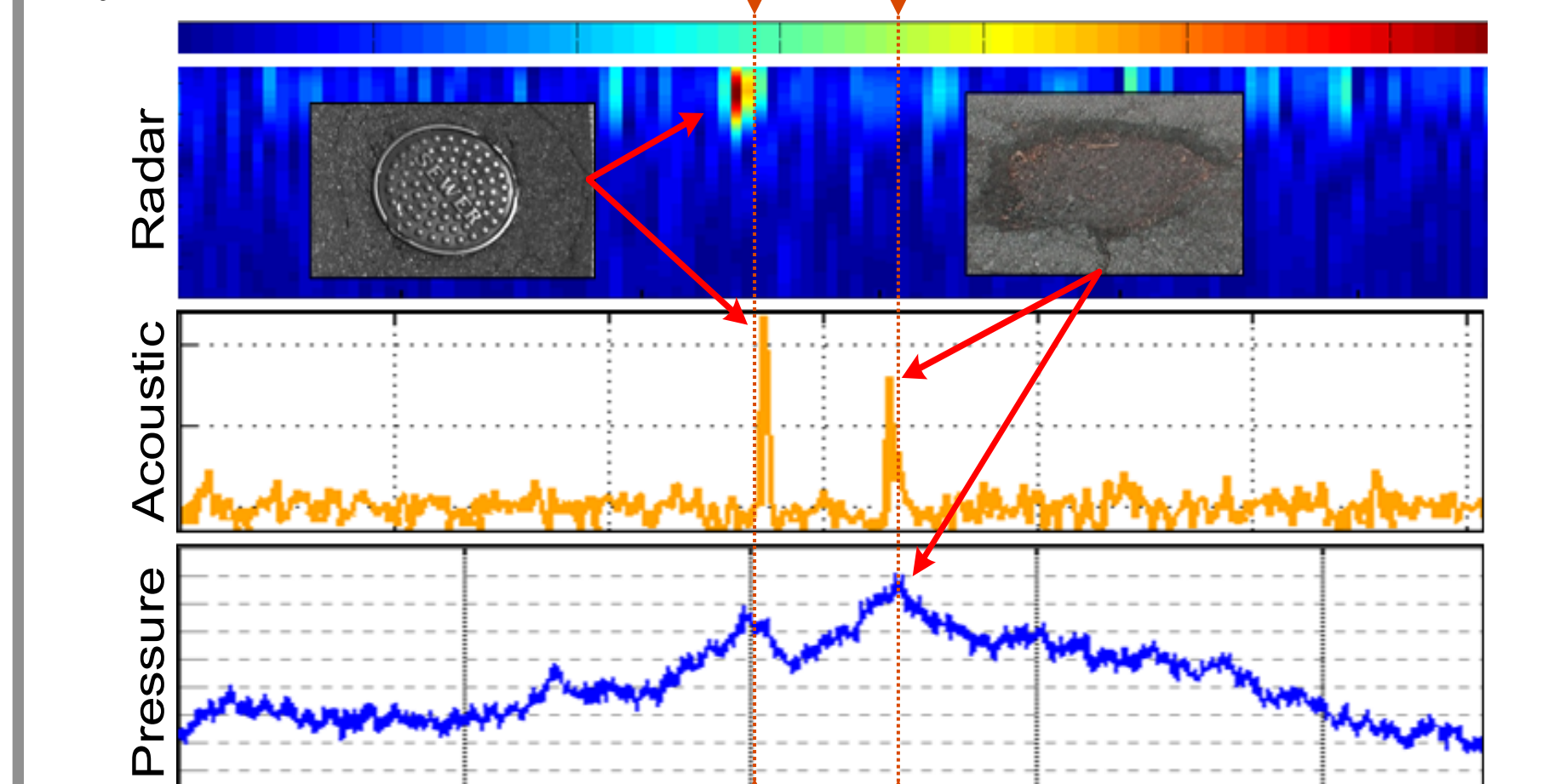
- Low resource utilization and Communication overhead
- Easy new sensors/MSAs integration
- Integration code < 50 LOC
- Expandability

## Latency Analysis and Timing Accuracy



- PTP, NTP Timing protocol
- Foundation for Synchron.

