SemanticVector: AI-Powered Semantic Compression for 1000x More Data-Efficient Transportation Intelligence

Sikai (Sky) Chen (Team Lead), Xiaopeng (Shaw) Li
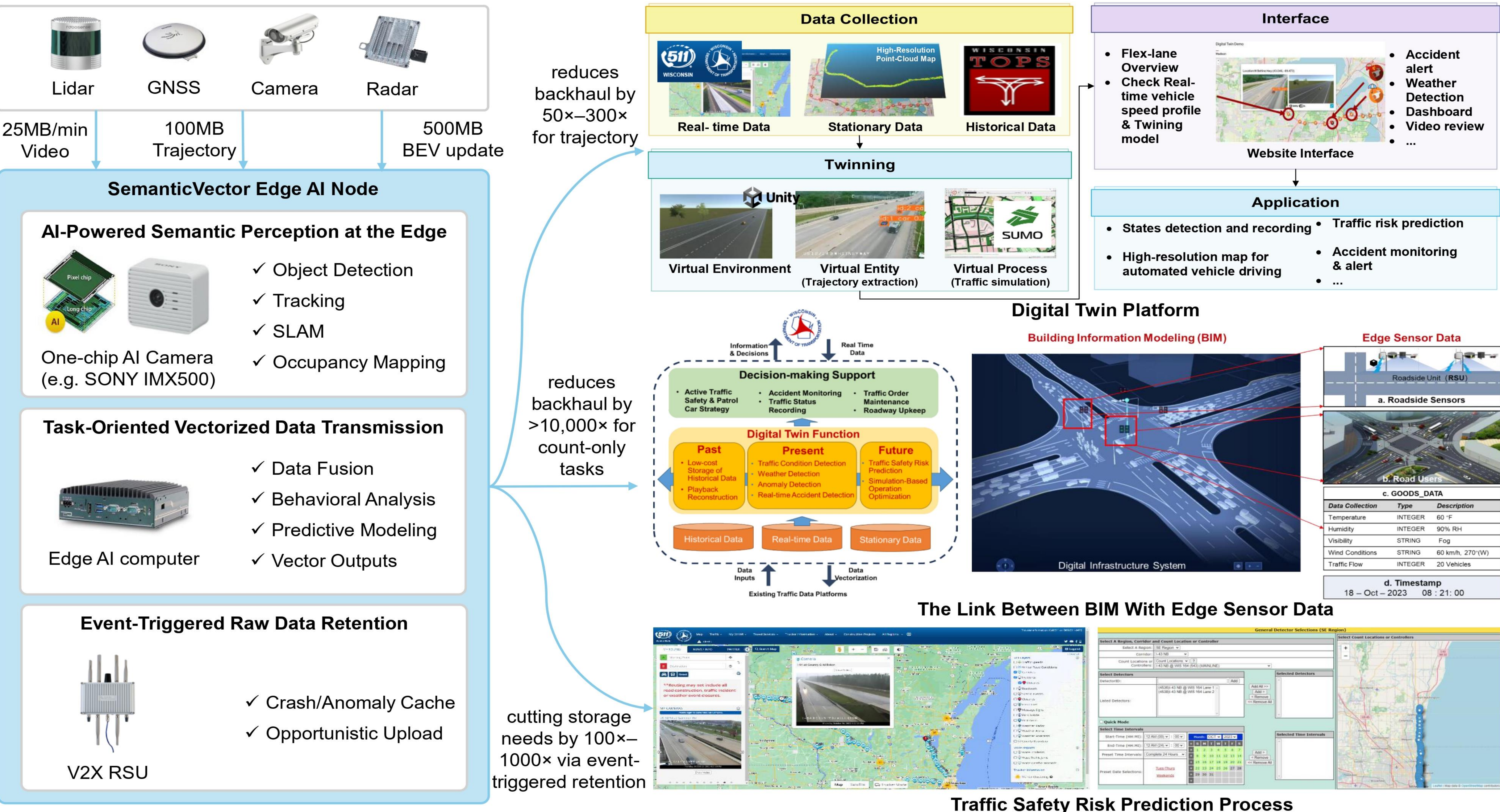
University of Wisconsin-Madison

Problem Statement

- Current traffic monitoring requires massive bandwidth (5-25 Mbps per camera) and expensive data centers
- Fiber installation costs $60,000-$80,000 per mile, creating deployment bottlenecks
- Over 95% of transmitted video contains redundant or non-critical information
- Network latency of 200-500ms degrades real-time response capabilities

