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Virtual Sensor System

Deployment of a Virtual Sensor System, based on Transit Probes, in an Operational Traffic Management System

by

Daniel J. Dailey
Professor
University of Washington
Dept. of Electrical Engr.
Seattle, Washington 98195

Frederick W. Cathey
Research Scientist
University of Washington
Dept. of Electrical Engr.
Seattle, Washington 98195

Washington State Transportation Center (TRAC)
University of Washington, Box 354802
University District Building, Suite 535
1107 N.E. 45th Street
Seattle, Washington 98105-4631

Washington State Department of Transportation
Technical Monitor
Ted Trepanier
State Traffic Engineer

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16. ABSTRACT

The Washington State Department of Transportation (WSDOT) operates a central traffic management system (TMS) for both day-to-day surveillance and traveler information. Past efforts developed the ability to create real-time traffic speed information by using virtual sensors that are based on transit vehicle tracking data.

This project developed a way to provide real-time congestion information from Seattle area arterials and freeways to the WSDOT TMS by using the Intelligent Transportation System Backbone. This system harvests existing automatic vehicle location (AVL) data from within King County Metro Transit and transports the raw data to the UW, where a series of operations converts the data into roadway speed information. This roadway speed information is color coded on the basis of specific, localized conditions for the arterials and freeways to reflect traffic congestion. The resulting traffic data product is then provided to WSDOT as a virtual sensor data source for roadways where presently there are no inductance loops. The project also created several user interfaces for traveler information, including a Java application that displays the spatial and temporal average speeds of transit vehicles on a map of the major arterials and freeways and a type of traveler information map.

This report also includes a quantitative evaluation of transit vehicles as traffic probes. A comparison of statistics between virtual sensors based on transit vehicles as probes and those from speed traps presently used by WSDOT suggested this virtual sensor technology can be used to identify both recurring and non-recurring congestion with the accuracy associated with speed traps. This means that additional roadways that do not presently have speed traps can be instrumented without installing equipment in the roadway.

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EXECUTIVE SUMMARY

The Washington State Department of Transportation (WSDOT) operates a central traffic management system (TMS) for both day-to-day surveillance and traveler information. Past research efforts demonstrated, on a small scale, the ability to create real-time traffic speed information by using virtual sensors that are based on transit vehicle tracking data. In order for this new, relative to existing inductance loops, virtual information source to be merged into the TMS, a number of issues, such as probe density in time and space, needed to be resolved.

This report presents the solution developed at the University of Washington (UW). This system provides real-time congestion information from Seattle area arterials and freeways—I-5, I-90, SR 520 and SR 99—to the WSDOT TMS by using the Intelligent Transportation System (ITS) Backbone, as shown in Figure ES1. This project harvests existing automatic vehicle location (AVL) data from within King County Metro Transit and transports the raw data to the UW, where a series of operations converts the data into roadway speed information. This roadway speed information is color coded on the basis of specific, localized conditions for the arterials and freeways to reflect traffic congestion. The resulting traffic data product is then provided to WSDOT as a virtual sensor data source for roadways where presently there are no inductance loops.

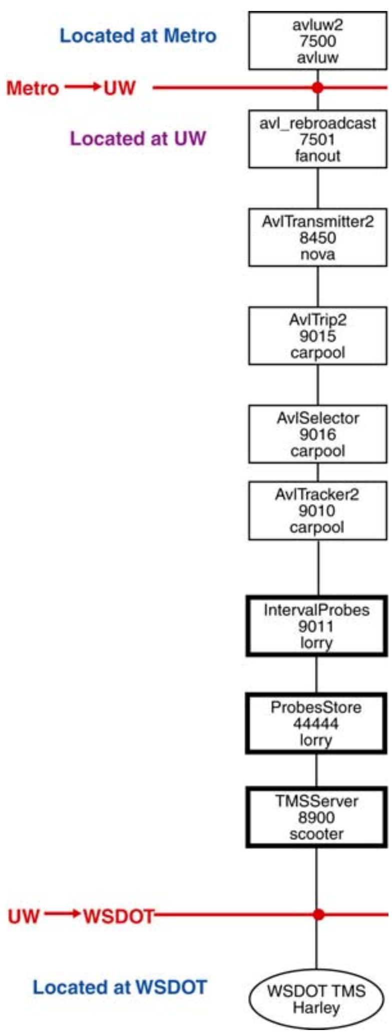

Figure ES1: ITS Backbone

This report also includes a quantitative evaluation of transit vehicles as traffic probes. Probe data were compared with speed trap data from instrumented roadway locations. Large-scale and small-scale evaluations showed that probe data compared favorably with the speed trap data.

In addition to creating the infrastructure for an AVL-equipped fleet to serve as probe vehicles, this project created several user interfaces for traveler information. One is “StoreView,” a Java application that displays the spatial and temporal average speeds of transit vehicles as bubbles on a map of the major arterials and freeways. The bubbles are color-coded to reflect the local traffic conditions (see Figure ES2). This application can be found at http://www.its.washington.edu/storeview/storeview.jnlp

Another type of traveler information, analogous to TrafficTV and WSDOT’s pictographic traffic maps, is also available. This interface is shown in Figure ES3 and can be found at http://www.its.washington.edu/probes_traffic/

This report documents a comparison of statistics from virtual sensors based on transit vehicles as probes and

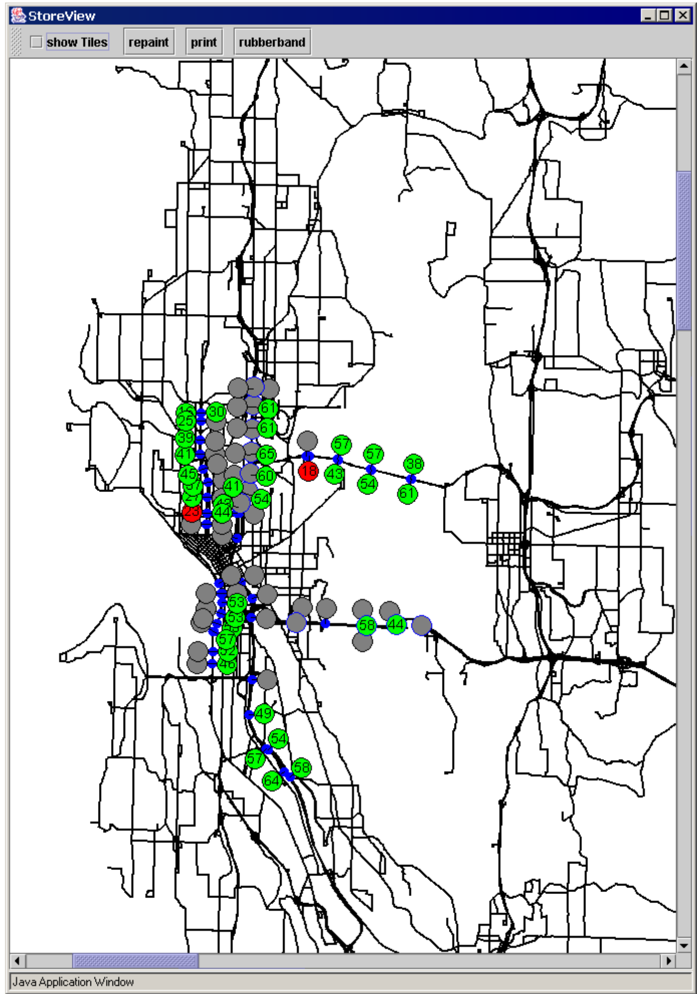

Figure ES2: StoreView

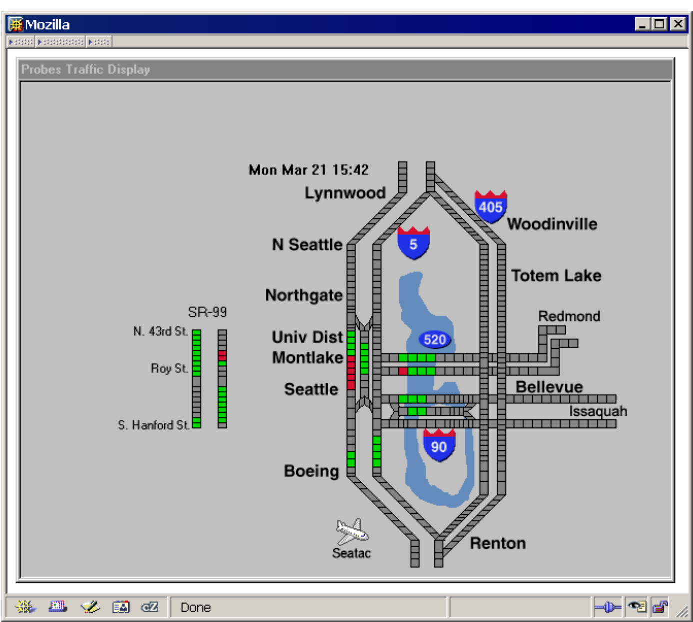

Figure ES3: Virtual sensor traffic congestion map based on the use of transit vehicles as traffic probes.

those from paired inductance loop speed traps presently used by WSDOT. The results of the comparison were very favorable, suggesting that this virtual sensor technology can be used to identify both recurring and non-recurring congestion with the accuracy associated with speed traps. This means that additional roadways that do not currently have speed traps, such as SR 520 and SR 99, can be instrumented without installing equipment in the roadway.

