

Fastest Path Determination at Lane Granularity using
a Vehicle-to-Vehicle-to-Infrastructure (V2V2I)
Intelligent Transportation System Architecture

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Outline

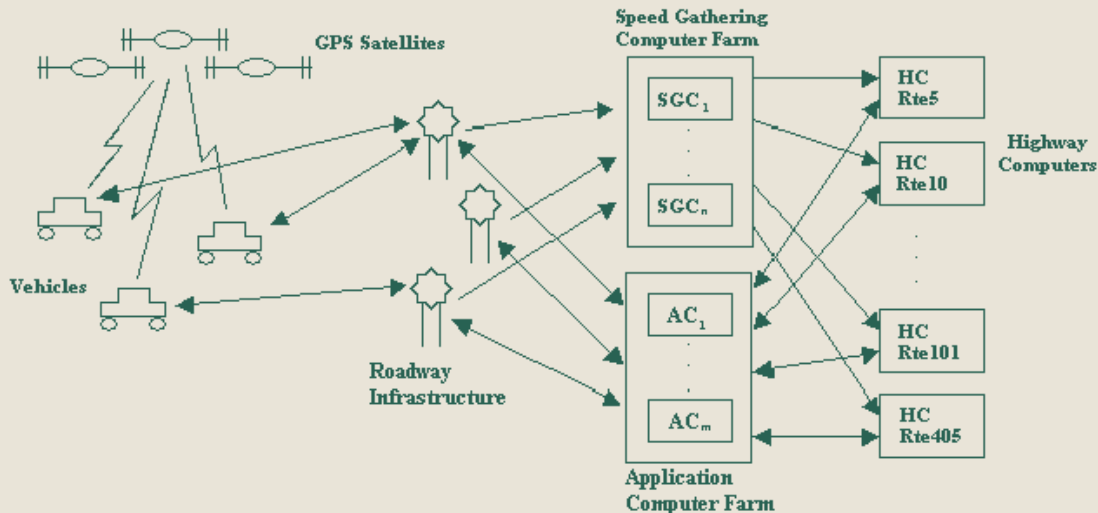
- Motivation
- V2I and V2V Architectures
- V2V2I Architecture Overview
- Fastest Path Analysis with V2V2I Architecture

Motivation

- Intelligent transportation systems expect vehicles to be able to communicate with other vehicles (V2V) and with hardware on the roadway (V2I)
- The amount of bandwidth and processing required by a central server for all of the vehicles within a given freeway system in a V2I network can be more than current technology supports
- The amount of data in a pure V2V network for ITS applications may allow for an unacceptable latency

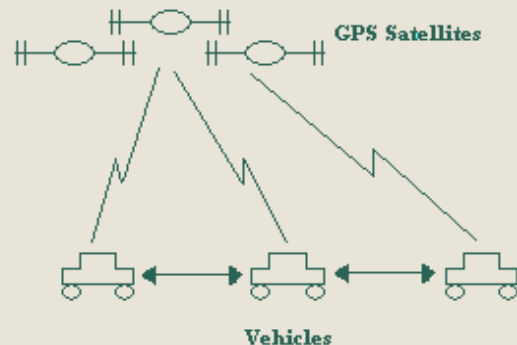
V2I Characteristics

- Central server can maintain all of the information about the speed of vehicles or sections of a transportation network
- Central server will respond to requests for ITS applications, such as determining fastest paths or durations of given paths
- Any centralized component (roadway infrastructure, server, network line) presents a single point-of-failure



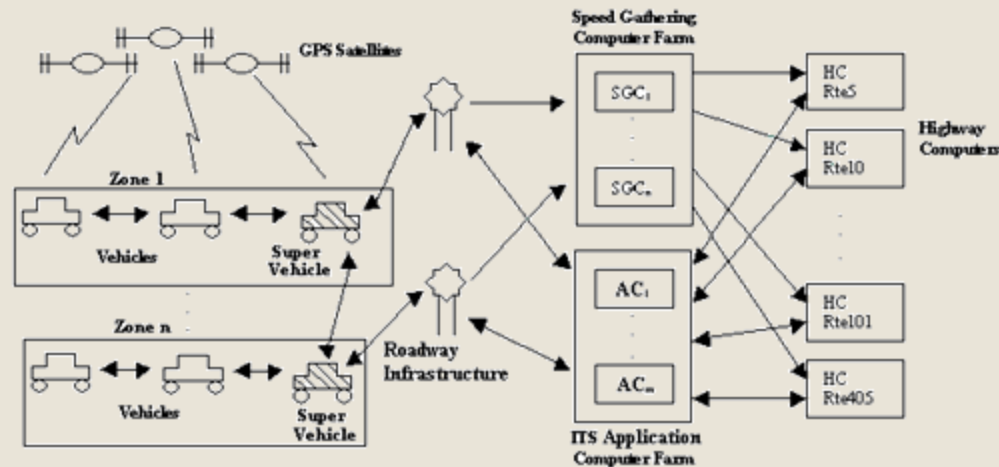
V2V Characteristics

- Vehicles communicate with other vehicles that are “close” in proximity to them
- Vehicles do not *need* to transmit their speeds and locations until a request is made for an ITS application that needs that data
- As multiple vehicles make requests for ITS applications, the amount of data to transmit will become too large for a wireless network to handle and provide responses for in a reasonable amount of time



V2V2I Characteristics

- Goals
 - Fast response times for ITS applications, similar to the V2I architecture
 - Fault tolerance, similar to the V2V architecture
 - Reduce the overall bandwidth required over both the V2I and V2V architectures