Vision: **What if we could turn raw sensor data into smart, vectorized knowledge directly at the source, using novel AI to compress information by over 1000x and revolutionize the cost and capability of traffic management?**
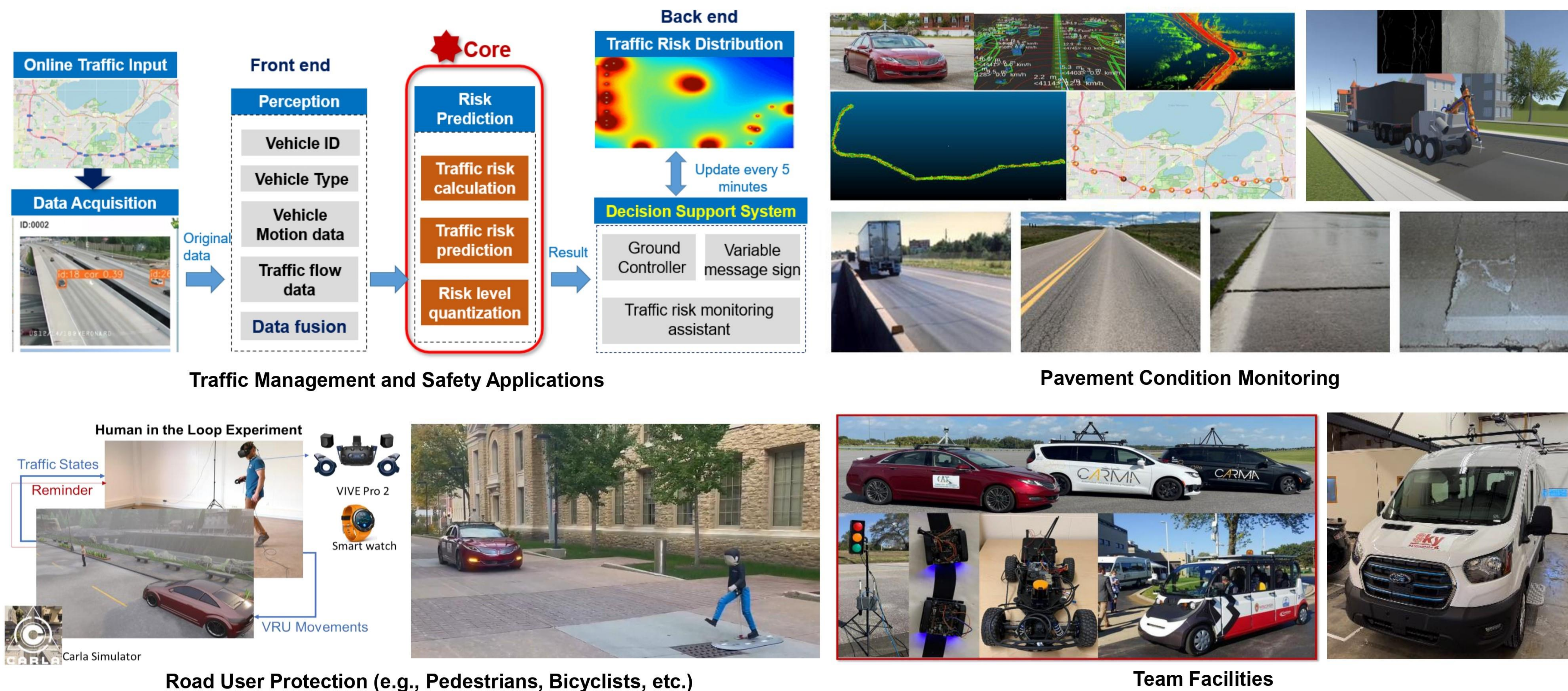
Breakthrough Solution: The SemanticVector Framework

- **AI-Powered Semantic Perception:** AI models perform perception, tracking, and trajectory reconstruction on-site.
- **Task-Oriented Vectorized Data Transmission:** Transmit only counts, trajectories, occupancy maps, and alerts.
- **Event-Triggered Retention:** Cache raw data for critical incidents (crashes/anomalies) only.
- **Bandwidth- & Storage-Aware Compression:** >10,000× reduction for counts, 100×–1000× storage savings.
- **Digital Twin Integration:** real-time feeds into TMC + simulation platforms

Data Collection / Interface / Twinning / Application

Digital Twin Platform

reduces backhaul by 50×–300× for trajectory

reduces backhaul by >10,000× for count-only tasks

cutting storage needs by 100×–1000× via event-triggered retention

The Link Between BIM With Edge Sensor Data

Traffic Safety Risk Prediction Process

SemanticVector Edge AI Node

AI-Powered Semantic Perception at the Edge
- ✓ Object Detection
- ✓ Tracking
- ✓ SLAM
- ✓ Occupancy Mapping

One-chip AI Camera (e.g. SONY IMX500)

Task-Oriented Vectorized Data Transmission
- ✓ Data Fusion
- ✓ Behavioral Analysis
- ✓ Predictive Modeling
- ✓ Vector Outputs

Edge AI computer

Event-Triggered Raw Data Retention
- ✓ Crash/Anomaly Cache
- ✓ Opportunistic Upload

V2X RSU

Lidar / GNSS / Camera / Radar

25MB/min Video / 100MB Trajectory / 500MB BEV update

Key Performance Metrics

- **Bandwidth reduction:** 50×-10,000× depending on application
- **Infrastructure cost reduction:** 1000× through eliminated fiber and data center requirements
- **Latency improvement:** <100ms vs. current 200-500ms
- **Deployment scaling:** 100× more sensing points within existing budgets

Traffic Management and Safety Applications

Pavement Condition Monitoring

Human in the Loop Experiment

Road User Protection (e.g., Pedestrians, Bicyclists, etc.)

Team Facilities

- ✓ Novel AI models perform 'semantic compression' directly at the roadside
- ✓ Transmit hyper-efficient vectorized insights instead of raw video streams
- ✓ Vehicle counts: 4 bytes vs. 25 MB per minute
- ✓ Trajectory data: 1-5 KB vs. 100 MB per trajectory
- ✓ Event alerts: 500 bytes vs. 50 MB per incident

Implementation Strategy

- Year 1: Core AI model development for semantic compression
- Year 2: Field trials on Madison Flex Lane and partner corridors
- Year 3: Multi-agency deployment and commercialization preparation

Transformational Impact

- **Economic:** Billions saved in fiber & storage, positive ROI within 1–2 years.
- **Safety:** Real-time alerts prevent crashes, protect road users, enable adaptive response.
- **Resilience:** Edge autonomy sustains monitoring during outages/cyberattacks.
- **Scalability:** National ITS deployment across urban & rural corridors.
- **Leadership:** Positions the U.S. at the forefront of AI-driven infrastructure innovation.