The set of applications and interfaces documented in this report demonstrates the viability of using an AVL-equipped fleet as a regional traffic surveillance system suitable for both traveler information and traffic management. While these ideas were implemented in King County with the King County Metro transit fleet AVL system as input, the underlying concept may be generalized to any area where a fleet of vehicles is tracked in real time.

1. INTRODUCTION

The Washington State Department of Transportation (WSDOT) performs congestion monitoring with a network of several thousand inductance loops deployed on the freeways, and a few arterials, around Seattle. However, on some important corridors it is not possible, for jurisdictional and fiscal reasons, to install inductance loops. To overcome this obstacle, the authors have described, in previous papers, the technology to create virtual sensors by using the automatic vehicle location (AVL) system operated by King County Metro Transit for fleet management [Elango and Dailey 2002, Dailey et al. 1996]. The AVL data are extracted from the AVL system and transferred to the University of Washington for processing into traffic probe data. Dailey and Cathey [2002] [Cathey and Dailey 2002] described a Kalman filter approach [Bell 2000, Jazwinski 1970, Rauch et al. 1965, Anderson and Moore 1979, Press et al. 1992] for making an optimal point speed estimate from the AVL observations as the vehicles pass over the virtual sensors. These estimates compared favorably with inductance loop data from the freeways and, just as with inductance loops, can be used to detect incidents. The speed estimates, in turn, can be used to estimate corridor travel times by integrating a speed function over space and time [Cathey and Dailey 2003].

The logical extension of this work was to create speed estimates on the un-instrumented arterials and make those data available to WSDOT. This involved some additional technical work: (1) algorithms to refine the speed estimate, (2) identification of suitable corridors and sites that would provide usable amounts of data, and (3) implementation of some additional Intelligent Transportation System (ITS) Backbone [Dailey et al. 2002, Dailey et al. 1999] components.

The probe vehicle-related ITS Backbone components are shown in Figure 1, as taken from documentation on the ITS Backbone, http://www.its.washington.edu/mid/ status_scripts/images/page2.htm. The AVL data are shown at the top as starting at a source component "AVLUW2," and the various products are shown as sink components at the bottom. This report describes the technical efforts necessary to make the virtual sensor data suitable and available to WSDOT through the ITS Backbone. In addition, a number of user interfaces to this data stream were developed and deployed on the University of Washington (UW) ITS website.

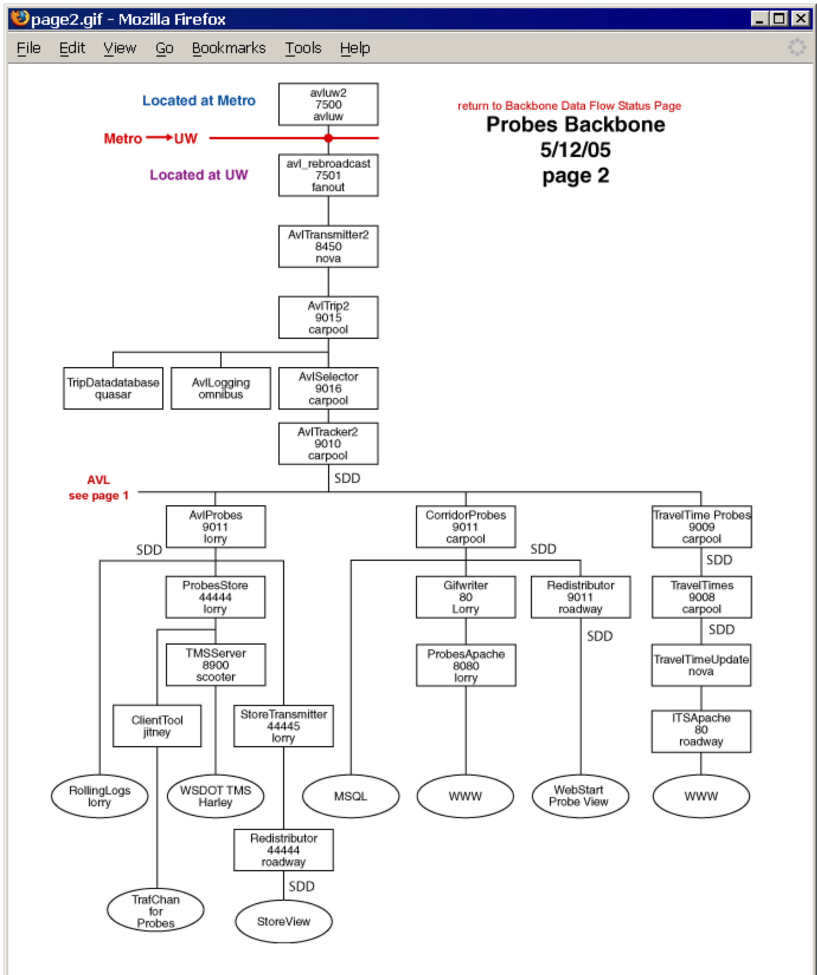

Figure 1 Virtual Sensor Backbone.

This report first describes the effort to provide a new data stream, based on virtual sensors constructed by using transit vehicles as probes, to WSDOT's Traffic Systems Management Center (TSMC) for use in the traffic management system (TMS). This data stream is indicated by the second sink from the left at the bottom of Figure 1, labeled "WSDOT TMS Harley."

This report also presents an evaluation of the probe vehicle system with quantitative metrics presented for representative roadway topologies. The regional traffic management agency, WSDOT, has accepted speed traps constructed from either inductance loops or radars as the “gold standard” for traffic sensors deployed in support of the traffic management system (TMS). To validate the use of probe vehicles as an input to the TMS, the performance of the virtual sensors, created by using transit vehicles as probes, was compared to speed trap results.

In addition, this report describes alternative application/user interfaces that demonstrate the use of virtual sensors, based on transit vehicles as probes, for traveler information. These additional applications/user interfaces include the following:

- StoreView is a Java applet that displays time and spatially averaged speeds for selected locations on SR 99, I-5, SR 520, and I-90. http://www.its.washington.edu/storeview/storeview.jnlp
- Pictographic Traffic Map is a traffic map GIF (Graphics Interchange Format) based on probe vehicles and is analogous to the traffic map found on TrafficTV but also includes SR 99. http://www.its.washington.edu/probes_traffic/

The set of applications and interfaces documented in this report demonstrates the viability of using an AVL-equipped fleet as a regional traffic surveillance system suitable for both traveler information and traffic management. While these ideas were implemented in King County with the King County Metro transit fleet AVL system as input, the underlying concept may be generalized to any area where a fleet of vehicles is tracked in real time.

2. VIRTUAL SENSORS: SPATIAL AND TEMPORAL SELECTION

One relatively un-instrumented facility of interest for WSDOT is State Route 99 (SR 99), which parallels Interstate 5 (I-5) in Seattle. Initially, sensors were requested halfway between signalized intersections for major arterials, or about every ten blocks (see Figure 2 left). The data stream flowing through the components contained data from all of these virtual sensors, as well as virtual sensors located on other arterials, and on freeways near inductance loops and speed traps (for comparison purposes). However, it was not possible to use all these virtual sensors within the TMS because of constraints on the transit schedule.

