ARTERIAL TRAVEL TIME USING MAGNETIC SIGNATURE RE-IDENTIFICATION THEORY OF APPLICATION AND ITS DEPLOYMENT IN SAN DIEGO

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Paper Abstract:

An Arterial Travel Time solution has been developed that provides high vehicle match rates while maintaining complete user privacy. The system re-identifies the magnetic signatures from vehicles as they pass over in-pavement sensor arrays at different points of interest. The system outputs the complete and accurate distribution of travel times for the arterial, even in the presence of signalized intersections.

This paper presents the theory of application of this Arterial Travel Time solution, a review as to the importance of vehicle match rates, the ground truth methodology used to verify performance and a review of its deployment by San Diego Association of Governments (SANDAG) in Chula Vista, California.

Keyword: Arterial Travel Time Wireless Magnetic Re-Identification Sensors

INTRODUCTION

Travel Time information on freeways has been available for sometime in large metropolitan areas in the US and around the world. However, there has been very limited information available on arterials. Many agencies recognize that arterial travel time and performance measures are essential for urban traffic management and have been seeking a cost effective solution for such measurements. Measuring arterial performance is more difficult due to varying delay occurring at intersection/traffic lights. In order to provide accurate measurements, an arterial travel time solution has been developed using small, self powered sensor nodes installed within the roadway. This solution measures the travel time of individual vehicles and provides accurate, real-time travel time distributions on key segments along an arterial. As an infrastructure based solution, the system is not reliant on any in-vehicle device and therefore provides a high degree of vehicle penetration as every vehicle is a virtual probe. In addition, as no identifiable information can be collected from the vehicle, it provides totally anonymous information.

ARTERIAL TRAVEL TIME THEORY OF APPLICATION

The system consists of an array of five vehicle sensor nodes deployed at strategic locations on the departure side of the intersection. Each sensor nodes contain a 3 axis magnetometer, microprocessor, memory, low power radio and batteries within a watertight case. After a vehicle passes over the sensor array, each sensor transmits its unique magnetic signature information to a wireless access point located within 150 feet of the array. If the sensor array is located outside this range, a battery operated repeater can retransmit the information up to 1,000 feet away. The access point collects the data from each sensor or repeater and re-transmits the information to a data archiving server. The access point uses TCP/IP to communicate with the server either by Ethernet or via high speed cellular modem. Once the information is collected by the data archive server, it is used by the re-id engine for travel time analysis. Figure 1 below shows the typical topography of the system.

