A Smart Work Zone Delay Estimation System for Rural Highway Operations

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Mountains & Minds

Overview

- Background
- User Requirements
- Methodology
  - Delay Algorithm
  - Equipment and Technology
  - Communications
- Summary

Background

- Work Zone Transportation Challenges
  - Safety
  - Delay
- Literature Review and State DOT Surveys
  - Literature Review
  - Summary of Agency Surveys
- Project Kickoff – October 2002
  - Project put on hold – June 2004
  - Restarted – January 2006
  - Completed – April 30, 2006

Source: Wisconsin DOT

Application Description

- Delay estimation and en-route real-time traveler information system
- Focused on two-lane rural highway work zones with a lane closure (i.e. pilot car)
- Usable in rural environments where highly variable delays are expected
- Designed to alleviate motorist frustration

User Requirements

- Estimate delay to ±2 minutes accuracy
- Limited communication availability
  - No line-of-sight
  - No commercial providers
- Minimal human input
- Easy-to-use

Methodology

Alignment with Caltrans Stages of Research Deployment

1. **Concept Stage**
2. **Laboratory Prototype Stage**
3. *Controlled Field Demonstration Stage*
4. *First Application (Contract) Field Pilot Stage*
5. *Specification & Standards with Full Corporate Deployment Stage*

"Proof of Concept"