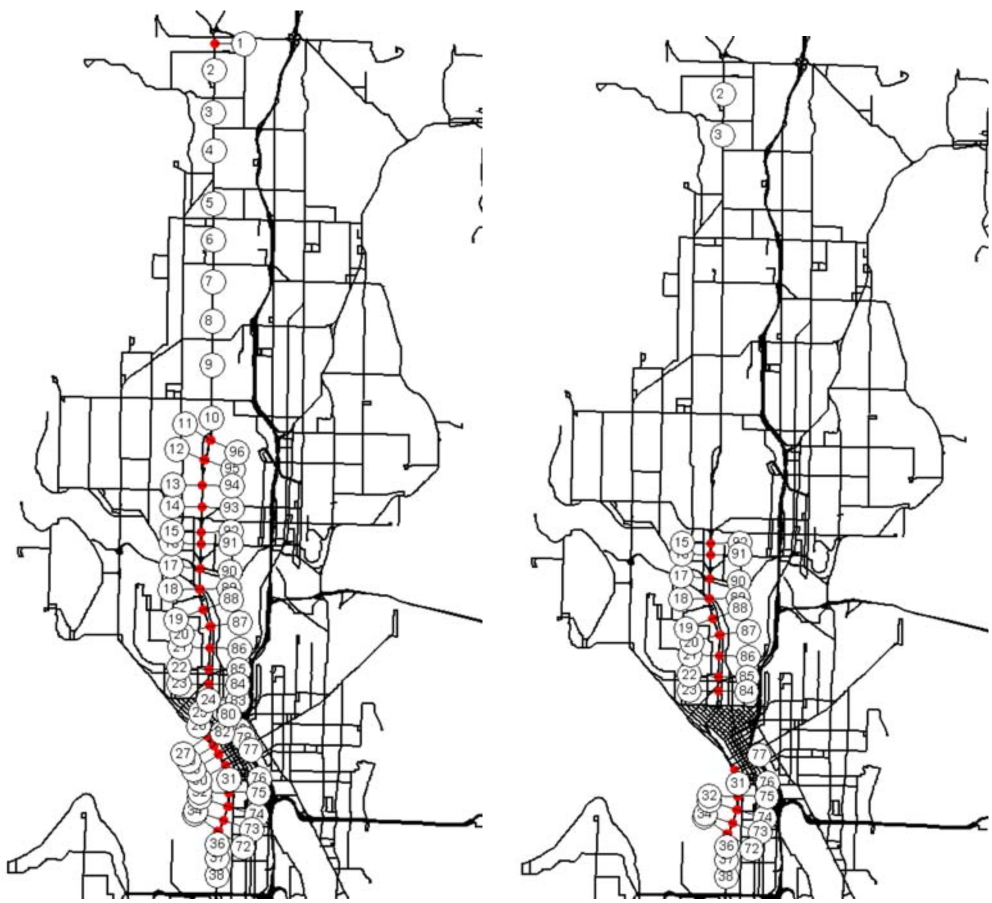

Figure 2: Map of roadways in Seattle. Requested virtual sensors on the left. Sensors with suitable coverage on the right.

WSDOT personnel desired continuous temporal coverage. To evaluate the potential temporal coverage, the authors examined the transit schedule database. Bus headways, the temporal distance between vehicles, in Seattle are rarely less than 15 minutes on individual routes; however, many routes operate on the chosen facility, SR 99. Because of the variability of the speed estimate from any single vehicle, it was decided that at least two speed estimates should be averaged to provide the speed estimate for WSDOT. This would create a sliding time window during which two reports from vehicles would likely be observed. There was a tradeoff between the length of this time window and the number of virtual sensors that would qualify as "useful." When the schedule was examined for each sensor location using the criteria that (1) there must be at least two vehicles scheduled within the selected time window, and (2) there must be at least 20 time windows in a row for which this was true, we were able to qualify some number of virtual sensors as useful. The second criterion of sequential time windows arose from WSDOT's requirement that for a sensor to be "useful," it must operate continuously for a reasonable period of time. Twenty sequential windows guaranteed that a sensor would operate continuously for over an hour.

A time window of 9 minutes was selected for time-averaging the transit vehicle reports. Note that the criteria for being a useful sensor only required that it operate continuously over a relatively short period. As it happens, the scheduled trips that met the criteria occurred during the morning/southbound and evening/northbound commute periods. Table 1 shows the periods of continuous operation on the northbound and southbound roadways of SR 99. Note that within the downtown area (sensors 31-38) monitoring occurred continuously in both the morning and afternoon. Data from some buses outside of these windows could have been used by the virtual sensors, but there would also have been periods when no information about traffic speed would have been acceptable, given the criteria for "usefulness".

The analysis performed for virtual sensor locations on SR 99 was also applied to locations on I-5, I-90, and SR 522 in the vicinity of Seattle. Figure 3 shows a map of the virtual sensors selected for TMS.

Using the transit schedule and propose a criteria for selecting virtual sensors that are "useful" to the TMS. We created a threshold that WSDOT uses to paint a traffic map.

Table 1 Example of the periods of continuous operation for "useful" locations.

Southbound		
Sensor	**Start Time**	**End Time**
2	6.61	8.51
3	6.42	8.31
15	6.92	8.71
16	6.93	8.72
17	6.48	9.26
18	6.49	9.27
19	6.51	9.29
20	6.52	9.30
21	6.54	9.31
22	7.04	9.33
23	7.05	9.33
31	7.45	9.56
31	11.36	17.85
32	7.20	9.57
32	11.38	17.86
33	7.20	9.57
33	11.38	17.86
34	7.23	9.59
34	11.39	17.88
35	7.23	9.59
35	11.39	17.89
36	7.24	9.60
36	11.40	17.90
37	7.24	9.60
37	11.40	17.90
38	7.26	9.62
38	11.42	17.92

Northbound		
Sensor	**Start Time**	**End Time**
2	17.19	18.74
3	17.10	18.70
36	7.50	8.87
36	16.57	18.31
37	7.50	8.87
37	16.57	18.31
38	7.48	8.85
38	16.55	18.29
72	7.51	8.88
72	16.58	18.32
73	7.51	8.89
73	16.58	18.32
74	7.52	8.91
74	16.59	18.33
75	7.53	8.91
75	16.60	18.33
76	7.54	8.99
76	16.11	18.34
77	7.55	9.40
77	16.11	18.35
84	13.13	18.30
85	13.14	18.30
86	6.28	7.88
86	13.10	18.90
87	6.29	7.90
87	13.12	18.91
88	6.39	7.91
88	13.14	18.93
89	6.40	7.92
89	13.15	18.94
90	6.41	7.68
90	13.17	15.95
90	16.10	18.95
91	16.83	18.07
92	16.84	18.07