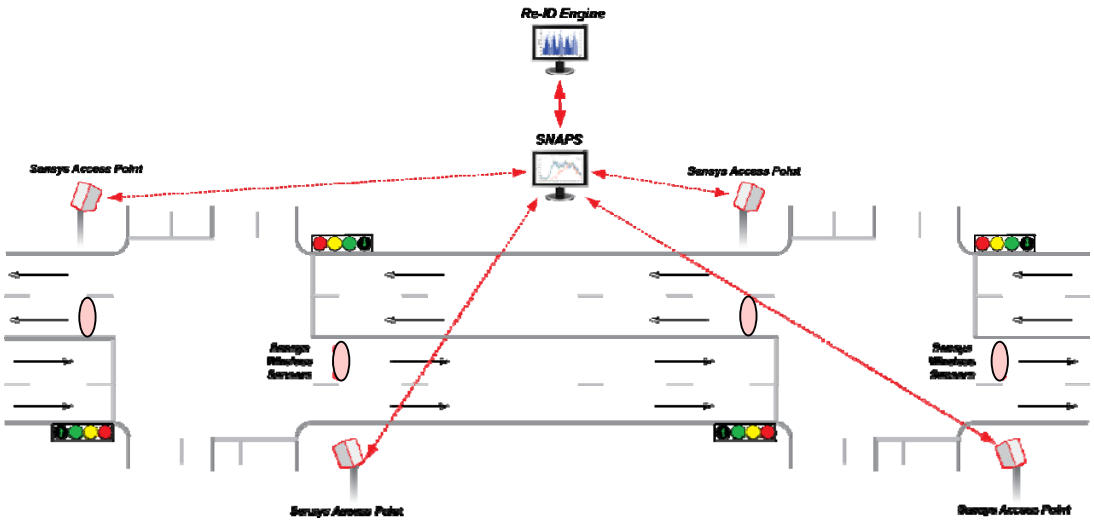

Figure 1: Arterial Travel Time System layout and components

As shown in Figure 1, each segment of the arterial has two sensors arrays: an upstream array and a downstream array. As vehicles cross the upstream sensor array, their unique magnetic signature is determined. Each sensor in the array then converts the raw magnetic profile into a speed independent, compressed magnetic signature for the vehicle. These signatures are transmitted to a re-identification (Re-Id) engine located at the Traffic Management Center (TMC). The Re-ID engine maintains and updates a statistical model of distance for matching and non matching vehicles. The Re-Id engine uses this model to determine the optimal matching set over a group of vehicles. The Re-ID engine finds the global maximum likelihood match of upstream vehicles to downstream vehicles using a dynamic programming algorithm. When the vehicle crosses the downstream sensor array, it is re-identified and the elapsed time recorded. This time-stamped re-identification process determines a distribution of individual vehicle travel times for arterial segments. A matching set is composed of matching from upstream array to downstream array, or from the upstream array to a turn or from a turn to the downstream array. Vehicles that pass over only one array are not eligible for re-identification.

The Re-Id engine provides the user with an XML data stream which contains the actual travel time for each matched vehicle matched along the arterial. Figure 2 below shows a typical travel time distribution for three segments and the overall arterial.