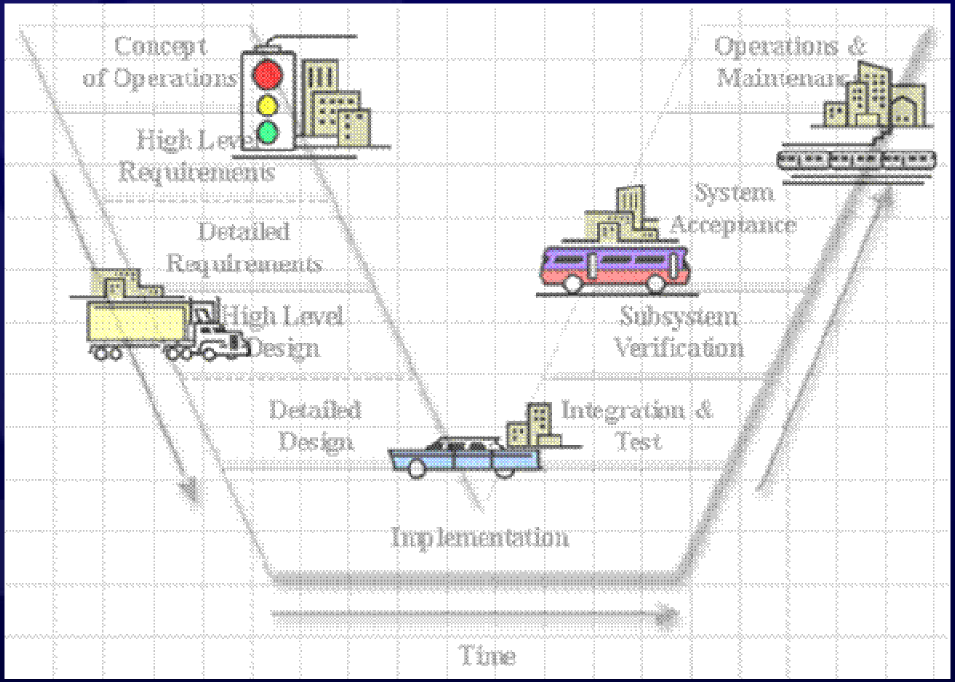
Completion: April 2006

Potential Future Research and Development

Methodology

Followed Systems Engineering Process and Primary Research Components

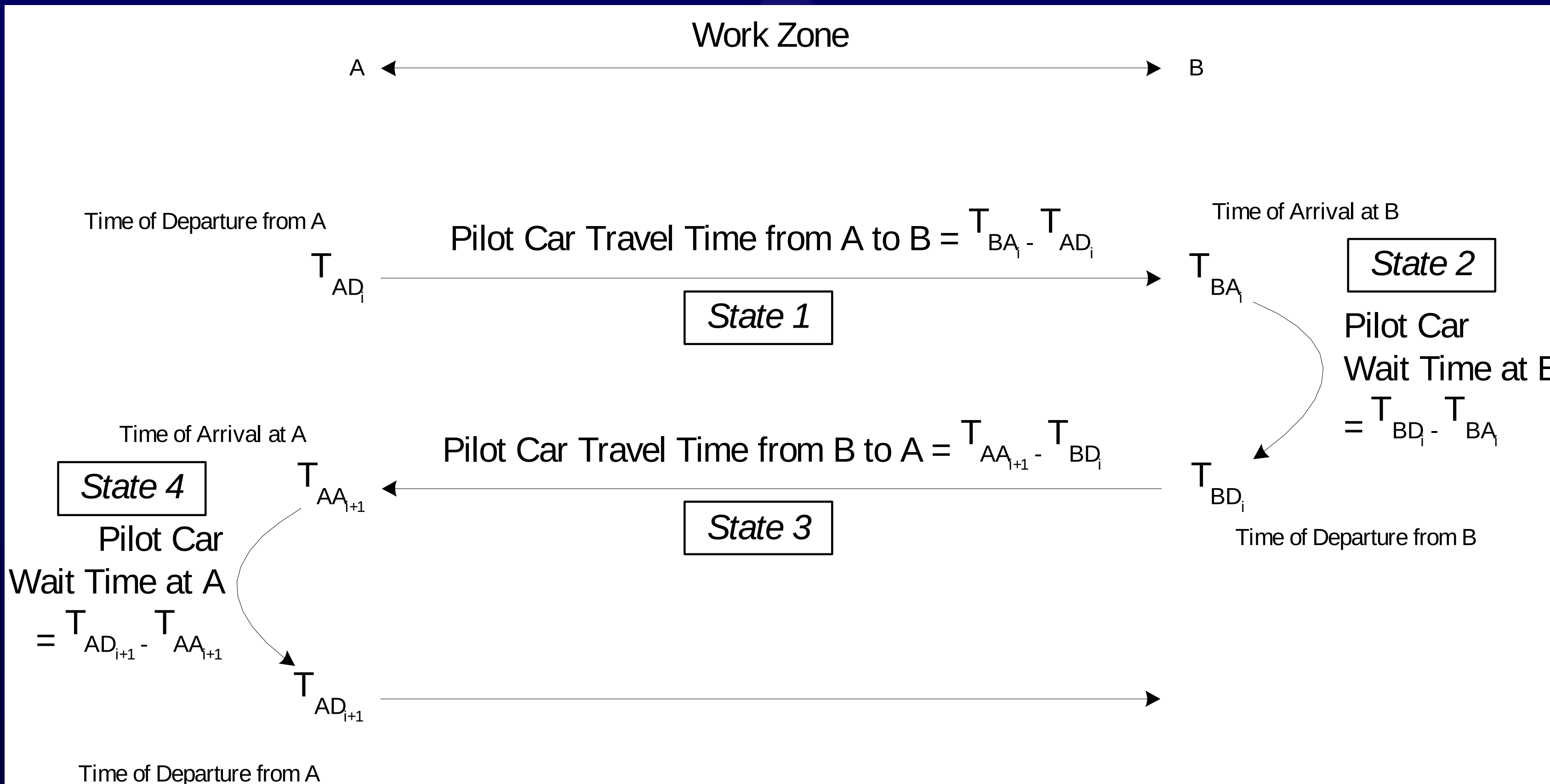
- “Vee” Model for Systems Engineering
- Major Components
  - Delay Estimation
  - Equipment and Technology
  - Communication Technology



Delay Estimation

- Governing policies
  - Maximum wait time of 15 minutes
  - Queue on either end is allowed to empty
  - Pilot car generally adheres to posted speed limit
- Definition of delay:
  - "Time before the first car in the queue starts to move to go through the work zone"

Components of Cycle Duration



Challenges and Assumptions

Challenges

- Real-time traffic data is not available
- Unknown traffic conditions
- Communication restricted to ends of work zone
- Communication may fail

Assumptions

- Estimate wait time at ends of work zone
- Cycle times available for previous ten cycles
- Wait time for first car
- Wait time count-down