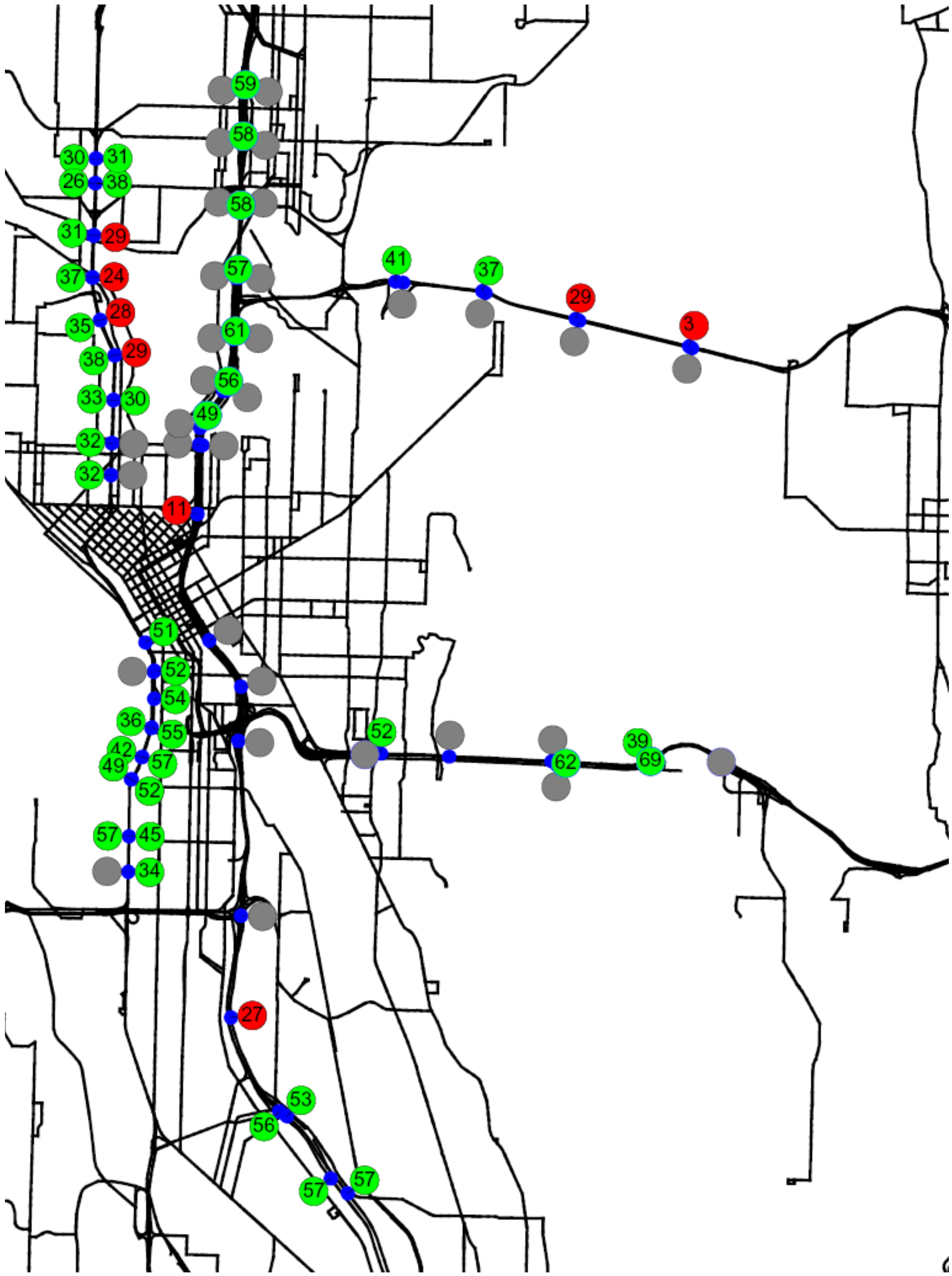

Figure 3 Map of virtual sensors in Seattle.

3. PROBE SENSOR INFRASTRUCTURE

The traffic management community is accustomed to having sensors report at fixed intervals. The WSDOT polls inductance loops, intersection master controllers, and traffic counters at intervals of from 20 seconds to 15 minutes. However, the virtual sensors created with probe vehicles only updated when a vehicle passed the location assigned to the virtual sensor. This created the need for new components for the Traffic Probes application.

The software that implements the "transit vehicle as traffic probes" concept was built in a modular manner and is made up of collaborating components, running on several computers, shown as individual boxes in Figure 4. Each component has a name, port, and computer name (Figure 4), and self-describing data (SDD) [Dailey et al. 2002] flow between the components on the TCP ports indicated on the figure. Each component performs a specific operation on the data flow. For example, the component labeled Tracker implements the Kalman filter described by Dailey and Cathey [2002]. To support the additional requirements of integrating these data into the transportation management framework, three additional components, shown in bold in Figure 3, were added: *Interval Probes*, *Probes Store*, and *TMS Server*.

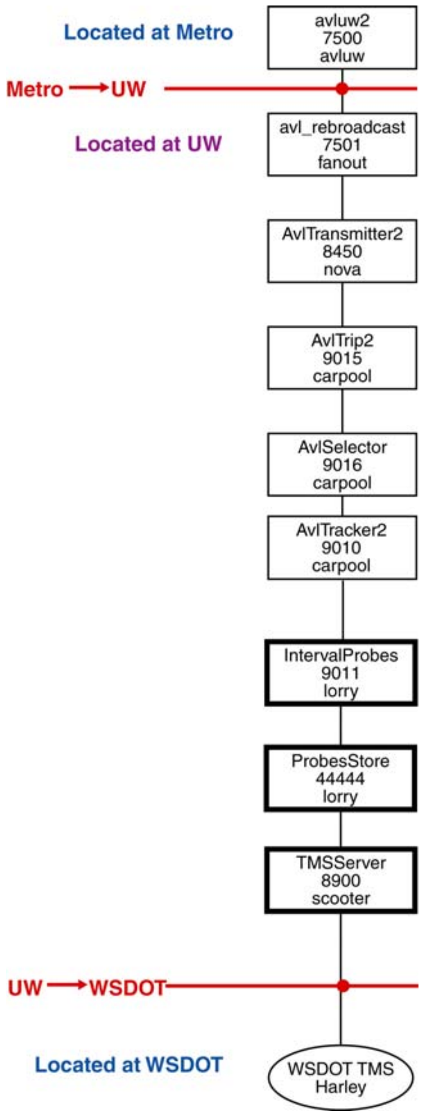

Figure 4 Application as colaborative components.

3.1 "Interval Probes" Component

In past work, the authors created virtual sensor reports only when a vehicle passed the exact geographic location of a virtual sensor [Dailey and Cathey 2002]. In an effort to create both more accurate and more frequent speed estimates, this project uses the notion of a “corridor” representing a roadway partitioned into intervals centered around virtual sensors. That way, whenever a probe vehicle reports from a corridor, its location is in some interval, and the report is assigned to the associated virtual sensor. This is advantageous for detection and location of incidents and severe congestion, when probe vehicles move slowly and remain in an interval for several polling periods.

To accomplish this interval-based approach, the researchers used a geographic information system (GIS) graph of arcs and nodes that represent the road system of King County. With this graph we created “corridors” that are directed paths or sequences of adjacent arcs that cover freeways and arterials (e.g., SR 99, I-5, I-90, SR 520).

“Virtual sensors” and “probe intervals” are distributed along the corridors. A virtual sensor location is specified by an arc and its distance from the start of the arc. The location of a virtual sensor on a corridor is determined by its distance from the start point of the corridor. Non-overlapping adjacent linear intervals are constructed around each virtual sensor location on each corridor.

The speed of a vehicle is estimated in the component labeled *AvlTracker2*. This speed estimate is a member of the data structure for the AVL report that is propagated throughout the ITS Backbone components shown in Figure 4. The component *Interval Probes* in Figure 4 implements the spatial expansion of the virtual sensor to an interval of roadway. For each AVL report, the corridor that the vehicle is traveling on is determined. In addition, if it is on a corridor, the probe interval containing the vehicle is determined. As the vehicle travels along the corridor, its position may change from one interval to another or stay in the same interval. For each AVL report, virtual sensor speed reports are output for the interval the vehicle is in, and interpolated speed reports are output for intermediate intervals traversed since the last report.

These data are averaged in the downstream *ProbesStore* component to create speed estimates from a region of the roadway and an interval of time. Increasing the number of vehicle speed estimates used to create an estimate of roadway speed improves the confidence in the roadway estimate.

3.2 “Probe Store” Component

The *Probes Store* component was added to support the averaging of the vehicle speed data over the selected time window. In addition, it implements the selection of specific sensors and maps the virtual sensors into the data structures required by the TMS. The TMS uses the notion of “cabinets,” which are both physical roadside cabinets that hold the inductance loop equipment and a data structure in the TMS software that stores the loop data.

The *Probes Store* component has two parts, an SDD receiver and a request/response server. The SDD receiver obtains the probe data, in SDD format, that are made up of the probe ID, the direction of travel, the time, the speed, and the vehicle ID. The server responds to data requests from the *TMS Server*.

At startup, the *Probes Store* component obtains the list of sensors requested by WSDOT from a file. This file ties the virtual sensor information to the notion of a “cabinet,” a data structure in the TMS that uses probe ID, roadway, road type, cross street, mile markers, corridor, x, y, and cabinet ID. There is a unique sensor ID for each roadway and direction pair, and several sensor IDs are associated with a cabinet ID, much as several loops (e.g., northbound, southbound, and reversible) are assigned to a cabinet.

By using the list of sensors, *Probes Store* creates a hash table to contain the actual reports received. As *Probes Store* receives a sensor report, it uses the hash key to look up the appropriate record, prunes the list of reports to include only the reports in the last nine minutes, adds the new report, and sets the last update time for that sensor.

The server side of *Probes Store* waits for requests, and upon receiving a request, it prunes the list for the sensors to enforce the time window, computes the average speed, and sends the appropriate report containing sensor ID, direction, road type, count, speed, number of vehicle IDs, and the time since last update.