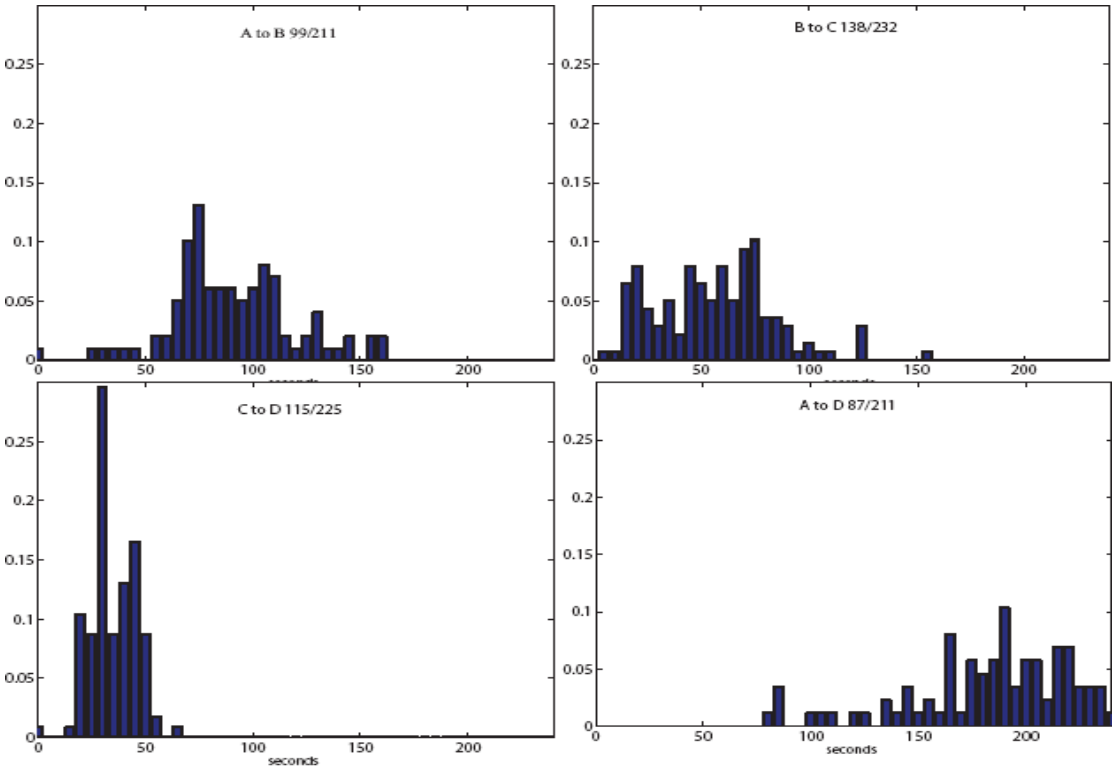

Figure 2: Plots of travel time distribution on segments of the San Pablo Arterial Travel Time System

VALUE OF VEHICLE PENETRATION

In order for an arterial travel time system to provide viable real time information, it is necessary that a high vehicle probe penetration rate be realized.

Percent Penetration is defined as the number of vehicles which are re-identified divided by the total number of vehicles during the same sample period. As an example, if 30 vehicles are detected out of a sample size of 1,000 vehicles, then the Percent Penetration is 30/1000 or 3%.

Chart 1 reflects the effect of varying penetration percentages on number of vehicles re-identified for various times assuming a sample size of 1,000 vehicles. As an example, if a Re-Id System is capable of a percent penetration of 5%, it will take 30 minutes to re-identify and compute a travel time for 25 vehicles out of 1,000.

	Number of Vehicles out of 1000 Re-Identified in X Minutes					
Percentage Penetration	**1 min**	**2 min**	**5 min**	**15 min**	**30 min**	**60 min**
1%	0.2	0.3	0.8	2.5	5.0	10.0
5%	0.8	1.7	4.2	12.5	25.0	50.0
10%	1.7	3.3	8.3	25.0	50.0	100.0
25%	4.2	8.3	20.8	62.5	125.0	250.0
50%	8.3	16.7	41.7	125.0	250.0	500.0
75%	12.5	25.0	62.5	187.5	375.0	750.0

Chart 1: The impact of Re-Identification Penetration Percentages on the amount of vehicles re-identified

Typical arterials produce a non-Gaussian travel time distribution with a large variance to mean ratio. This is due to cars traveling through arterials with varying speeds, driving habits and the various impacts of traffic signals. A large number of re-identified vehicles are required to accurately describe these distributions. If the results are required in real time or near real time, a high re-identification or penetration rate is essential. For example, if one assumes that 25 valid “probe” data points are required for statistical significance in determining an arterial travel time measurement on an arterial with 500 vehicles per hour, it will require a system with 1% penetration 2.5 hours to determine this measurement, while it will take just over 5 minutes for a system with 50% penetration.

Figure 3 below graphically illustrates the impact of how long it will take an arterial travel time system to generate accurate data based on vehicle flow rate and percent penetration, assuming that a minimum sample size of 25 vehicles is required to accurately measure the real travel time distribution. A system with 5% penetration on an arterial with a traffic flow of 500 vehicles per hour, will take 60 minutes to provide the minimum sample size. A system which delivers a 50% penetration will provide the same information in 6 minutes.

For transportation professional desiring to use performance measures in real time to manage their arterial traffic flow and provide accurate travel time information to the motoring public, a high penetration rate is a necessary prerequisite.