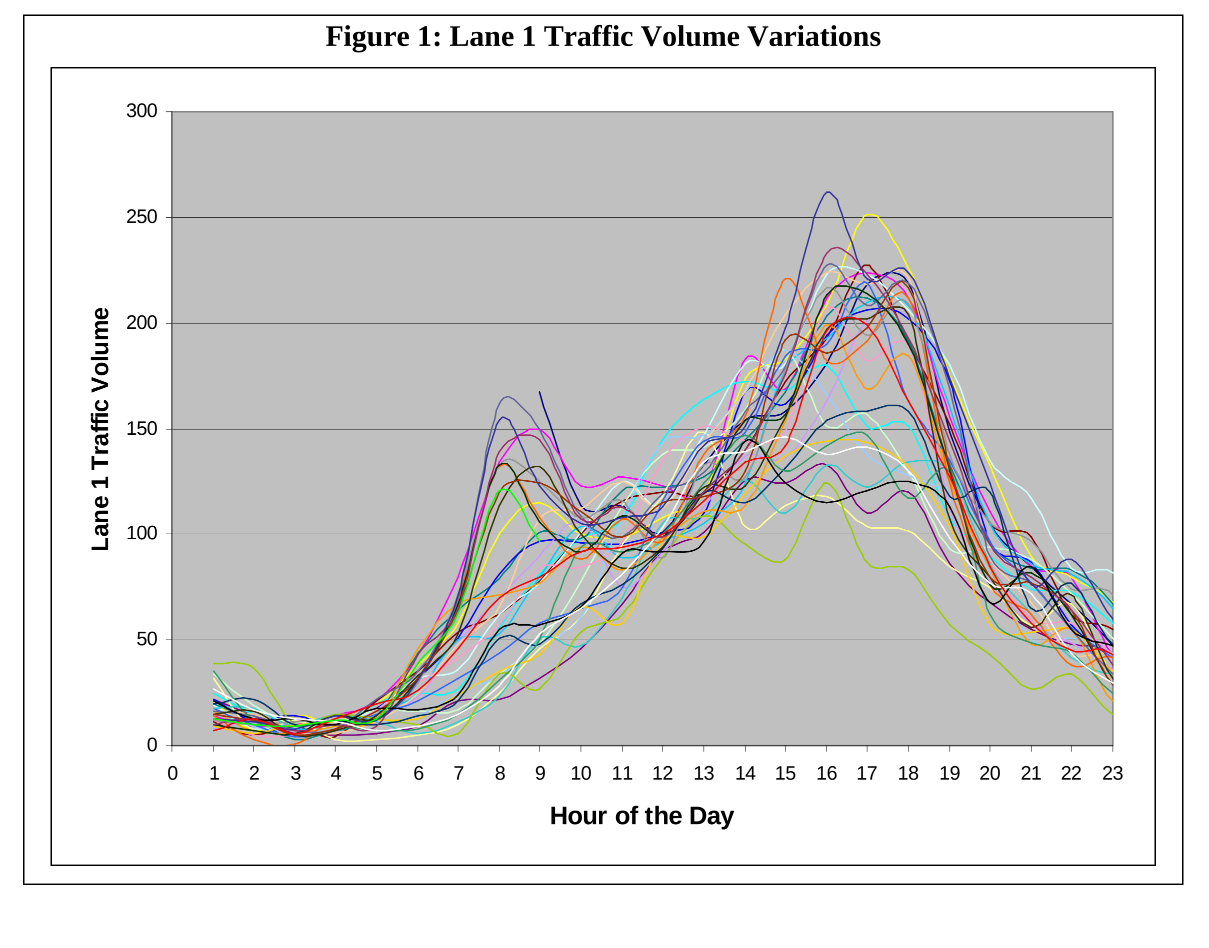
Additional Challenge:
Knowing When the Flagger Closes Traffic

- Necessary so that the system can determine when to display delay time.
- Can’t be automatically determined without additional technology or input from flagger.
- Can be estimated: corresponds to wait time of pilot car at other end.