In the case of the TMS, the polling cycle is 20 seconds, and so the store responds with the averaged data every 20 seconds. As mentioned above, the scheduling of vehicles means that a sensor is effectively off-line when there are no transit vehicles.

3.3 “TMS Server” Component

The final new component is the *TMS Server*. This component listens for requests from the TMS and responds to the TMS with virtual sensor data. The TMS polls all of the field equipment every 20 seconds. When the poll is received, the *TMS Server* makes a request to *Probes Store* for the virtual sensor data and relays them to the TMS.

The TMS was designed to handle inductance loop data in two forms. The first form is that of a "loop," in which the information is (1) "volume," number of vehicles passing over the loop, and (2) "scan count," the number of 1/60th-second scans of the loop in the last 20 seconds that the loop had a vehicle above it. The second form of TMS data is a "speed trap," which consists of two physical loops, but the data reported are average speed and average length. WSDOT requested that the virtual sensor data be cast into the "loop" data structure. Furthermore, the TMS uses a derivative of the scan count, "occupancy," the fraction of time that the loop is covered by a vehicle, as the measure of congestion, and it creates a traffic condition map based on thresholds on the occupancy.

The "loop" structure does not contain any notion of speed. However, the authors desired a painted traffic map similar to the existing occupancy-based map. The existing map has three thresholds for occupancy: green (1-15 percent occupancy), yellow (16-22 percent), and red (22-30 percent).

To create a similar quantization for the virtual sensors, the researchers developed histograms for the selected sensors along SR 99. Figure 5 shows the histogram for two months of data for a virtual sensor. We concluded from examining the resulting histograms that it was unrealistic to obtain a tri-modal distribution from the virtual sensor data. Instead, a bimodal distribution is proposed—congested and uncongested—with a distribution boundary at 30 miles per hour for the example sensor.

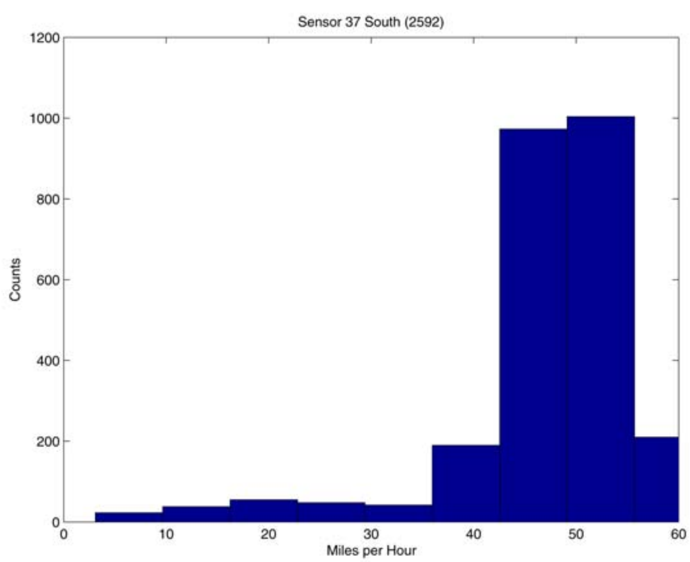

Figure 5 Histogram of two months of speed data at one virtual sensor.

Because of the different road geometries found on arterials, an analysis of the probability distribution for each sensor was used to create a threshold between the two modes for that sensor. The modes corresponded to red and green for the TMS traffic map. By using a threshold for the probe vehicle speed, we assigned one of three values to the scan count:

(1) A scan count equal to zero indicates that no probe vehicles passed in the last time window.

(2) WSDOT defines congestion as 22 percent occupancy or more, and under these conditions it would paint the congestion map red. To be conservative, this would be equivalent to a scan count of 300 for the sensor described above, and so, when the example virtual sensor speed drops below 30 MPH, the scan count is set to 300.

(3) When the example virtual sensor speed is greater than 30 MPH, the scan count is set to 120, and the TMS paints the traffic map green in the region of the virtual sensor.

The volume is set to the number of vehicles observed in the interval of the virtual sensor for the last time window. In this way, the virtual sensor data are reformatted so that they can be used by the existing TMS applications for traffic management and traveler information without any software changes by WSDOT. This incorporates the virtual sensor system into the TMS.

3.4 Summary: Virtual Sensors for Traffic Surveillance

This project created an application that expands the sensing capabilities of the Washington State DOT to areas where it does not have installed infrastructure. Past work described algorithms to create virtual sensors on arterials and freeways by using existing transit vehicles. This section described modifications to the algorithms necessary to allow the virtual sensors to be used within the existing traffic management system in Seattle. This section also documented a threshold that WSDOT uses to paint a traffic map, and it described the overall framework that will provide WSDOT with expanded surveillance capabilities by reusing data from another agency with algorithms from the University of Washington.

4. QUANTITATIVE EVALUATION

4.1 Large-Scale Statistics for Transit Probe Vehicles

The University of Washington has archived over eight years of inductance loop data sampled at 20-second intervals. Probe vehicle data have also been archived over several years. To validate the use of the transit probe vehicle system the data from virtual probe sensor locations were compared with the speed trap data collected by WSDOT.

The first comparison presented here used the data collected over the course of a month at several locations and on several roadways. These locations included

(1) the I-5 limited access freeway at a straight location near Boeing Field known to have daily congestion (Figure 6)

(2) (northbound on the Alaska way viaduct, a limited access arterial on State Route 99 through downtown Seattle (Figure 7)

(3) southbound on the Alaska way viaduct, a limited access arterial on State Route 99 through downtown Seattle (Figure 7)

(4) on the west high-rise of the I-90 bridge where it crosses Lake Washington and is known to have recurring congestion (Figure 8).

Data from the inductance loop/radar speed traps at each of these locations were matched temporally with the virtual sensor data derived from transit AVL and plotted on the left of figures 6 to 8. In addition, statistics about the differences between the two types of speed measurements were calculated. A histogram of the differences as well as the mean and standard deviation of the differences was constructed. The histogram of the raw measurements was, as expected, bimodal, corresponding to the existence of congested and un-congested periods over the course of a day. It is shown in Figure 9, with the speed trap data on the left and the corresponding virtual sensor on the right. The histograms comparing the differences between the two sensor outputs are shown on the right of figures 6 to 8.