V2V2I Description

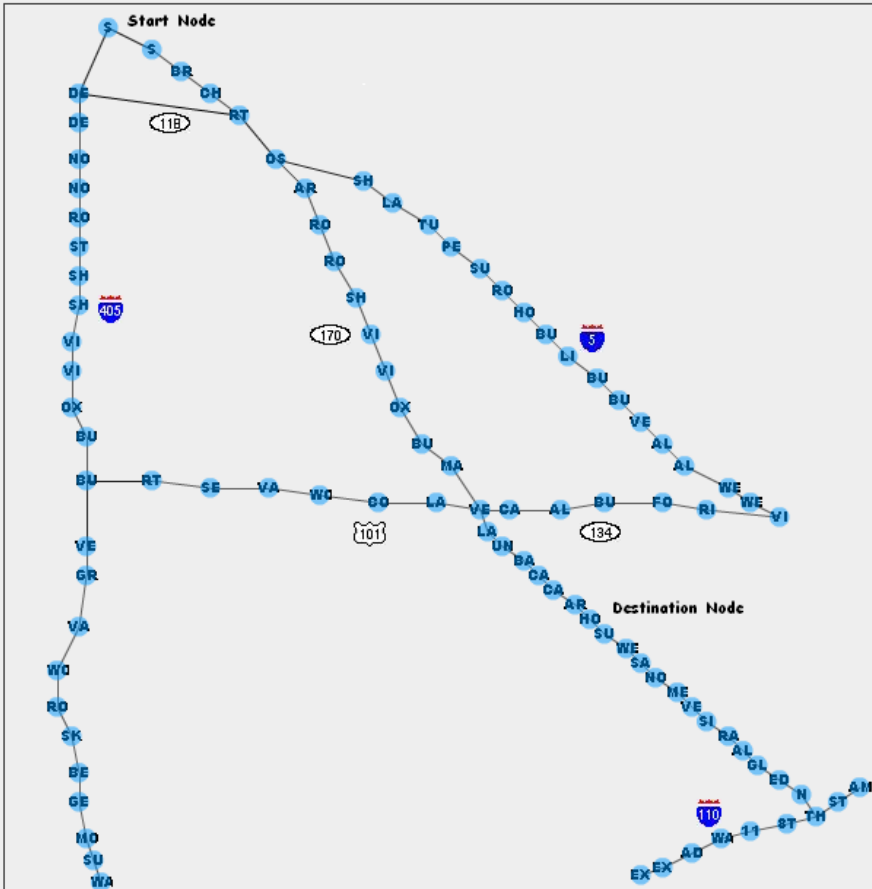
- Break road network into “zones”
 - The size of the zones is dependent upon the bandwidth available and accuracy needed by the ITS application using the data
 - Any two vehicles in the zone must be able to communicate with each other
- Each zone has at least one vehicle designated as a Super Vehicle
 - Responsible for communicating the data for the zone to the roadway infrastructure and to the Super Vehicles of adjacent zones
 - In the event of a failure, the network can revert to a V2V architecture consisting of Super Vehicles

V2V2I Description

- Non Super Vehicles in the zone send their speed and location to the Super Vehicle of the zone
- Super Vehicles will aggregate the data of the vehicles within its zone and transmit the aggregated data to the central server
 - The aggregated algorithm will determine how accurate the data will be at the central server
- The amount of bandwidth required by the central server is reduced since instead of every vehicle sending its speed and location, only the Super Vehicle for each zone will send the aggregated speed and location

V2V2I Fastest Path Analysis

- Although the Super Vehicle can transmit as much data as it would like, I performed an analysis with one speed per zone being transmitted from a Super Vehicle every 30 seconds for a 3 hour period
 - Live loop detector data from the California Department of Transportation was transformed to continuous data for the analysis
- The transportation graph contained 96 vertices and 99 edges
- Fastest paths were computed from a source node to a destination node every 30 seconds



Caltrans Northwest Loop Detectors

Freeway System
 Load Freeway System
 Zone Configuration
 Load Zone Configuration

Start
 End
 Fastest Path Algorithm
 Fastest Path Shortest Path
 Zoom In Create Vehicle

Messages
Fastest Path
 Path = LA-5-S S FERNANDO 1 ML1 LA-5-S S F
 Distance = 15.63 miles
 Time = 14 minutes 26 seconds
 Refresh Freeway System

Start
 End
 Speed Lane Update Speed

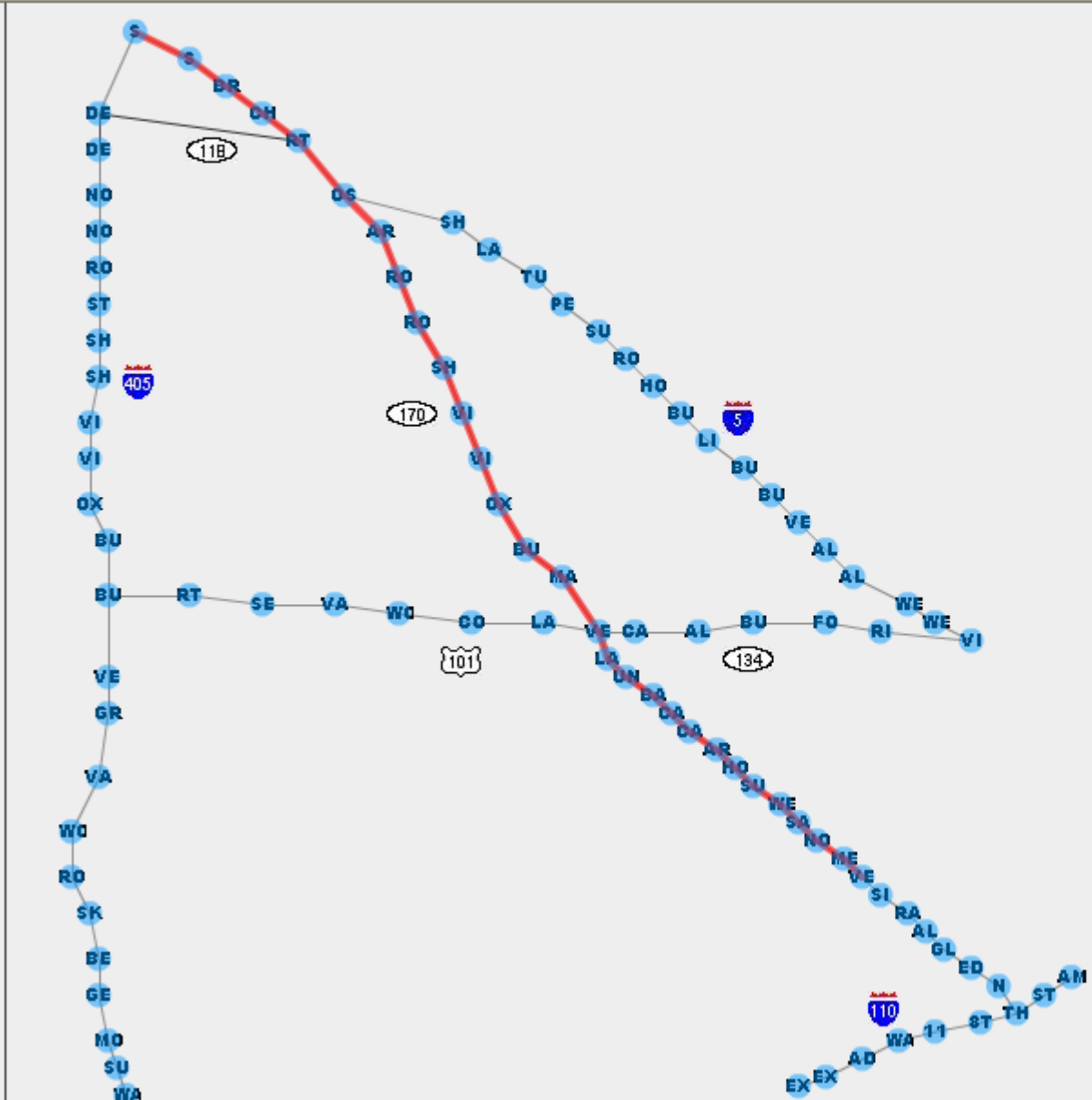
File Caltrans Loop Detectors Lanes Load File