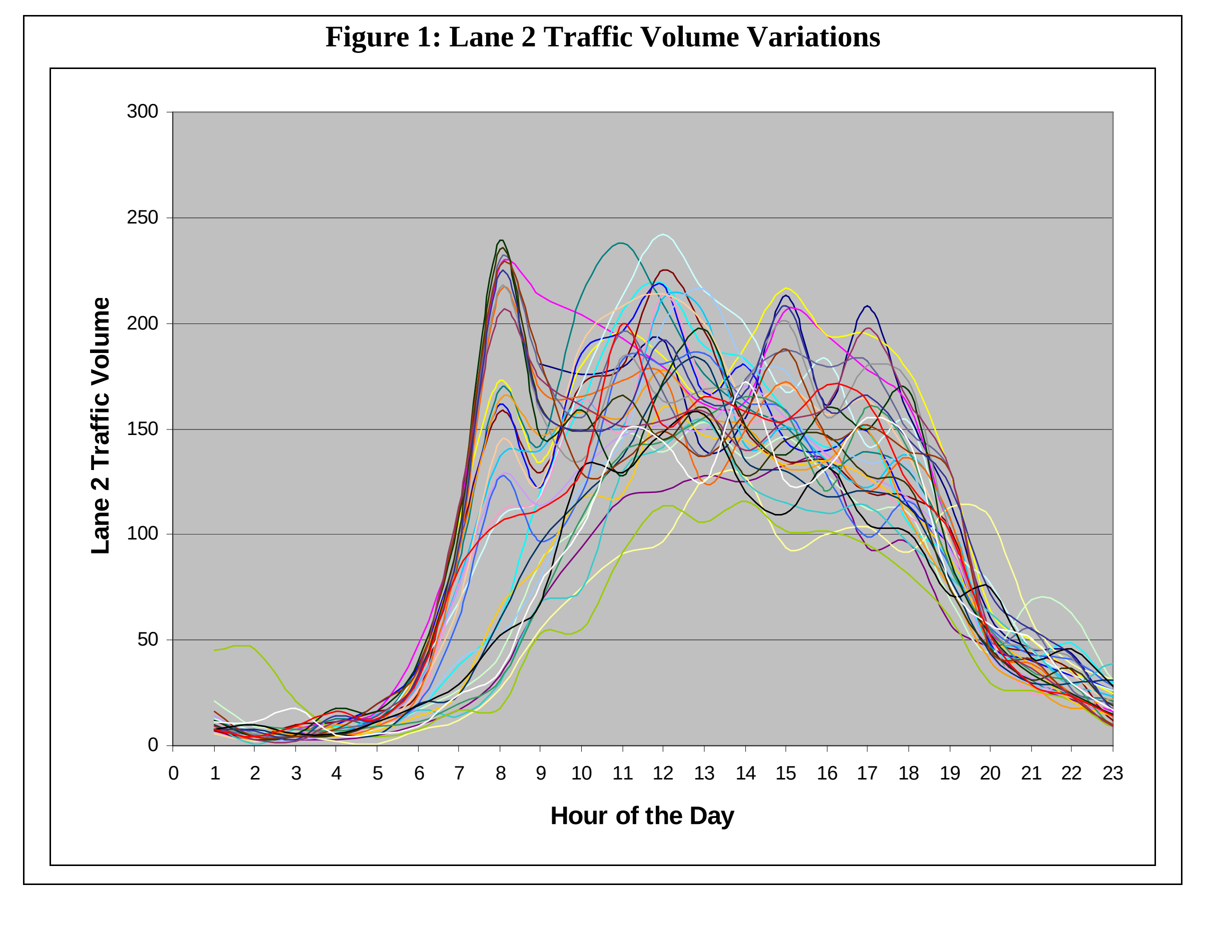
Algorithms

- Moving Averages
  - Wait Time from Last Cycle
  - Average of Last 10 Cycles
  - Exponential Decay of Weights of Last 10 Cycles
  - Linear Decay of Weights of Last 10 Cycles
- Possible Improvements to Moving Averages by Incorporating:
  - Trends for Time of Day
  - Trends for Day of Week
  - Trends for Direction
- Other Methods than Moving Averages
  - Time Series, Fourier Series, Markov Chain