## Synchronization



- Temporal/Spatial correlation
- Sensor fusion

## City-wide Infrastructure Performance Inspection

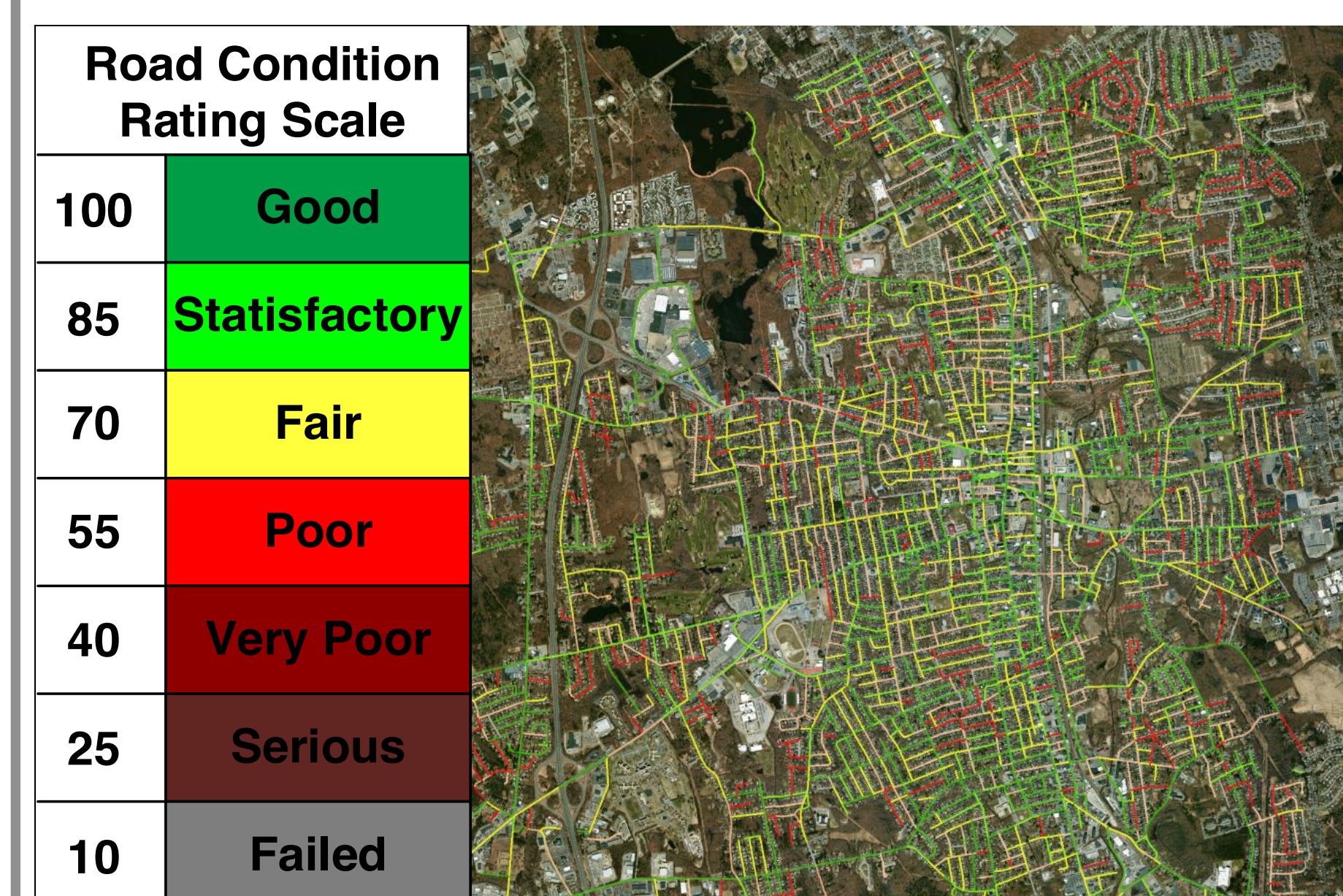


TABLE III: 300 miles coverage of Brockton, MA

	Data Collection [h]	Data Transfer [h]	Data Processing [h]	Total [h]
Traditional Methods	800	0	320	<b>1120</b>
Van-based systems	32	16	320	<b>248</b>
SIROM <sup>3</sup>	11	16	14	<b>41</b>

30 times speedup