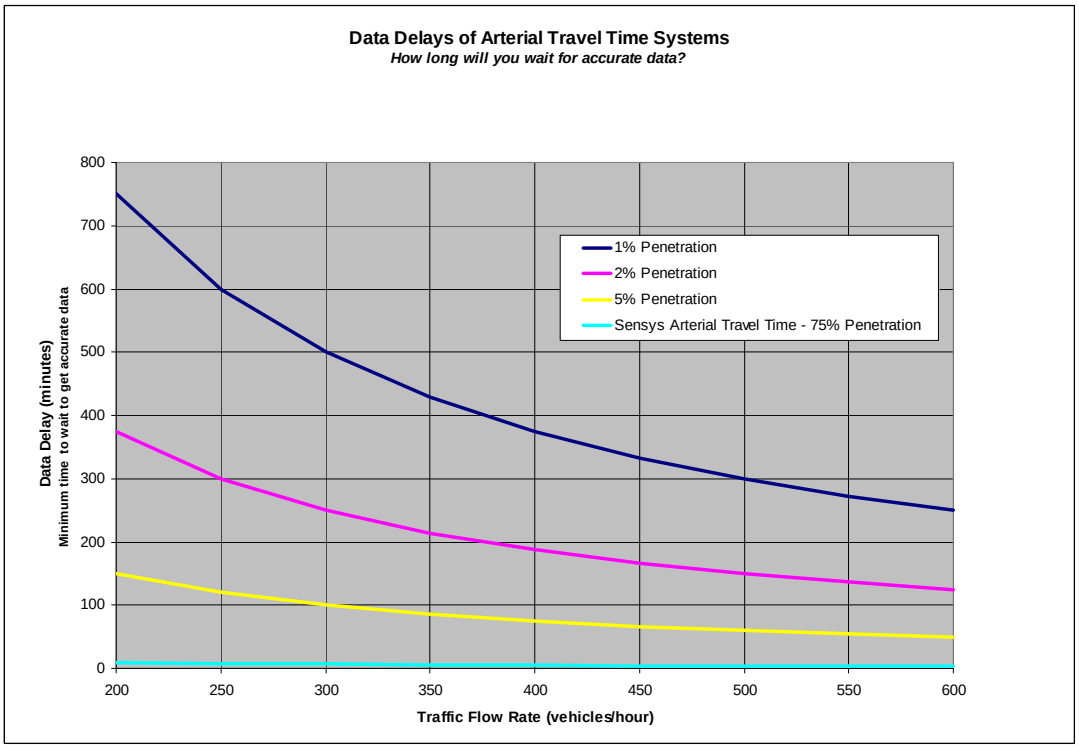

Figure 3: The impact of re-identification penetration percentages on the time required to obtain a statistically significant arterial travel time

PERFORMANCE LEVELS OF MAGENTIC SIGNATURE RE-IDENTIFICATION

Validation of the performance levels of using a magnetic signature re-identification system was performed in Alameda County, California using a video based ground truth.

Time-stamped video was recorded for a one hour period along a crowded arterial segment instrumented with the magnetic signature re-identification system. The video covered the entire segment of interest including a traffic signal. The video was manually broken down to provide a per vehicle travel time ground truth. The two data points, the magnetic signature re-identification and the ground truthed travel time, were then collated and compared. It should be noted that the ground truth included around 20% more vehicles which did not go over both sensor arrays, due to vehicles entering and exiting the segment. It is important to note that the two values trend each other very closely as shown in Figure 4.