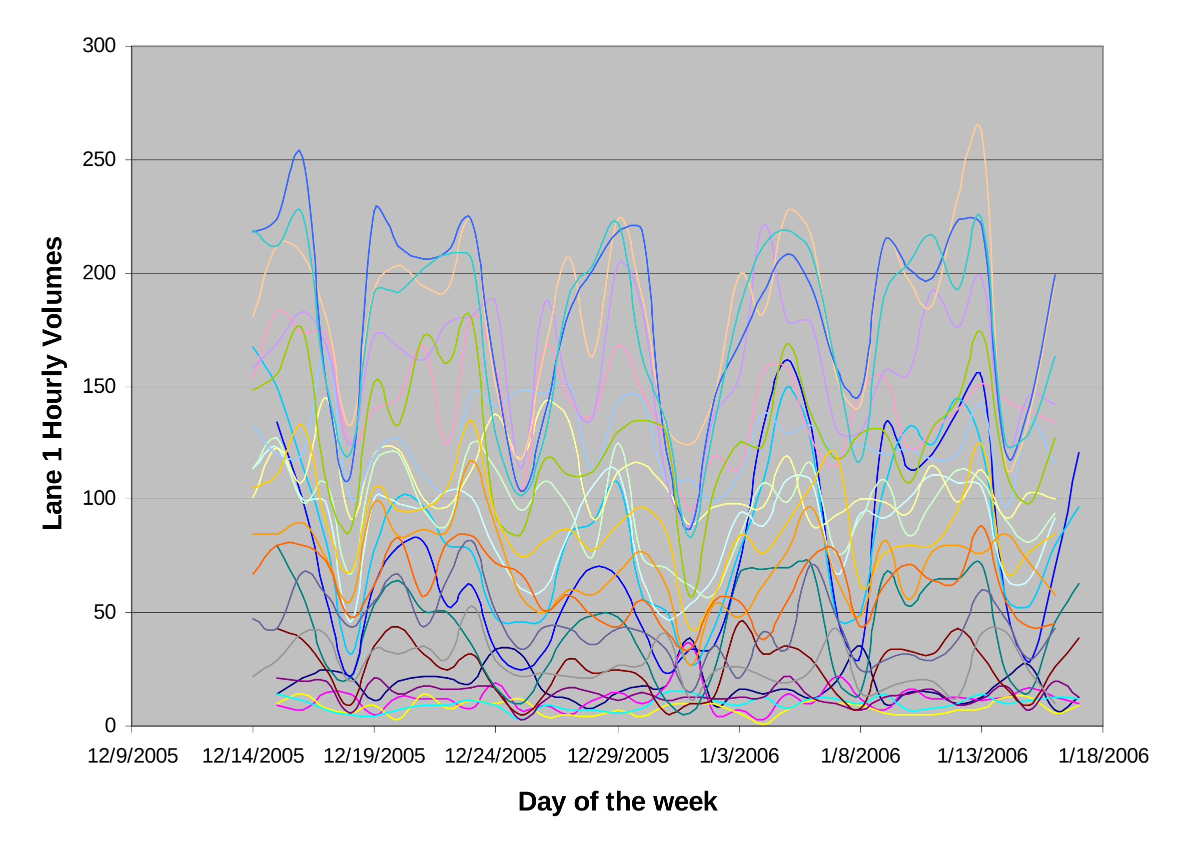
Traffic Volumes and Trends
Bella Vista – SR 299
Lane 1 Traffic Volume by Hour



Traffic Volumes and Trends
Bella Vista – SR 299
Lane 2 Traffic Volume by Hour



Traffic Volumes and Trends
Bella Vista – SR 299
Lane 2 Traffic Volume by Day of the Week



Testing

- Limited Simulation
  - No known software to simulate pilot car operations in a two-lane rural work zone.
  - SimProcess – software for manufacturing simulation was used.
  - Counts from Bella Vista (SR-299) used to simulate several scenarios to calculate wait times and travel times.
  - Algorithms to be tested using simulation.
- Lab-Controlled Testing

Equipment and Technology
Basic Logical Components

- Signs
- Controllers
- Transmitters
- Receivers
- Data Loggers
- Location Sensors
- User Interfaces
- Other: Traffic Counters, etc.

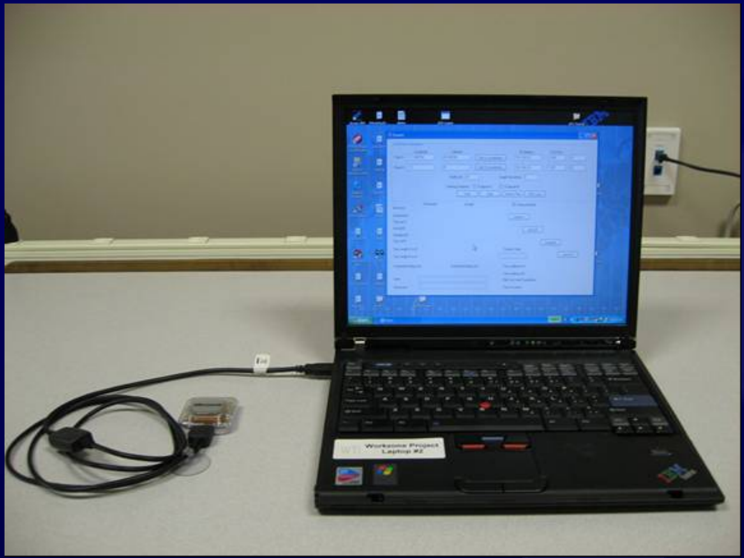
It was not feasible to evaluate all possible configurations and technologies. The project team focused on a configuration that was most promising as a "proof of concept."