Execute File Stop Execution

```
72|0|10|S FERNANDO 2|LA-5-S|BRAND|LA-5-S|78|ML1
72|0|10|S FERNANDO 2|LA-5-S|BRAND|LA-5-S|78|Summary
72|0|10|CHATSWORTH|LA-5-S|RTE 118 CN|LA-5-S|69|ML1
72|0|10|CHATSWORTH|LA-5-S|RTE 118 CN|LA-5-S|69|ML2
72|0|10|CHATSWORTH|LA-5-S|RTE 118 CN|LA-5-S|69|Summary
72|0|10|RTE 118 CN|LA-5-S|OSBORNE 2|LA-5-S|68|ML2
```

Messages

Simulation Time 0



Caltrans Northwest Loop Detectors

Freeway System

Start

End

Fastest Path Algorithm

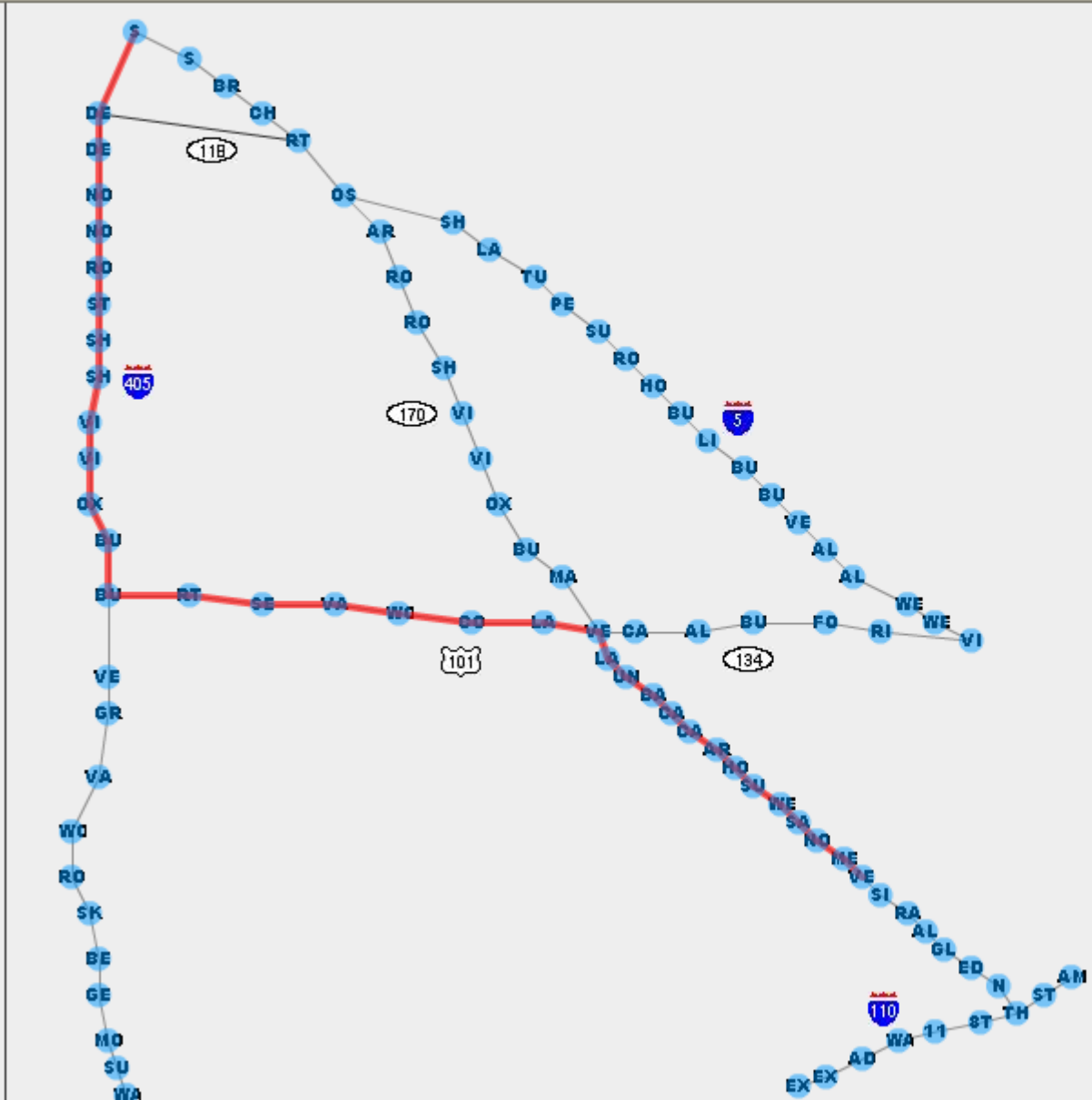
Messages

Fastest Path
 Path = S FERNANDO 1 S FERNANDO 2 BRANI
 Distance = 15.63 miles
 Time = 14 minutes 26 seconds