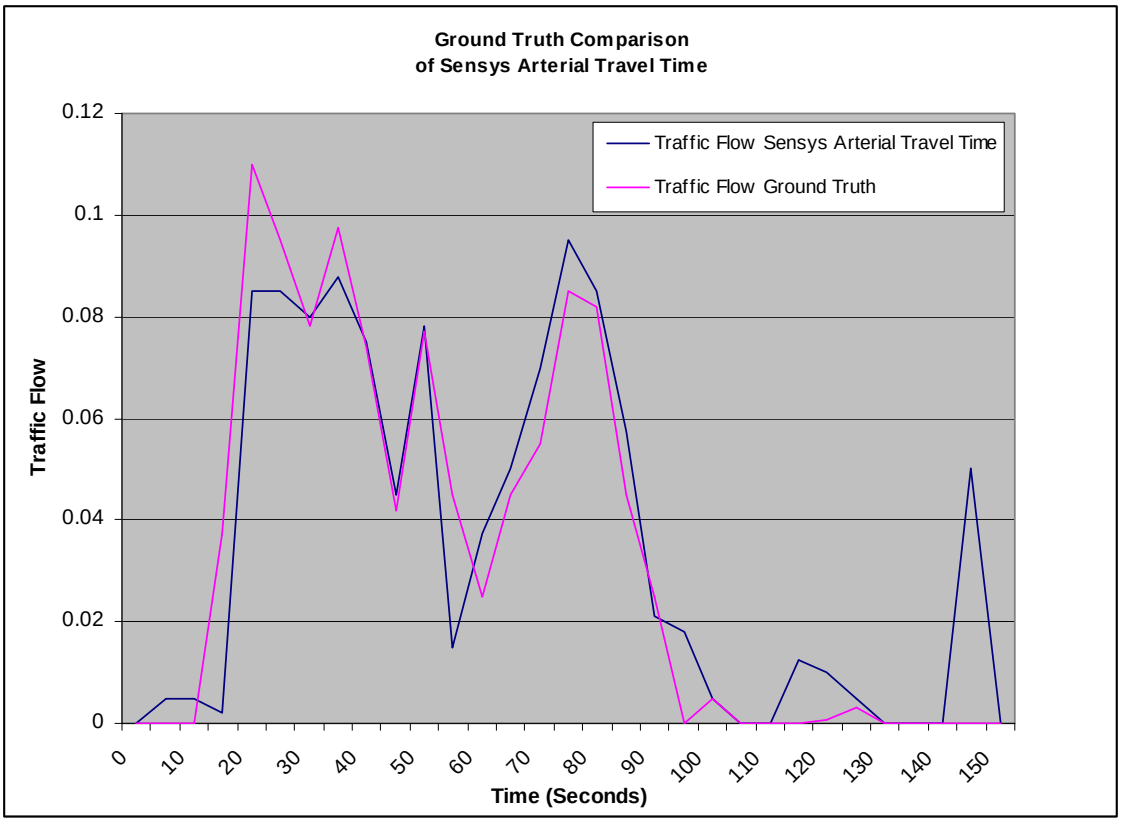

Figure 4: This plot illustrates the number of vehicles matched compared to the time travelled

Over the time period analyzed, there were 347 vehicles which traveled through the segment. The magnetic signature re-identification system properly matched 240 of the vehicles for a 70% penetration. In addition, Chart 2 illustrates the median, 80% and 90% travel times tracked very closely to the ground truth.

	Median Travel Time	80th Percentile Travel Time	90th Percentile Travel Time
Video Ground Truth	46 sec	77 sec	83 sec
Sensys Re-ID	50 sec	78 sec	86 sec
Error	8%	1%	3%

Chart 2: The comparison of key performance metrics between the measured and ground truth travel times

PRIVACY

An area of concern to the motoring public is privacy. Individuals want the freedom to travel without fear that their vehicle is being tracked in real time or re-constructed based on stored data.

Unlike other re-identification technologies, there are no specific identifying items used in the magnetic signature re-identifying process which could, in either reality or perception, allow a vehicle's location or routing to be determined.

Other solutions which have been developed, including license plate recognition, toll tag reading, cell phone, GPS and Bluetooth, contain personal information which could, in reality or perception, allow a vehicle's location or routing to be determined.

SANDAG DEPLOYMENT REVIEW

The travel time system was installed in Chula Vista, California (south of the City of San Diego) area by San Diego Association of Governments (SANDAG) as part of project to evaluate technologies that provide arterial performance measures. The system was installed along 4 miles along Telegraph Canyon and Otay Lakes Road, a heavily travelled roadway in Chula Vista, with average daily traffic volumes in excess of 70,000. This arterial has many unique features, resulting in a variety of traffic conditions. It is the main entrance road to Southwestern Community College as well as a primary cut through route between I805 and CA 125.