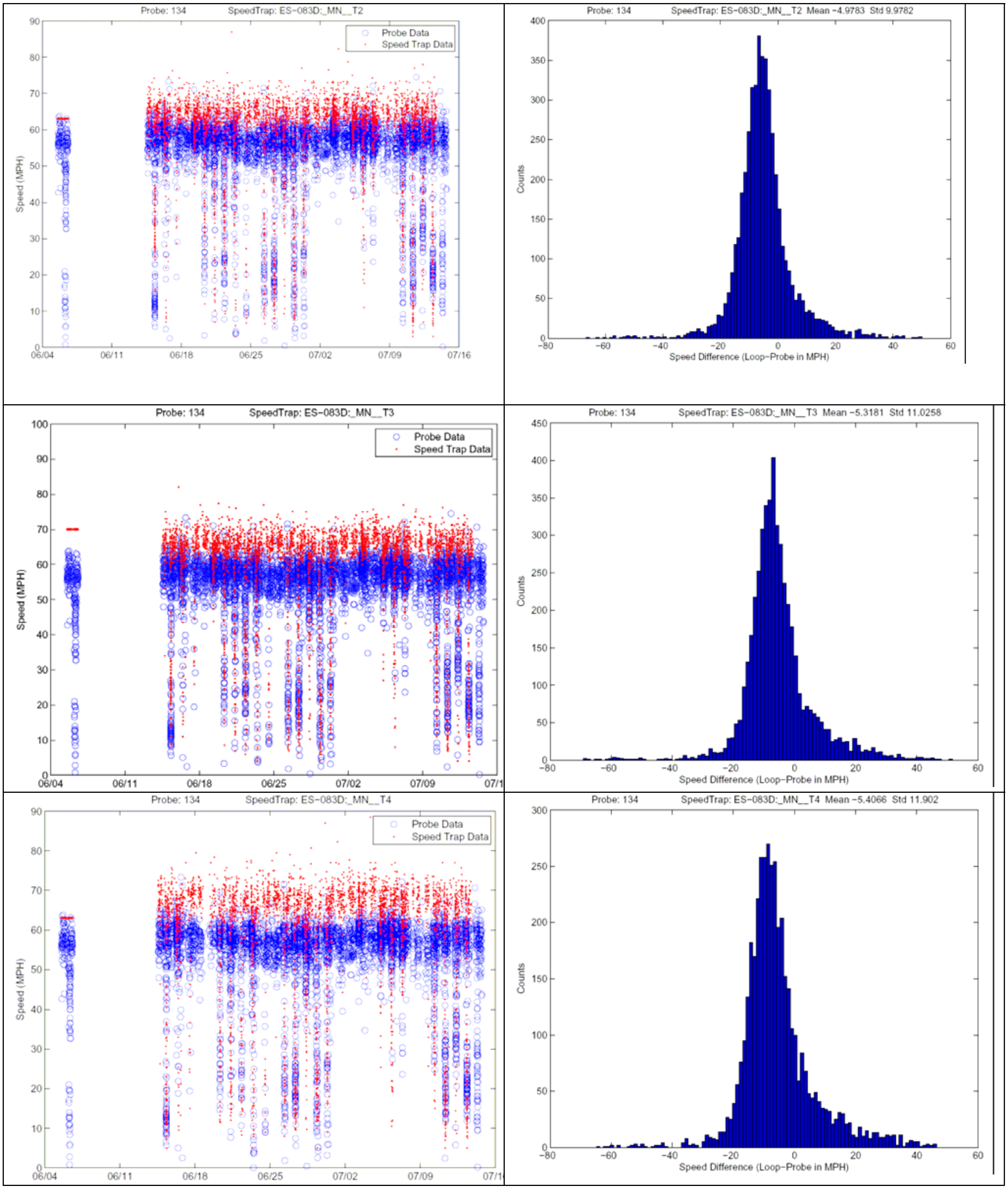

Figure 6 **Data comparison, at left and histogram, at right for I-5.**

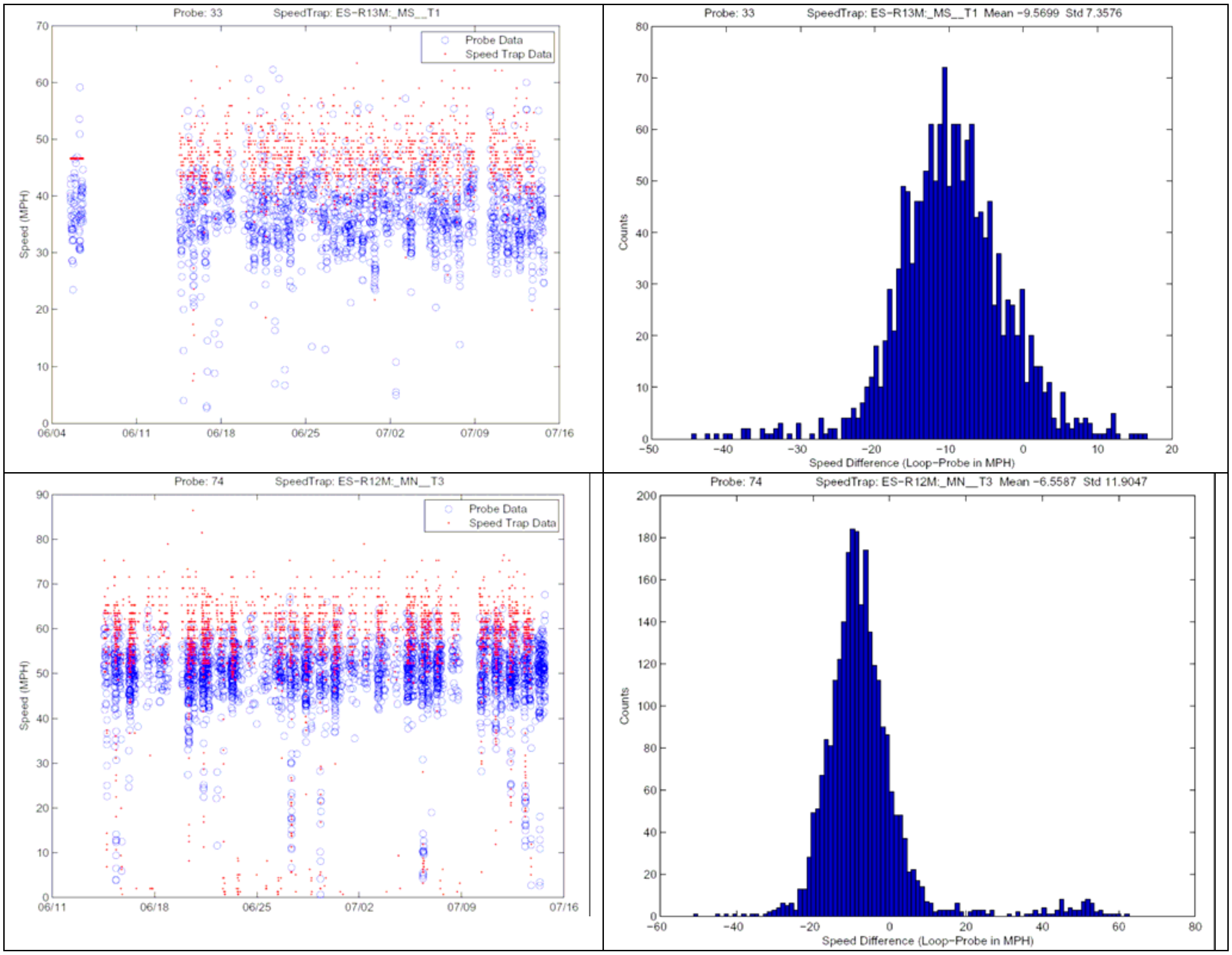

Figure 7 Data comparison, at left and histogram, at right for SR 99.

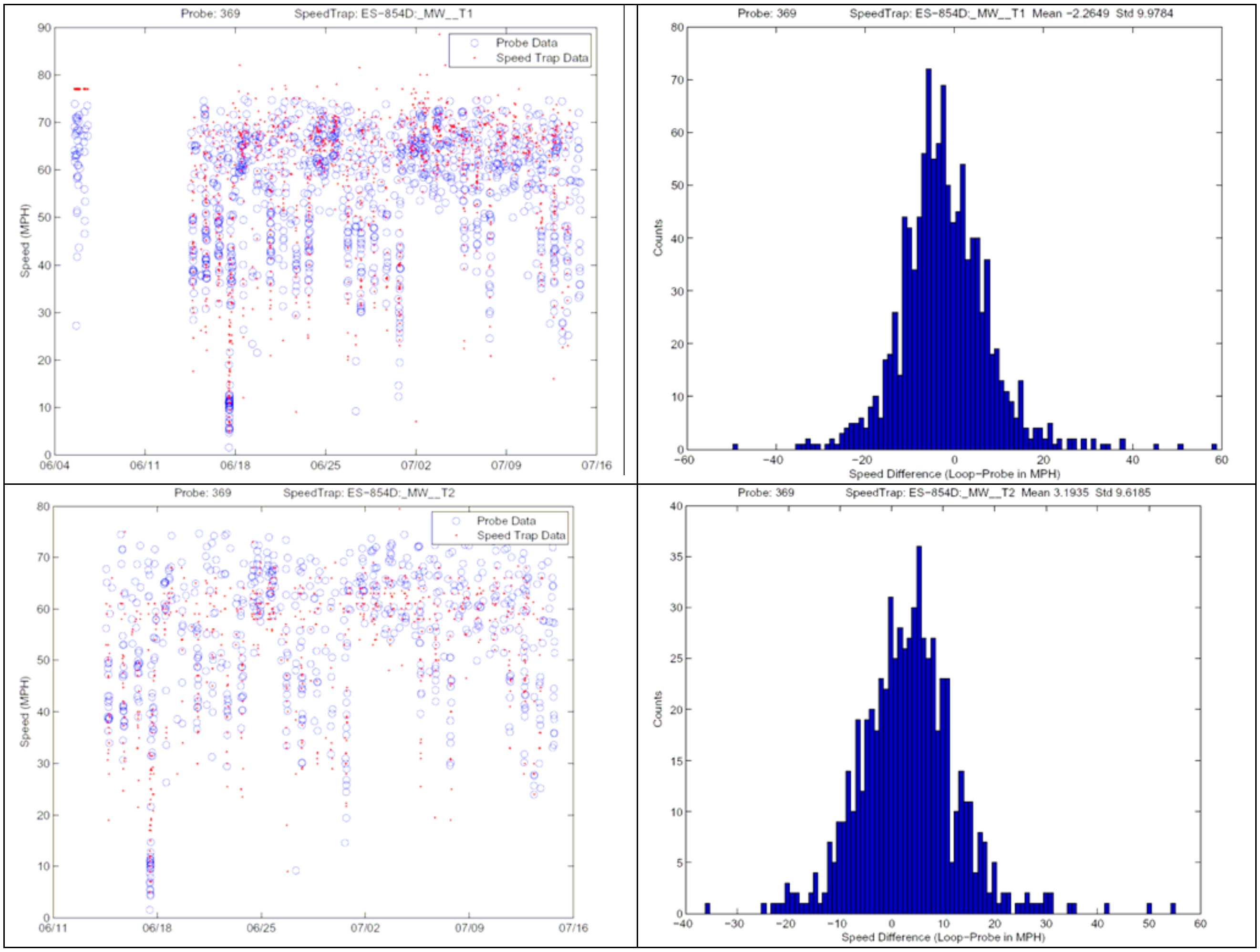

Figure 8 Data comparison, at left and histograms, at right for I-90.