Start

End

Speed



Caltrans Northwest Loop Detectors

Freeway System LA Northwest

Load Freeway System

Start LA-5-S at S FERNANDO 1

End LA-101-S at VERMONT

Fastest Path Algorithm APAP Update

Fastest Path

Shortest Path

Messages

Fastest Path

Path = S FERNANDO 1 DEVONSHIRE 2 DEVONSHIRE 1
 Distance = 21.65 miles
 Time = 19 minutes 59 seconds

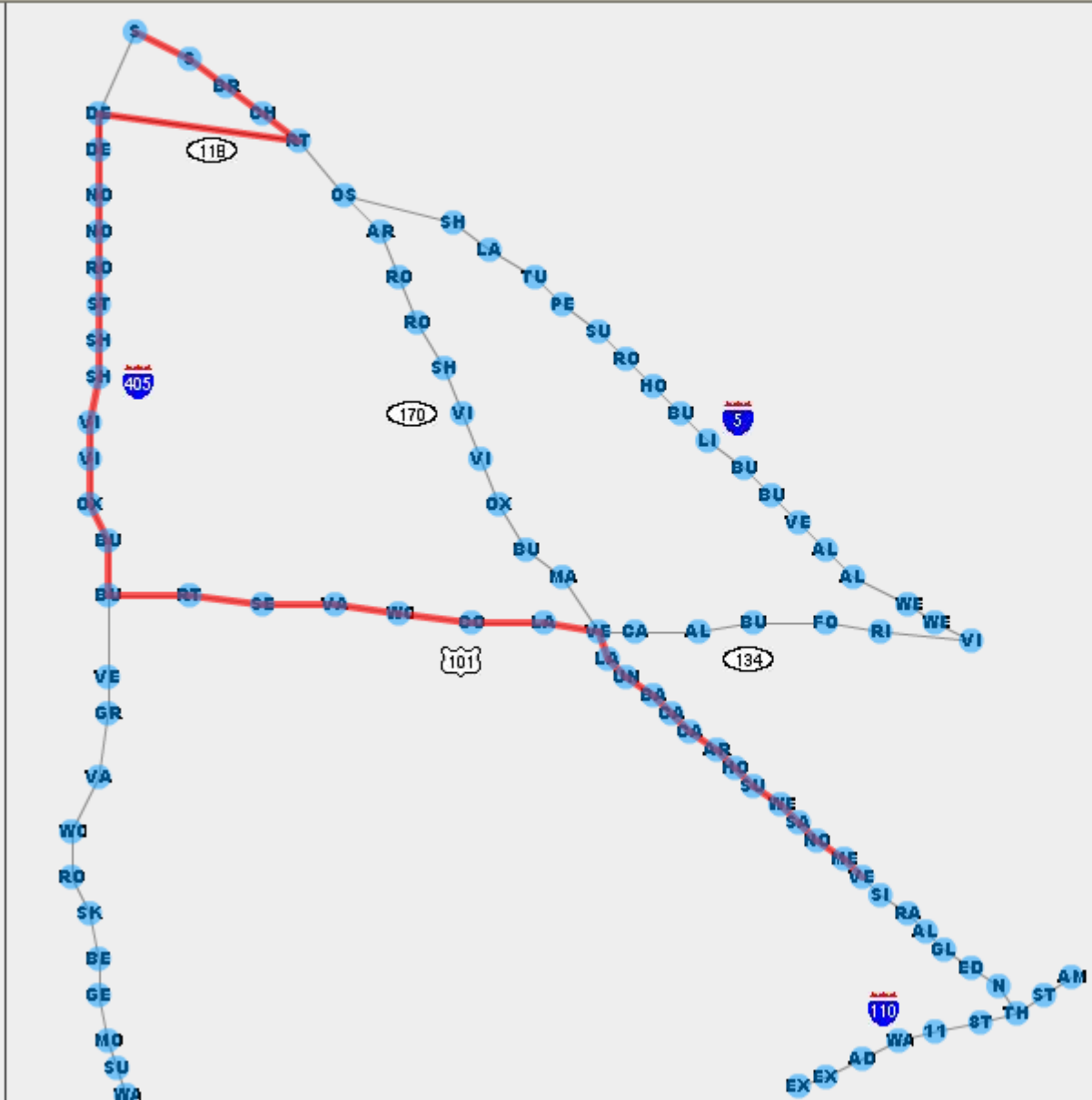
Remove Paths

Start LA-5-S at OSBORNE 2

End LA-170-S at ARLETA

Speed 4

Update Speed



Caltrans Northwest Loop Detectors

Freeway System LA Northwest

Load Freeway System

Start LA-5-S at S FERNANDO 1

End LA-101-S at VERMONT

Fastest Path Algorithm Dijkstra

Fastest Path

Shortest Path

Messages

Fastest Path
 Path = S FERNANDO 1 S FERNANDO 2 BRANI
 Distance = 22.16 miles
 Time = 20 minutes 27 seconds