SANDAG is interested in measuring arterial performance as well as providing door-to-door travel time information. Performance measures of interest to SANDAG include vehicle counts (throughput), delay and travel time. In addition, this system is being used by the City of Chula Vista to monitor Level of Service (LOS). Chula Vista's Growth Management Oversight Commission measures 11 different quality of life standards, including transportation, to determine if new growth will be allowed to happen. Chula Vista policy is that no arterial can have a LOS of "D" or worse for more than 2 hours per day. If this is not achieved, then measures must be implemented to correct the deficiency. LOS measurements have typically been performed by the City of Chula Vista using traditional floating car studies per the Highway Capacity Manual. These studies are taken over a two to three day period, limiting the amount of information available for active transportation management.

This installation consisted of 9 Re-Id Stations. Each Re-Id station consisted of both directions of traffic, using 5 sensors per lane for a total of 90 sensors. Each access point was equipped with a high speed cellular internet connection. In addition, 27 repeaters were required.

The entire project was installed within a four day window. As each site was installed, the access point immediately began transmitting the probe data to the central data archive server and the Re-Id. As a result, the system was operational within 4 days of the first construction event. Figure 5 below shows both the travel time link installed within SANDAG as well as a sample graphical output.

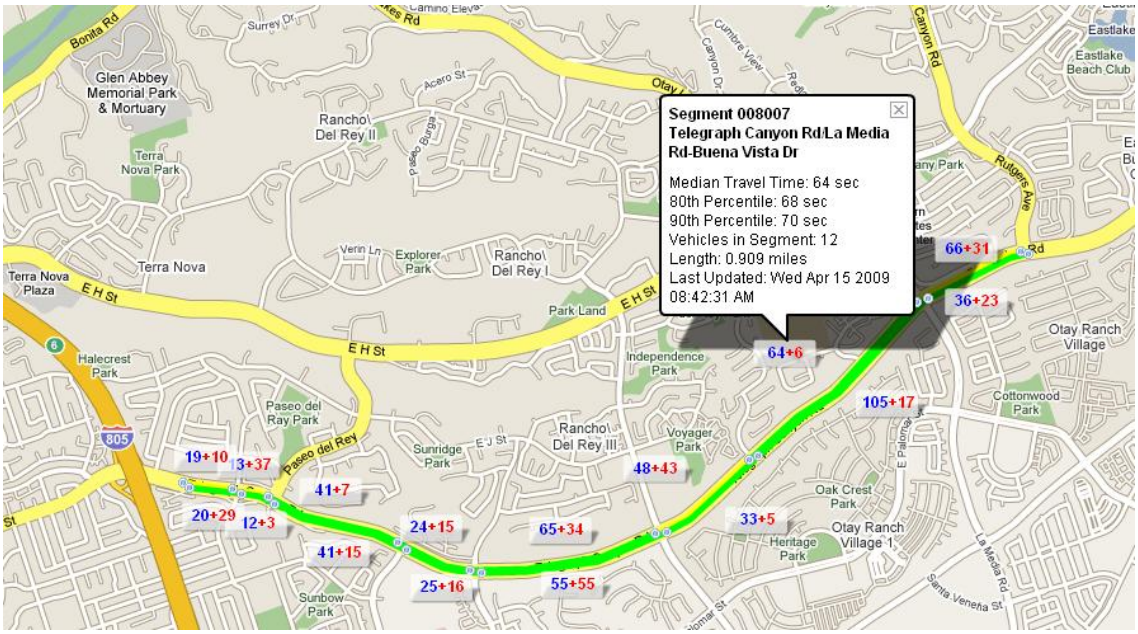

Figure 5: Sample graphical output of the SANDAG Travel Time System

Using the Magnetic Signature Re-Identification solution, Chula Vista now has the ability to collect and manage the performance of this arterial continuously. The Graph as shown in Figure 6 below illustrates the Level of Service along the arterial.