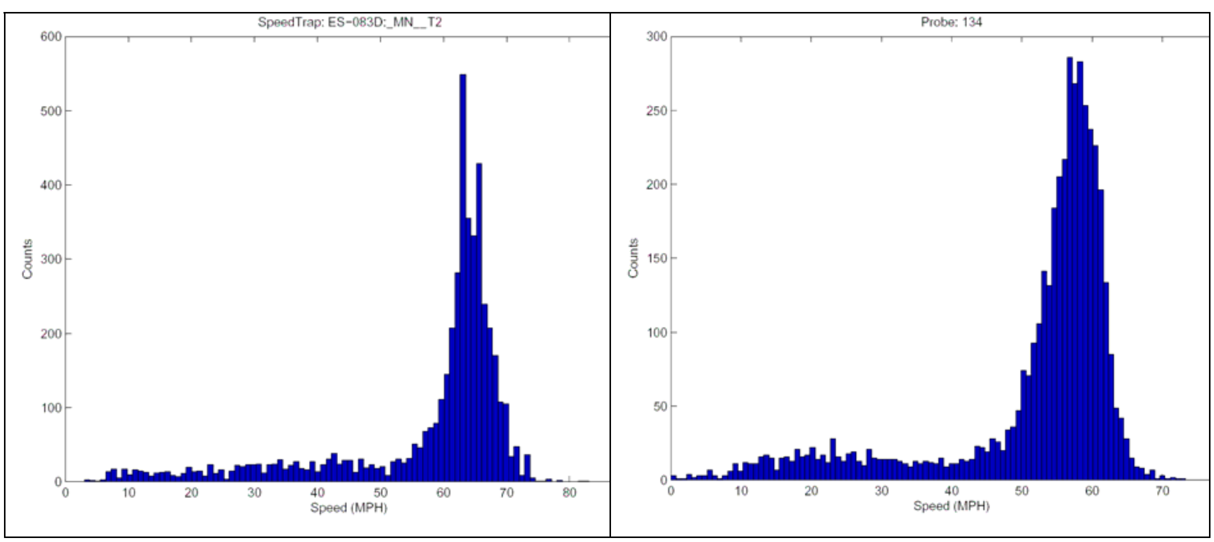

Figure 9 Histograms of sensor data from speed trap, at left, and probe sensor, at right.

A comparison between three lanes of speed trap data and probe data is presented on the left in Figure 9. These data were from a straight portion of I-5 near Boeing field, where three lanes are instrumented with speed traps. The probe vehicle data were gathered from a number of transit vehicle passages, and it is not possible to identify the lane used by any individual bus. This makes the virtual sensor similar to what WSDOT has labeled a "Station" sensor, which is an average across the roadway. (Note that WSDOT uses volume and occupancy measurements for the "Station" data.) Figure 9 on the left shows recurring congestion as depressions in speed, which appear as nearly vertical lines because of the time scale. The virtual sensor data are shown as circles and the speed traps as points. The probe data overlay the speed data relatively accurately, with the probe sensors showing the changes in speed at the same times as the speed trap data, but with a generally lower speed measurement. The histograms for the differences between the two sensor types are shown at the right of Figure 6 and are uni-modal with a strong central tendency, as one might expect when two measurements of the same underlying process are compared. The deviation has a negative mean of approximately 5 MPH, indicating that the probe vehicles tended to register a slightly lower speed value, which is consistent with buses in the flow of traffic. The standard deviation between the measurements is about 11 MPH, which is consistent with the sum of the variability of the processes.

In Figure 7, data from SR 99, both southbound at the top and northbound at the bottom, are presented. The figure compares the radar speed trap measurements with probe vehicle measurements. Again, the times with reduced speed, as measured by both technologies, agree, and the probe-based technology provided a generally lower speed measurement. The histograms on the right of Figure 7 are also uni-modal with a strong central tendency. The mean for southbound traffic is negative 10 MPH, again indicating that the buses travel somewhat slower than overall traffic. The standard deviation between the measurements is approximately 7 MPH. In the northbound direction the mean is negative 6.5 MPH, again indicating slightly slower buses. The standard deviation is approximately 12 MPH, similar to the variability found on I-5.

Figure 8 shows a comparison of measurements on the I-90 limited access freeway bridge over Lake Washington. Two lanes of speed trap data were available and were compared to probe sensor measurements. Recurring congestion was identified by both technologies at the same time. In one lane, the mean is negative 2 MPH and in the other it is 3 MPH. The probe data were again made up of data from buses in both lanes, so that it would be expected to be about the average of the two lanes. The standard deviation for both lanes is about 10 MPH, similar to that found on I-5 and SR 99.

4.2 Small-Scale Statistics for Transit Probe Vehicles

In addition to the overall statistics described above, a detailed time series comparison between the probe vehicle sensors and the speed traps was developed. The goal was to test the constancy of identifying the onset and clearing of congestion for recurring and non-recurring congestion.

Figure 10 contains one day of data for each of the sites discussed above at which a significant congestion event occurred. The upper left of Figure 10 shows the I-5 site, where morning "rush hour" congestion was clearly observed by both sensing technologies. The probe sensor clearly identified the onset and clearing of the congestion.

The measurements for the I-90 Bridge on a Saturday are presented in the upper right. Non-recurring congestion that began at approximately noon and continued until after 6:00 PM was identified by both sensor technologies. This congestion may have been caused by the fact that the only parallel route across lake Washington, the SR 520 floating bridge, was closed for maintenance that day.

The two plots at the bottom of Figure 10 are for the northbound section of SR 99. The two plots are for July 6th and June 27th and clearly show recurring morning "rush hour" congestion. Again, both technologies agreed on the times of the onset and dissipation of congestion.