Remove Paths

Start LA-5-S at S FERNANDO 1

End LA-405-S at DEVONSHIRE 2

Speed 1

Update Speed



http://www.freewaysimulator.com/demo/index.html



Yahoo! Search



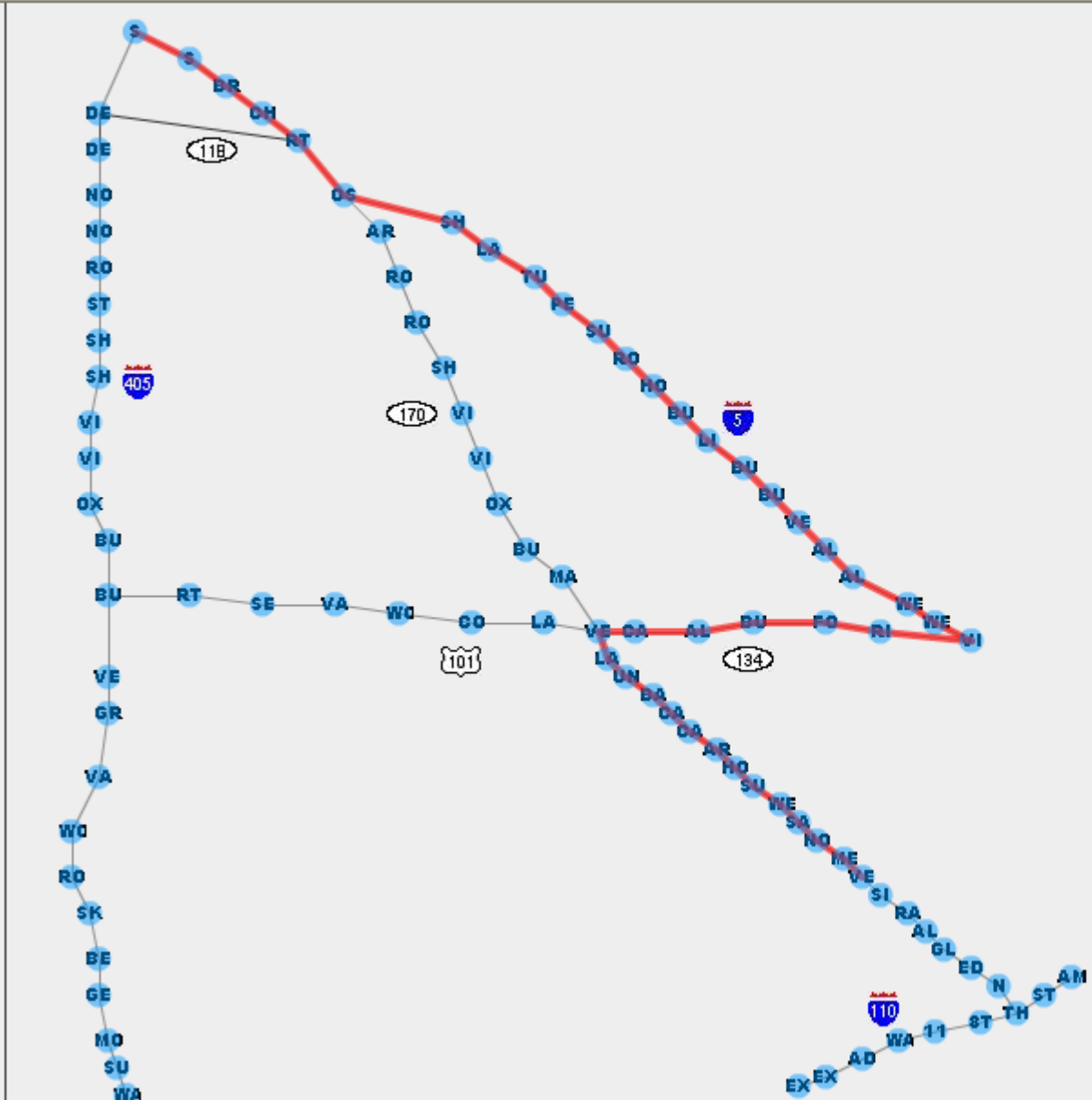
FreeSim: A Free Real-Time Freeway Traffic Simulator