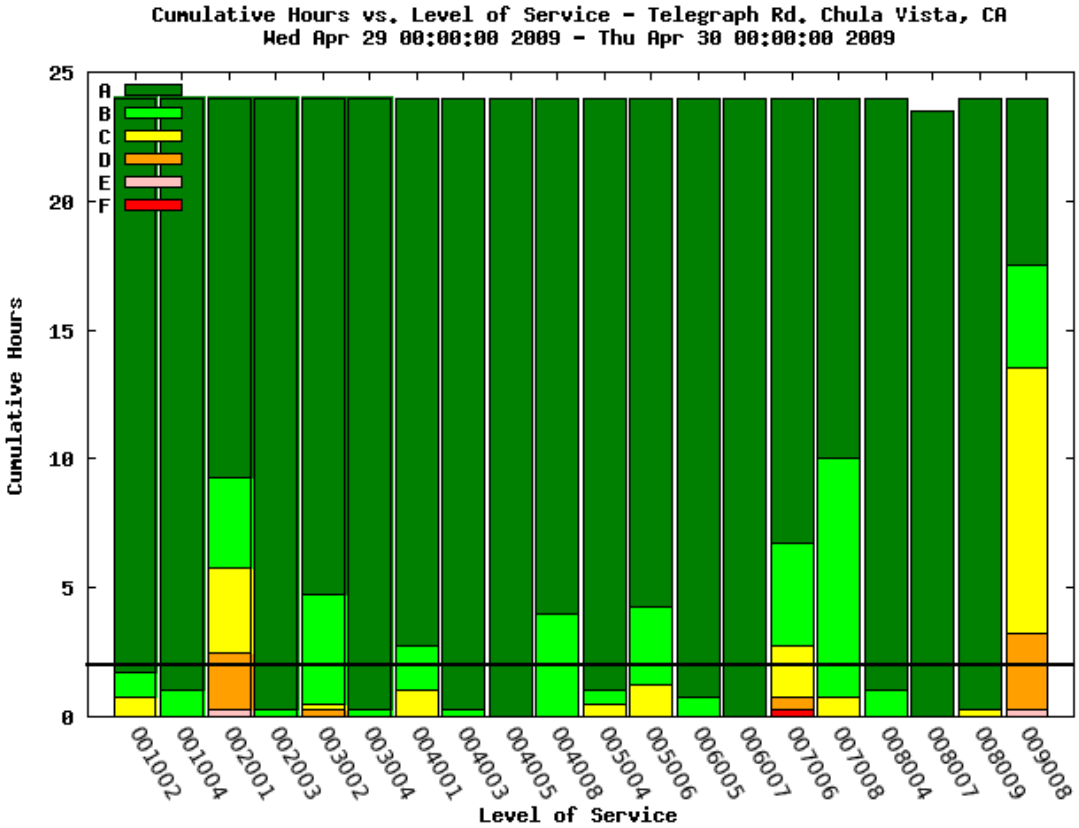

Figure 6: Histogram showing the Level of Service along the arterial

In addition to providing the Level of Service, the travel time distributions can be used to determine both the median and 90th percentile arterial travel times as shown in Figure 7 and 8 below.