Equipment and Technology
Challenges

- Data Communication
- Need Hardened Equipment for Prospective Deployment
- Interface Issues
- Setup Issues
- Power
- Integration of Components

Equipment and Technology

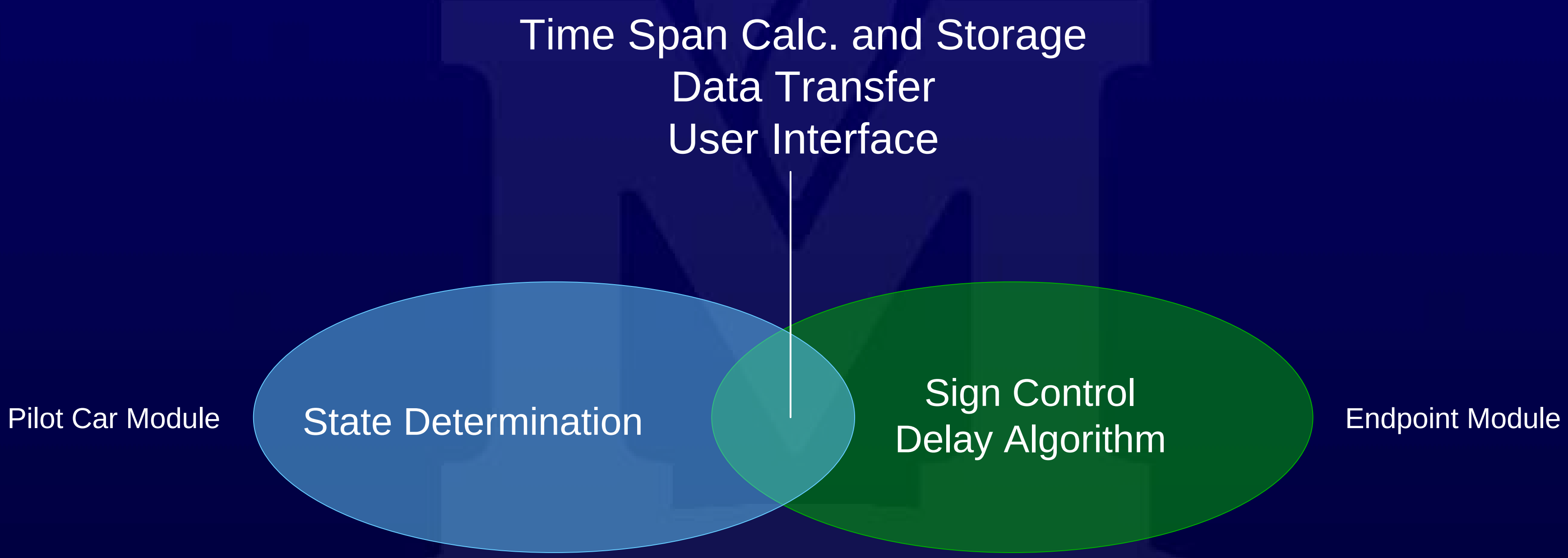
Proof of Concept System Modules



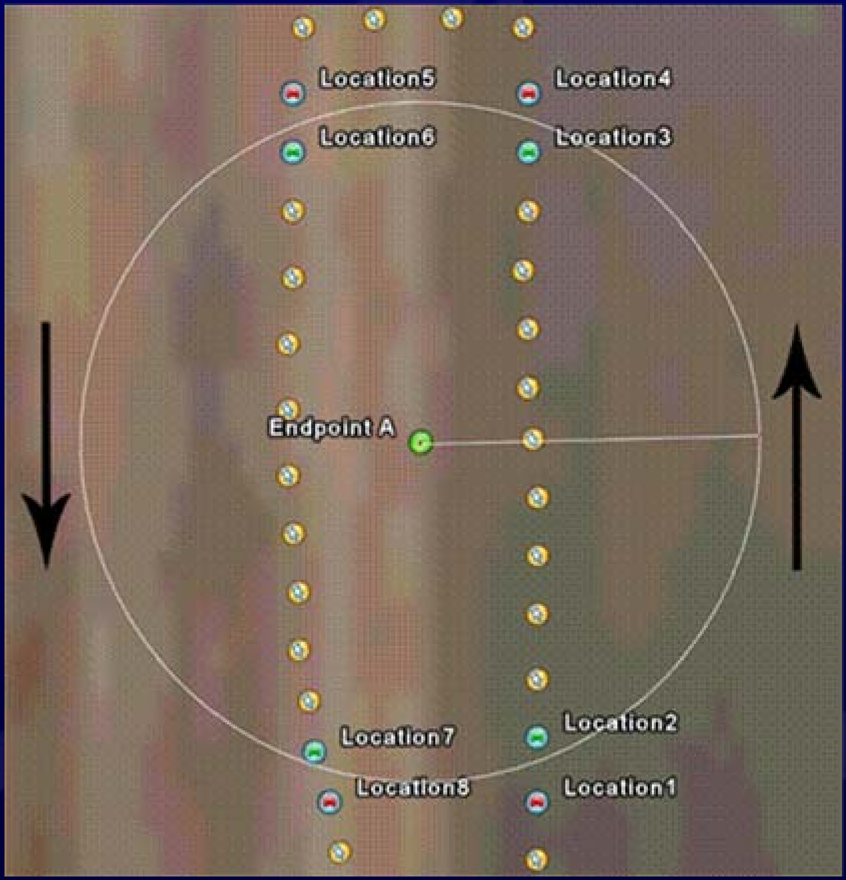
Pilot Car Module

Endpoint Module

Equipment and Technology
Functionality



Equipment and Technology
State Determination: Use of Buffer Zone



Equipment and Technology Functionality

- Data transfer -- between applications using TCP/IP over 802.11g Wi-Fi
- Time Span Calculation and Storage – time spans vs. time stamps
- Sign Control – standard protocol and interface
- User Interface – initialization GUI, voice state change
- Delay Algorithm – modular design

Equipment and Technology

Equipment Testing: Test Work Zone at WTI

Testing: Summary

- All components worked properly
  - System initialized properly
  - States were detected correctly
  - Communication worked correctly
  - Estimation algorithms received proper inputs
- The system did support the estimation algorithms and displayed information correctly on the sign
- “Proof of Concept” was successful

Testing – Lab Controlled Testing
Expected Results

- Measure accuracy of automated time interval recordings.
- Measure accuracy of archiving.
- Measure accuracy of estimates of wait times.
- Measure accuracy of message displays.

Testing Results

Accuracy of Automated Time Interval Recordings

- Small Discrepancy between actual cycle times and those measured by system (1 s/cycle)
- Noticeable difference between average error in actual versus measured pilot car wait times at end points
- Measured pilot car wait times > actuals
  Measured pilot car trip times < actuals
- Average trip times, regardless of direction, are very close

Testing Results

Accuracy of Archiving

- No problems were detected with archiving mechanism
- Number of cycles recorded corresponded to actual number of cycles

Testing Results

Accuracy of Estimated Wait Times

- Wait time calculations appeared to be accurate in the lab setting.