Page



Tools



Caltrans Northwest Loop Detectors

Freeway System

Start

End

Fastest Path Algorithm

Messages

Fastest Path

Path = S FERNANDO 1 S FERNANDO 2 BRANI

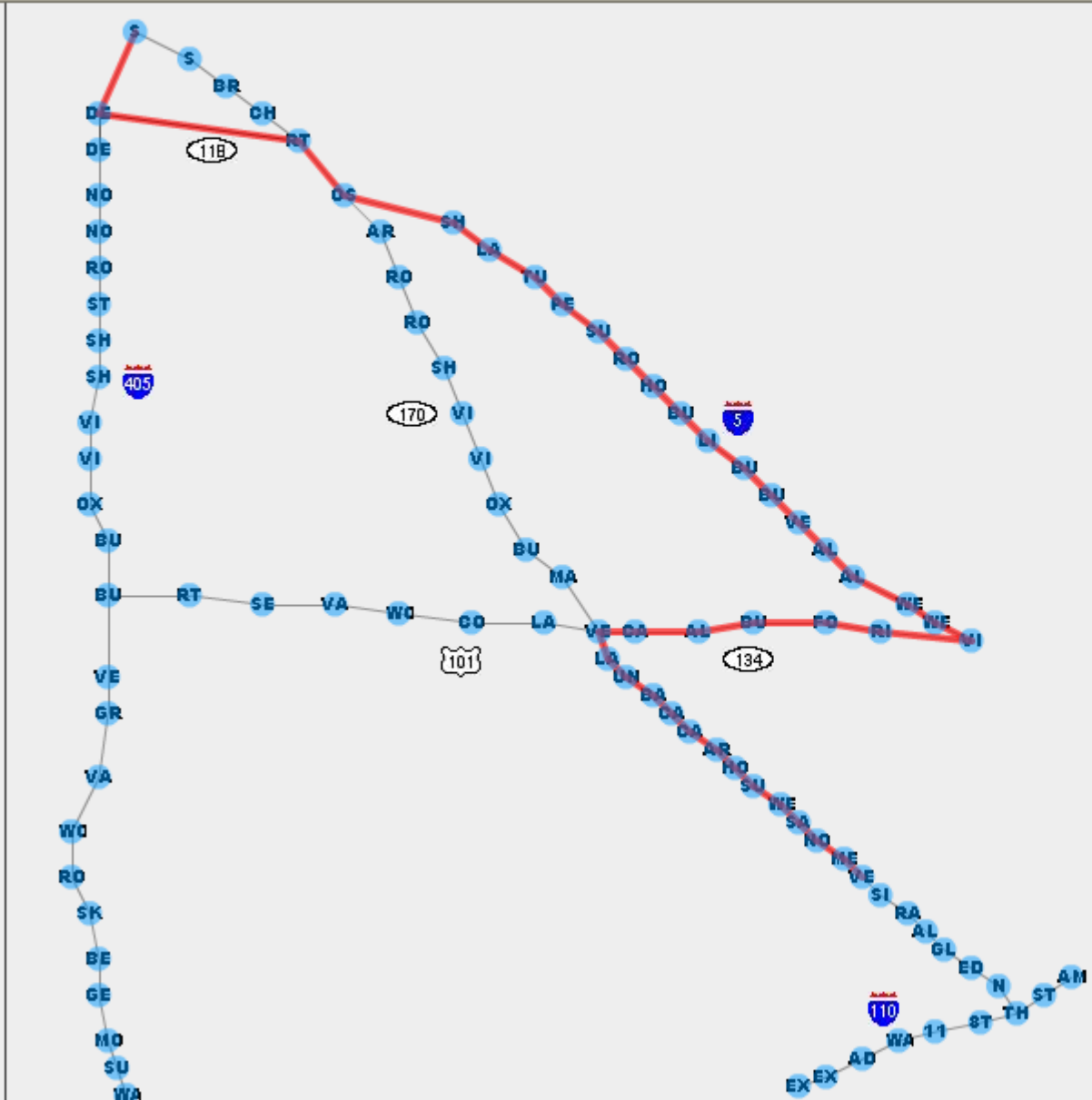
Distance = 24.63 miles

Time = 22 minutes 44 seconds

Start

End

Speed



Caltrans Northwest Loop Detectors

Freeway System

Start

End

Fastest Path Algorithm

Messages

Fastest Path

Path = S FERNANDO 1 DEVONSHIRE 2 RTE 11:
 Distance = 27.40 miles
 Time = 25 minutes 18 seconds

Start

End

Speed

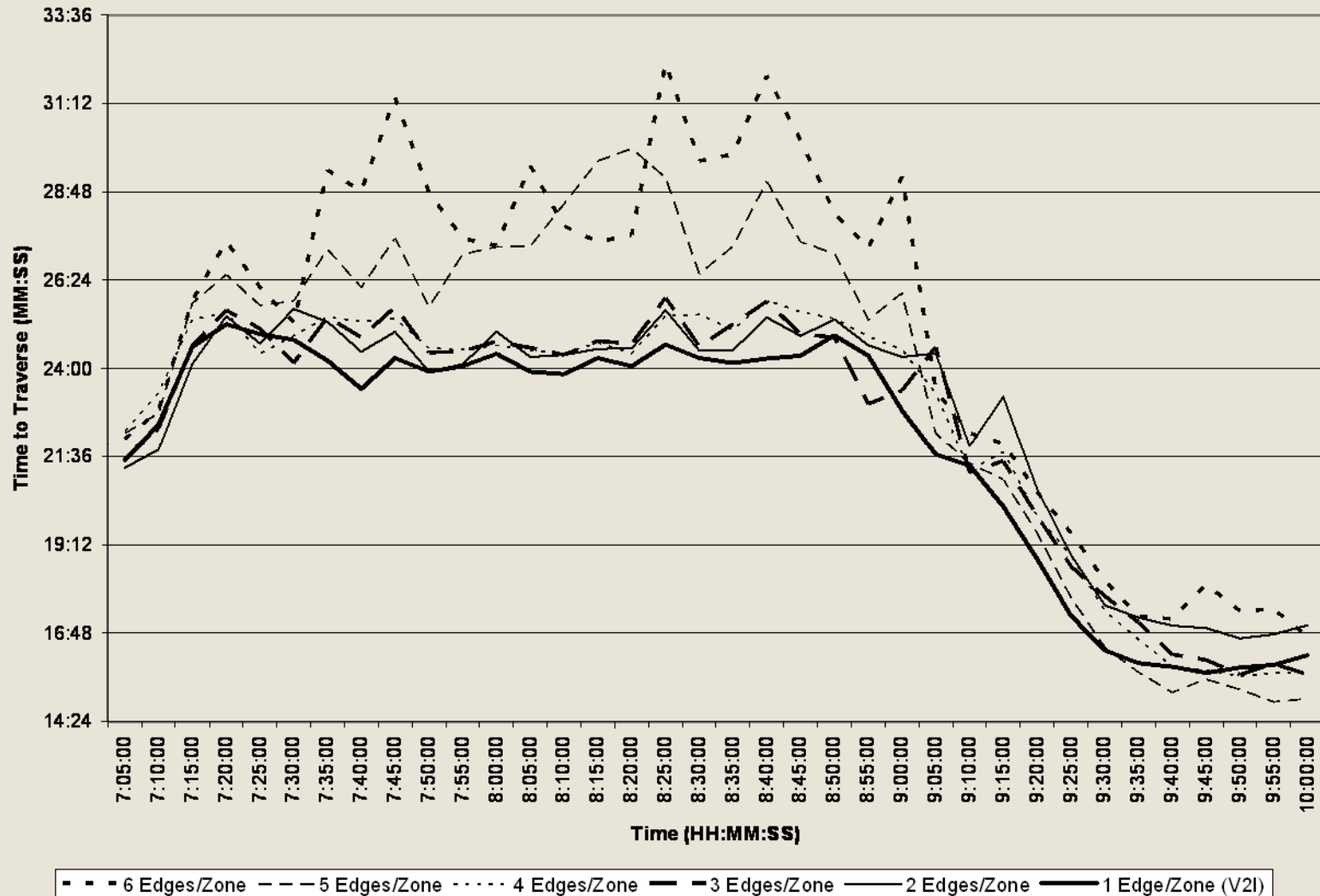
Paths from Source to Destination Node

Path #	Path	Distance in miles / kilometers	Time to Traverse at Speed Limit (65mph/104kph) (mm:ss)
Path 1	5S – 170S – 101S	15.63/25.16	14:26
Path 2	405S – 101S	21.65/34.86	19:59
Path 3	405S – 118E – 5S – 170S – 101S	18.40/29.62	16:59
Path 4	405S – 118E – 5S – 134W – 101S	27.40/44.11	25:18
Path 5	5S – 134W – 101S	24.63/39.65	22:44
Path 6	4S – 118W – 405S – 101S	22.16/35.68	20:27

V2V2I Simulations

- The simulation was run 6 times, with between 1 and 6 edges per zone
 - The 1 edge per zone case is equivalent to the V2I architecture with one speed being reported for each edge
 - The rest of the simulations contained between 17 and 50 zones based on the number of edges per zone
 - The fastest path was determined every 30 seconds for each of the edge per zone cases

Time to Traverse Fastest Path with Zones



V2V2I Fastest Path with Zones Analysis

- Looking at the graph, it appears that as the number of edges per zone increases, the time to traverse the fastest path becomes more inaccurate, however