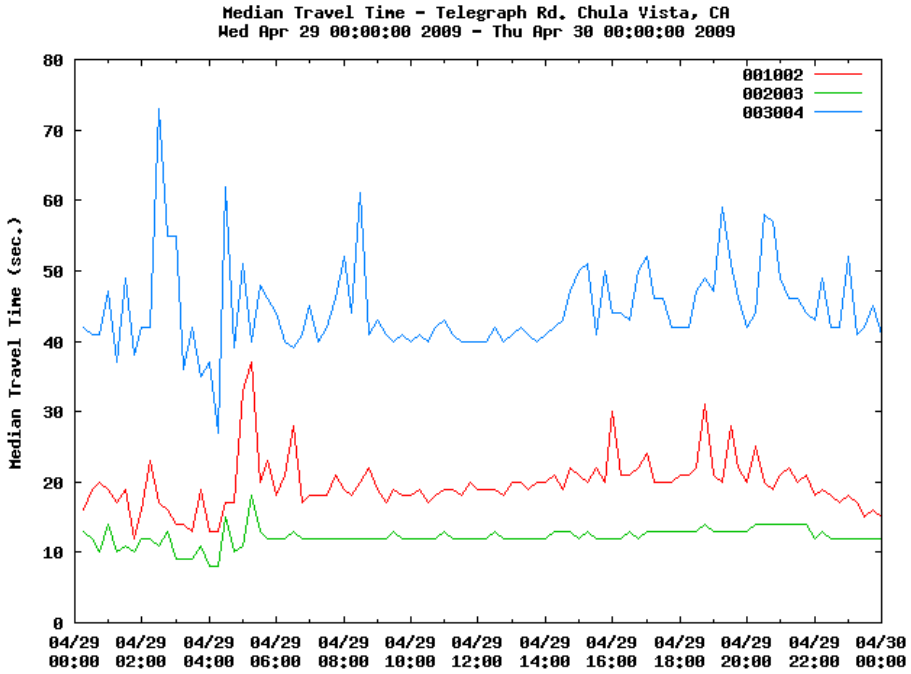

Figure 6: Plot showing the Median Travel Time over 3 segments

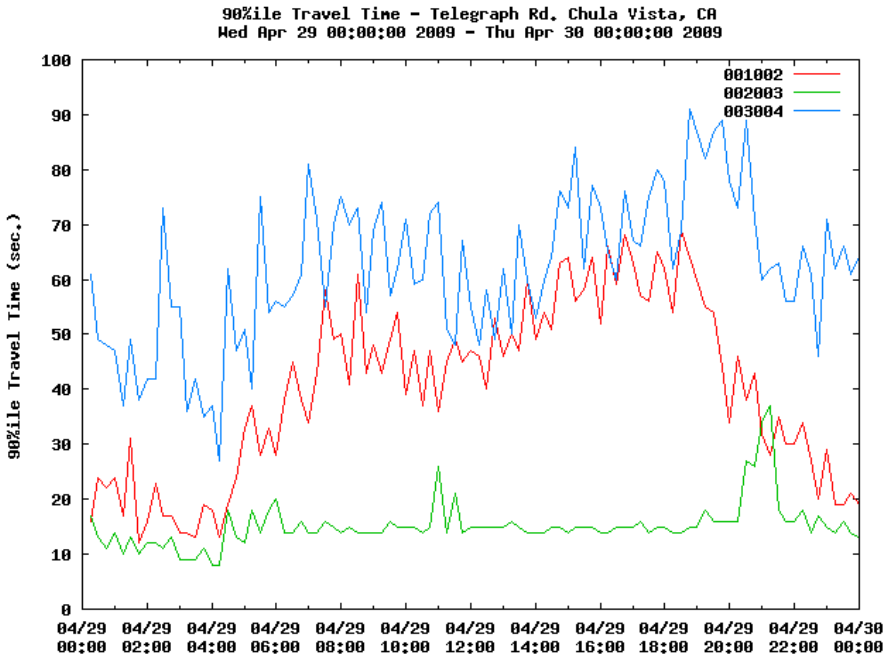

Figure 7: Plot showing the 90th Percentile Travel Time over 3 segments

The Re-Identification solution has performed well after installation. The trend data matches both the historical floating car studies, as well as matched their professional expectations in both free flow and congested travel levels. The system will be ground truthed in the near future when the road will be measured using the floating car study.

Chula Vista is pleased with the performance on the system and is looking to expand their deployment.

CONCLUSION

An arterial travel time system which provides accurate travel time distributions has been developed and is readily deployable. The system provides several key attributes:

- Infrastructure based, which yields very high penetration rates
- Accurate under all traffic conditions and in the presence of traffic signals
- Anonymous data collection eliminates privacy concerns
- Provides real time data

For the first time, transportation professionals will have continuous empirical data feedback on the operation of their arterials.