- Further testing would be necessary to incorporate trends in volume, anomalies, etc. to truly measure effectiveness of algorithms.
- Testing only concludes that the algorithms could be implemented within the proof of concept system.

Testing Results
Accuracy of Display Messages

- Informal observations were used to test the accuracy of the messages on the signs.
- Messages appear accurate.
- More rigorous testing would be necessary for conclusive results.

Testing: Recommendations

- System is not ready for field use
- Other devices might be used in place of laptop computers
- GPS may not be suitable in all terrain – should investigate alternatives
- Should investigate alternatives to Wi-Fi
- User Interface is not suitable for field use – must further investigate interface issues
- System needs to be tested with actual signs used in the field

Communications Technology

Background – Possible Configurations

1. At End Points Only: The pilot car can communicate with the end points when in proximity.
2. At End Points and from End Point to End Point: The pilot car can communicate with the end points when in proximity and the end points can communicate with each other.
3. Complete: The pilot car can communicate with the end points from anywhere within the work zone and the end points can communicate with each other.

Communications Technology

Challenges

- The System must be operable in rugged terrain
  - Implies that line-of-sight or near-line-of-sight wireless technology will be of limited use.
- The System must be operable in rural areas.
  - Implies that existing communication infrastructure (public or private) will be limited and can not be assumed.
- The System shall require minimal setup.
  - Further limits options, because certain technologies require careful positioning and configuration of equipment.
- The System shall not depend on commercial services that have recurring service charges.
  - Eliminates options such as satellite, which would likely come closest to providing full coverage of rural areas.
- Constraints are also imposed by power, because it can not be assumed that power is readily available.