# Edges per Zone	Average # of seconds fastest path differs from V2I fastest path
2	59
3	60
4	39
5	131
6	194

- The algorithm used for aggregating speeds in each zone found the average speed on each edge in the zone and then divided by the number of edges in the zone

V2V2I Fastest Path with Zones Analysis

- Each path at each time period for each zone execution was compared to the V2I case for accuracy

# Edges per Zone	# Incorrect Fastest Paths	% Incorrect Fastest Paths	# Correct Fastest Paths	% Correct Fastest Paths
1	0	0%	361	100.0%
2	49	13.6%	312	86.4%
3	53	14.7%	308	85.3%
4	65	18.0%	296	82.0%
5	118	32.7%	243	67.3%
6	48	13.3%	313	86.7%

- The 6 edge per zone and 2 edge per zone cases were the most accurate, at just over 13% of the paths being different

V2V2I Fastest Path with Zones Analysis

- These results appear to contradict with the graph showing the average differences in time between the V2V2I and the V2I architecture
 - However, take the 4 edges per zone case, which differed from the V2I fastest path by only 39 seconds, but did so with 18.0% of the paths being different
 - The six edges per zone case differed from the V2I fastest path by 194 seconds, though only 13.3% of the paths were different
 - This shows the inaccuracy of determining the time to traverse for the 6 edge per zone configuration, though finding the actual fastest path is rather accurate

V2V2I Zone Bandwidth Analysis

- Based on the California Department of Transportation Average Annual Daily Traffic in 2003, there were approximately 100,000 vehicles represented in the simulation
 - With 100 edges, there were approximately 1,000 vehicles on each edge
 - Using the V2V2I architecture instead of the V2I architecture would save $x/1000$ bps, where x is the number of edges per zone
 - So, assuming 1 byte to represent the speed of a vehicle, 8 bytes to represent the location, and 40 bytes of overhead, 37.4Mbps would be needed by the V2I architecture
 - With 2 edges per zone in the V2V2I architecture, only 19.1Kbps would be needed, though the accuracy rivals that of the V2I

V2V2I Fastest Paths with Lanes

- The data obtained from the California Department of Transportation consisted of occupancy, number of vehicles, and the estimated speed of each lane on the highway
- Can drivers save time by traversing the fastest paths based on choosing the optimal lane?
 - The transportation network remained the same as in the previous simulations, though lanes were now included



Caltrans Northwest Loop Detectors

Freeway System LA Northwest

Zone Configuration 1 Edge

Start LA-5-S at S FERNANDO 1
End LA-101-S at HOLLYWOOD
Fastest Path Algorithm APAP Update

Messages

Start LA-5-S at OSBORNE 2
End LA-5-S at SHELDON
Speed 10 **Lane** ML3

File Caltrans Loop Detectors Lanes

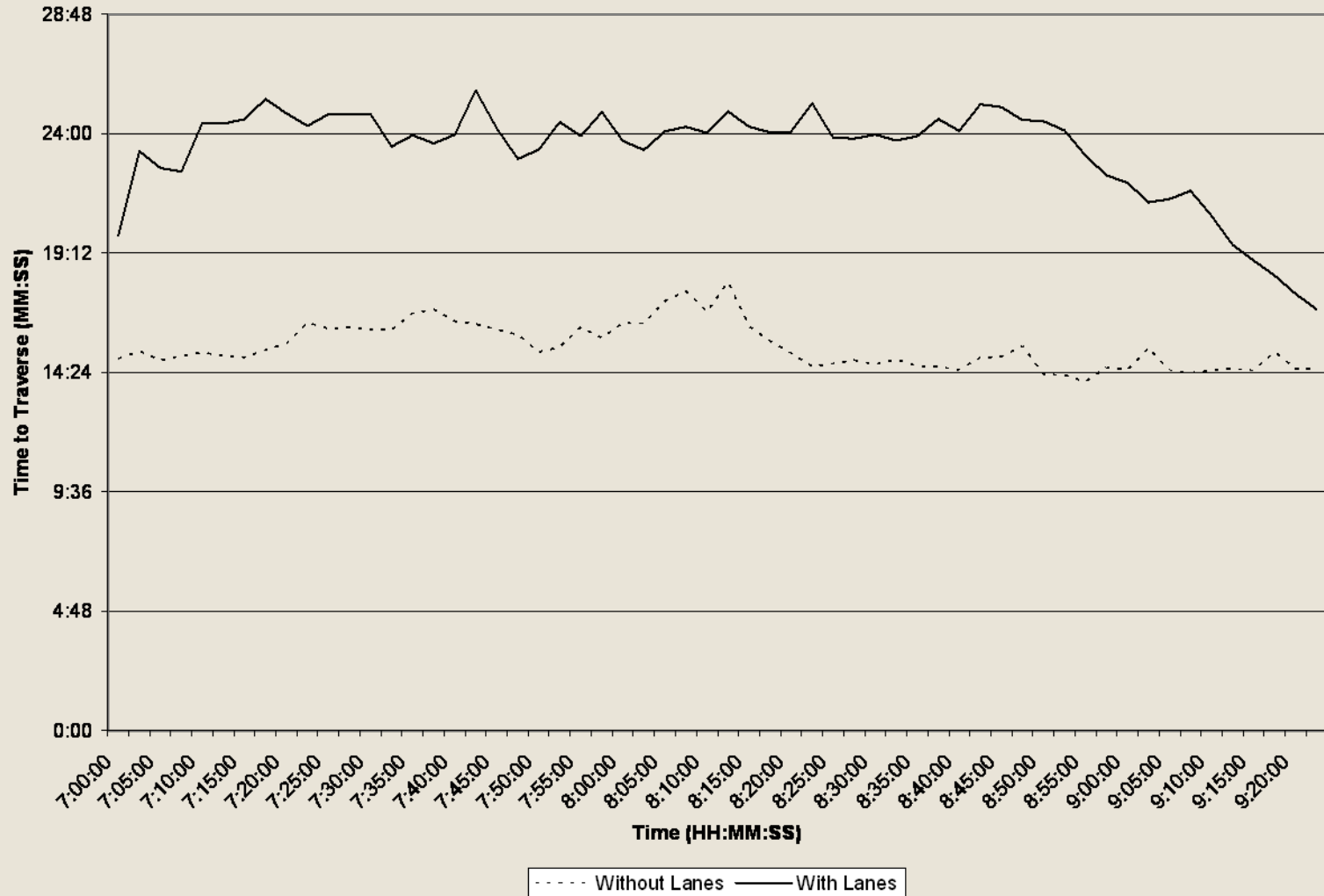
```

Caltrans Northwest Loop Detectors
# VEHICLE_COMMAND_NEW_VEHICLE[VEHICLE_ID]TIME_TO_E
70|0|0|0|0|0|0
70|1|0|S FERNANDO 1|LA-5-S|VERMONT|LA-101-S
76|1|1|0|S FERNANDO 1|LA-5-S|Summary|S FERNANDO 2|LA-5-S|Summ
76|1|1|0|S FERNANDO 1|LA-5-S|Summary|DEVONSHIRE 2|LA-405-S|Sun
  