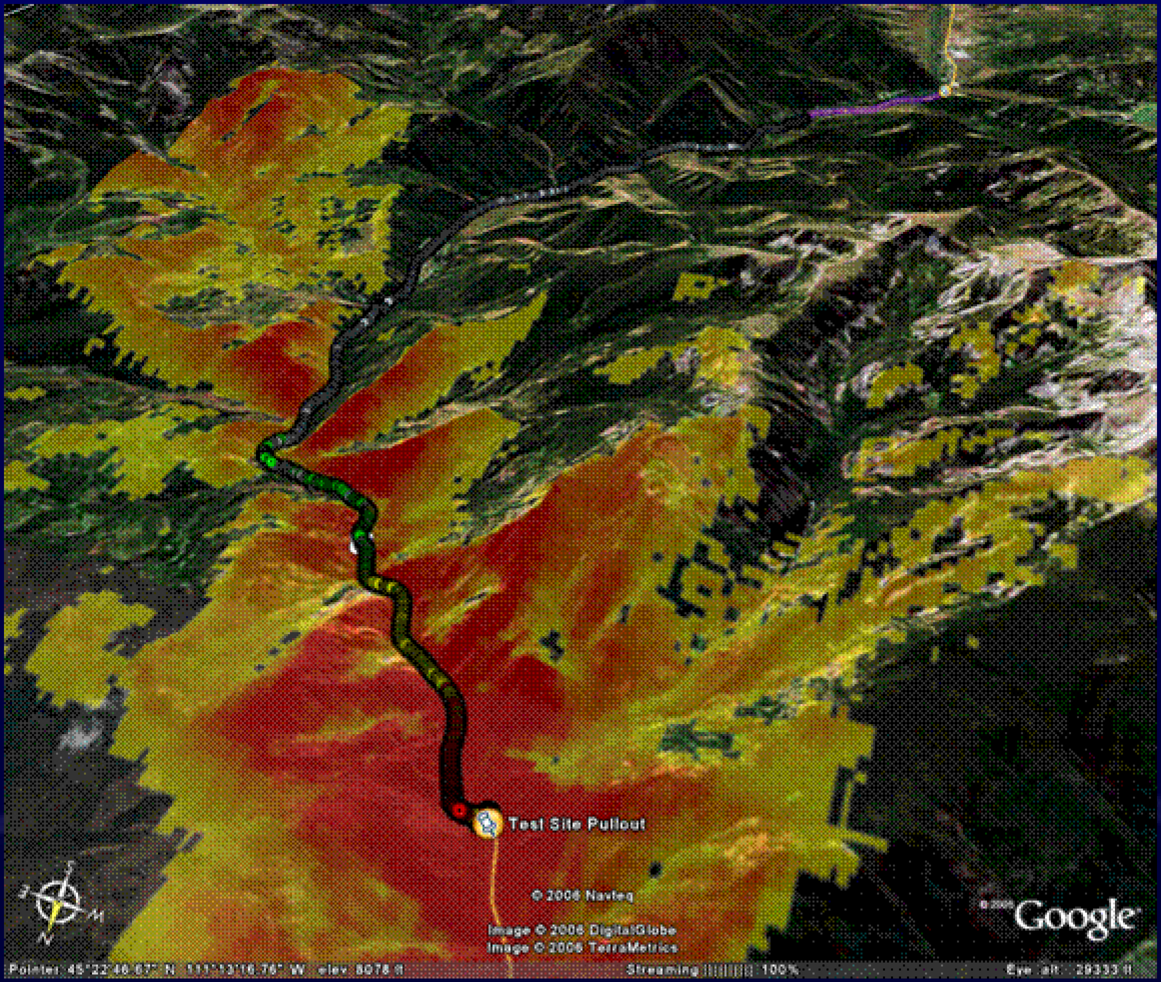
Communications Technology

Summary of Applicable Technology

- Wired Technology
  - Significant setup and pathway access difficulty
- Wireless Technology
  - Greater flexibility, easy setup

Communications Technology

Lab and Field Testing : Tested Along US 191 South of Bozeman



Communications Technology

Lab and Field Testing : Signal Obstruction at 3 Miles

Communications Technology
Findings

- Propagation studies and corresponding field tests indicate that it would difficult if not impossible to implement a system that satisfies project requirements for minimal setup and provides continuous communication from end point to end point in rugged terrain.
- Success was achieved in implementing a system in which communication between the pilot cars and signs occur in proximity to the signs. Results shown in prior sections indicate that this approach may truly be viable for a production system.

Communications Technology
Recommendations

- Further investigation into communication alternatives
  - Wi-Fi: Low cost, good availability; unlicensed spectrum
  - Licensed technologies are more expensive, may be difficult to obtain licenses and permits
  - VHF and UHF: better propagation in rugged terrain, but uses licensed frequencies
- Other areas of investigation before system is field-ready
  - Hardened components
  - Integration of communication components with other components
  - Provisions for power

Summary

- A proof-of-concept system was developed that demonstrates the viability of a work zone delay estimation and display system
- Equipment and technology was evaluated and integrated to create the system
- Multiple delay estimation algorithms were researched and tested for prospective use within the system
- Communication alternatives were identified and tested for use in rugged terrain