```

Messages

Simulation Time
0

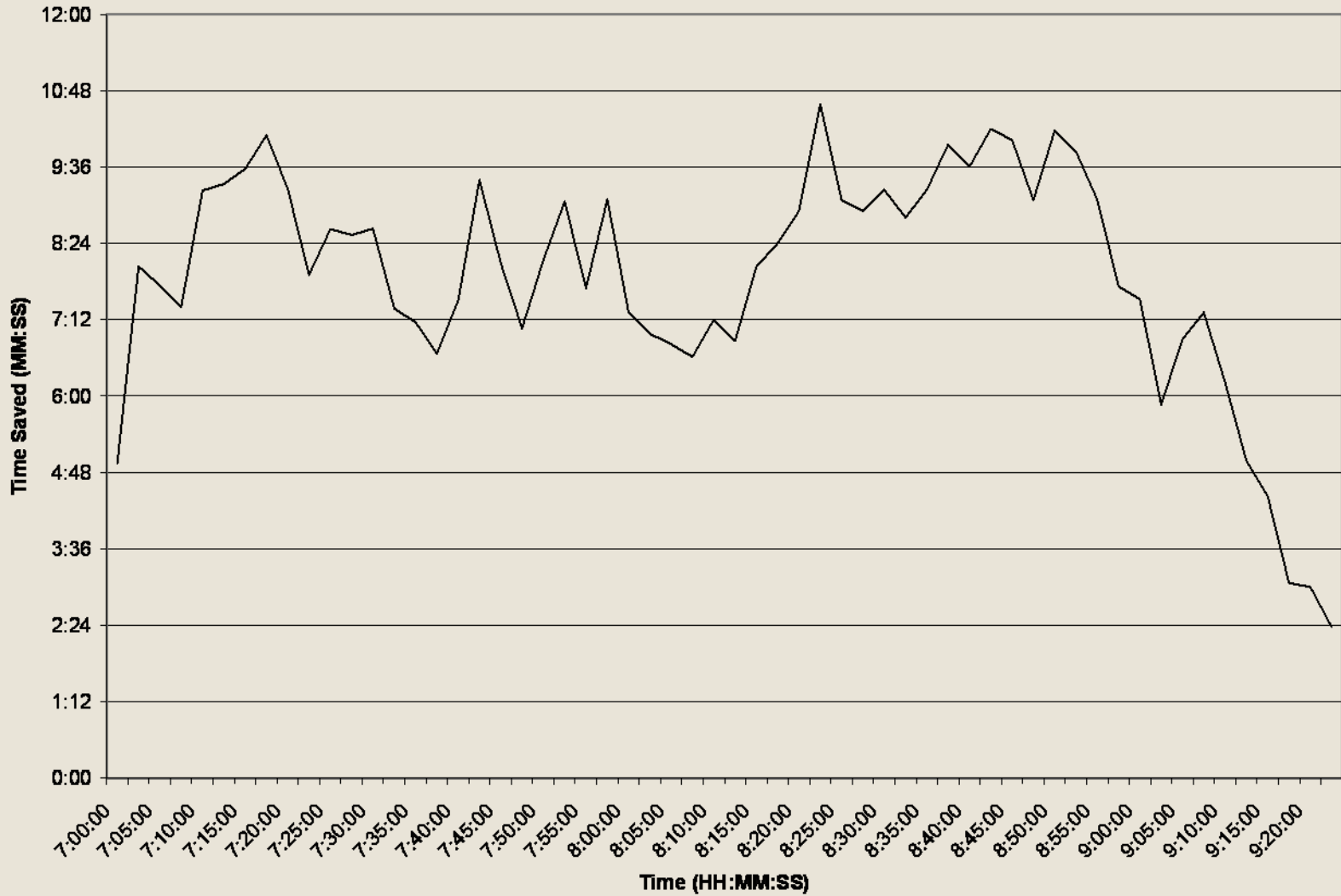
Time to Traverse Fastest Paths With and Without Lanes



Time to Traverse With Lanes Analysis

- The fastest path with lanes was always the shortest path
- The fastest path without lanes varied between path 1 (shortest) and path 5 (second longest but least traveled)
- The difference in the amount of time determined for the fastest path when using lanes is between 3 and 10 minutes for a path that optimally takes 15 minutes
 - On average, a driver can save 7.5 minutes on his travel time with lanes analyzed as opposed to an average speed for all of the lanes of an edge

Difference in Time Determined for Fastest Path With Lanes



Conclusion

- The V2V2I architecture provides fault tolerance as the V2V architecture does and fast queries and accuracy as the V2I architecture does
 - Depending on the accuracy of the data needed, the V2V2I architecture can greatly reduce the bandwidth required while still providing the necessary functionality to an ITS application
 - The fewer edges there are in a zone, the more accurate the fastest path obtained
 - The amount of time to traverse the fastest path can be obtained with four edges per zone (even though the path may not be correct)
 - The fastest path was accurately produced with six edges per zone, though the time to traverse the path was substantially different

Conclusion

- Routing vehicles in lanes has become feasible with the use of differential GPS
 - The accuracy of the amount of time to traverse a fastest path using optimal lane data can save a driver over 10 minutes at times on a 15 minute path with optimal speeds
 - On average, it can save a driver between 30-60% of the overall travel time