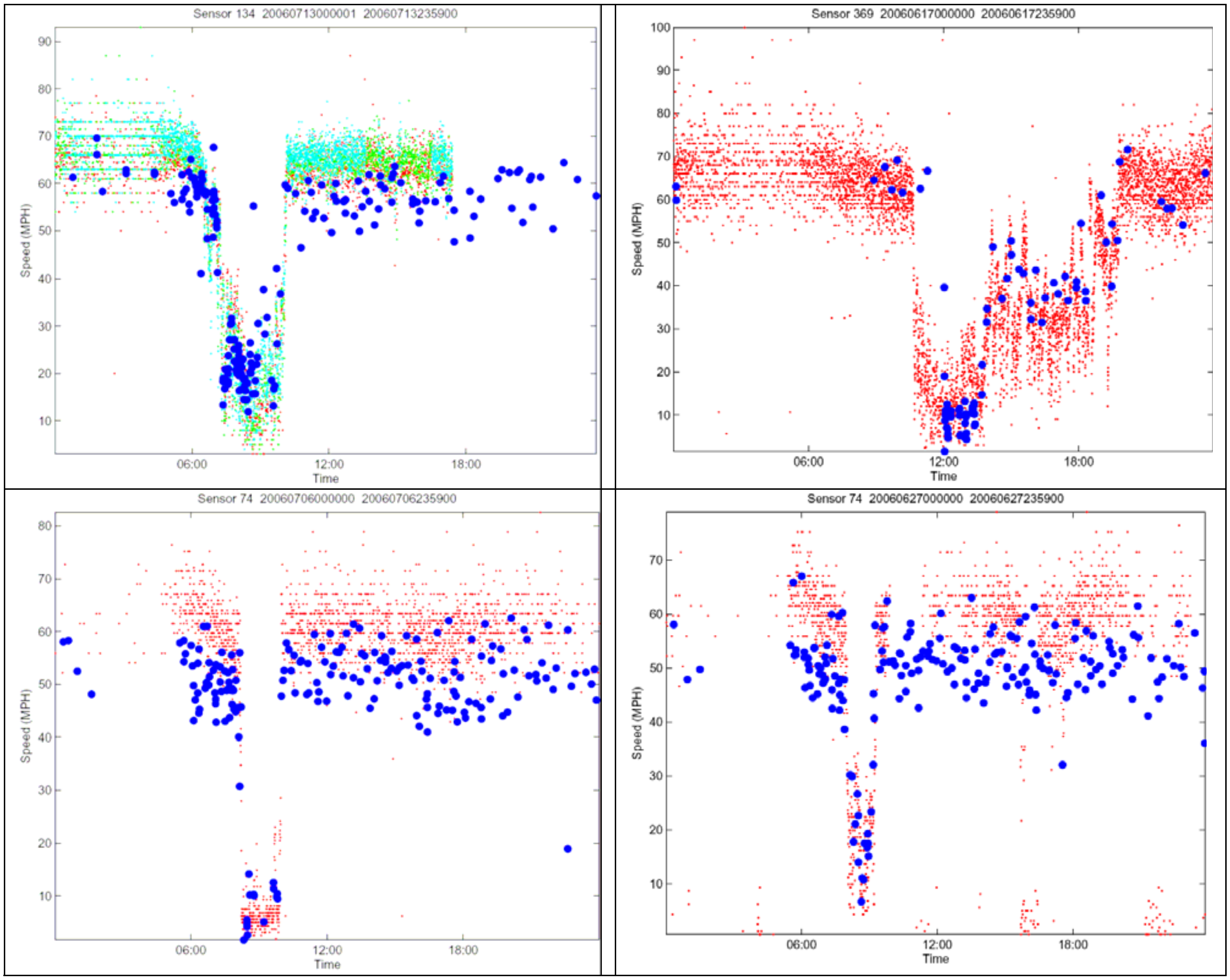

Figure 10 Congestion sensing by probe sensors and speed traps. I-5, upper left, SR 99, at the bottom, and I-90, upper right.

Incident Example: Virtual sensor data were compared with inductance loop speeds during incidents identified in the WSDOT incident log. The right side of Figure 11 is the layout for northbound I-5 in Seattle that shows the locations of virtual sensors 399, 24, 420, and 15 from south to north, respectively. The incident identified by WSDOT camera operators was at North 85th street, and virtual sensor 15 coincides with an inductance loop location. On the left of Figure 11 are the time histories of the four virtual sensors upstream of the incident that began at 17:29 and ended at 18:50. The virtual sensors clearly identified the incident.

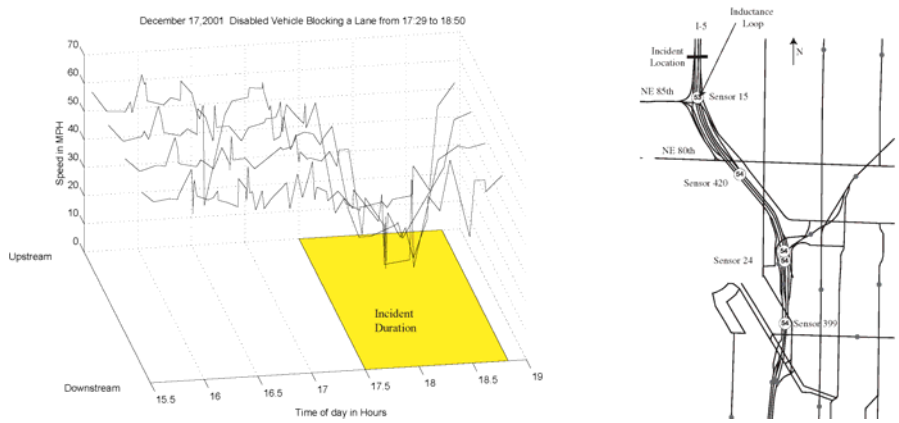

Figure 11 The left side is probe data from December 17, 2001, when an incident was reported between 17:29 and 18:50. On the right is a map of northbound I-5 with the sensor locations identified.

Figure 12 is a comparison of the speed estimated by an inductance loop and that estimated by a virtual sensor derived from transit probes. It is clear from this plot that the virtual sensors, if properly deployed, can create a data stream similar in character to inductance loop data for similar traffic conditions.

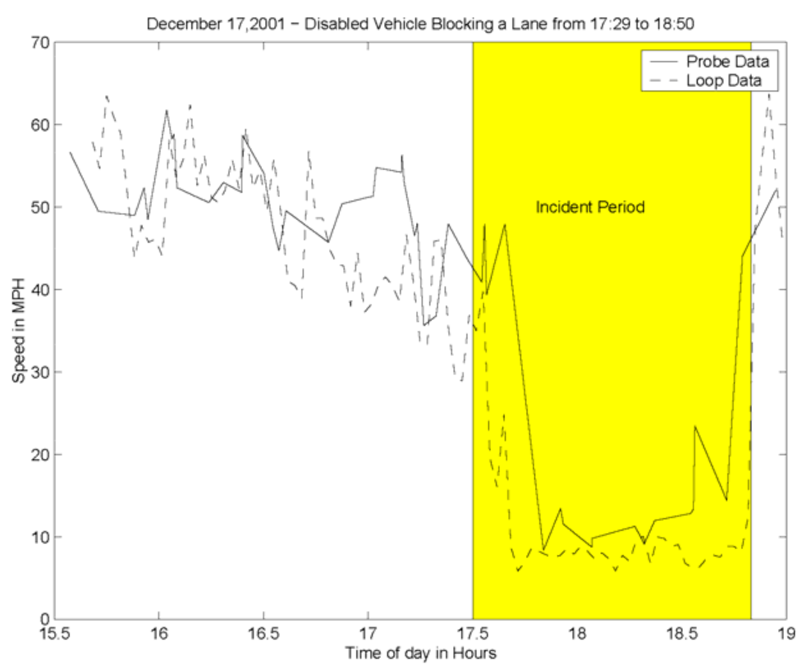

Figure 12 Virtual densor data from a sensor nearest to an inductance loop location.

4.4 Summary: Quantitative Evaluation

This section describes a comparison of statistics between virtual sensors based on transit vehicles as probes and speed traps presently used by WSDOT. The comparison is very favorable, suggesting that this virtual sensor technology can be used to identify both recurring and non-recurring congestion with the same accuracy associated with speed traps. This means that additional roadways that do not presently have speed traps, such as SR 520 and SR 99 can be instrumented without installing equipment in the roadway.

5. STOREVIEW

StoreView is a Java Webstart application that displays time and spatially averaged speeds for selected locations on SR 99, I-5, SR 520, and I-90. (http://www.its.washington.edu/storeview/storeview.jnlp) It is a variant of the original ProbeView application, but it uses threshold logic to display ProbeStore speed information in red, green, or gray bubbles on a background map.

StoreView receives data from the “StoreTransmitter,” as shown in Figure 4. The StoreTransmitter is an SDD version of ProbeStore, which broadcasts a batch of reports every 20 seconds. Each report is actually a pair of reports with the same sensor ID: a ProbeStore report (the time-average of speeds reported in a probe interval) and the last associated IntervalProbes report. StoreView displays the ProbeStore speeds in colored bubbles on a background map and accumulates distinct IntervalProbes reports for display in popup graphs and tables. Because data are broadcast every 20 seconds, not at vehicle location report update times, multiple reports will be received with the same value for report_time. A report is added to the sensor history only if it is not a duplicate of the preceding report.

StoreView paints a bubble for every probe sensor location, whether or not current data are available (see Figure 13). The following color scheme is used:

- gray: no current report
- green: current report with scancount <= 120
- red: current report with scancount >= 300

The speed value shown in the bubble is the current time average speed. The scancount is an indication of whether the average speed is above a certain sensor-dependent threshold. The display is repainted every time the model receives data, which is a nominal rate of every 20 seconds.

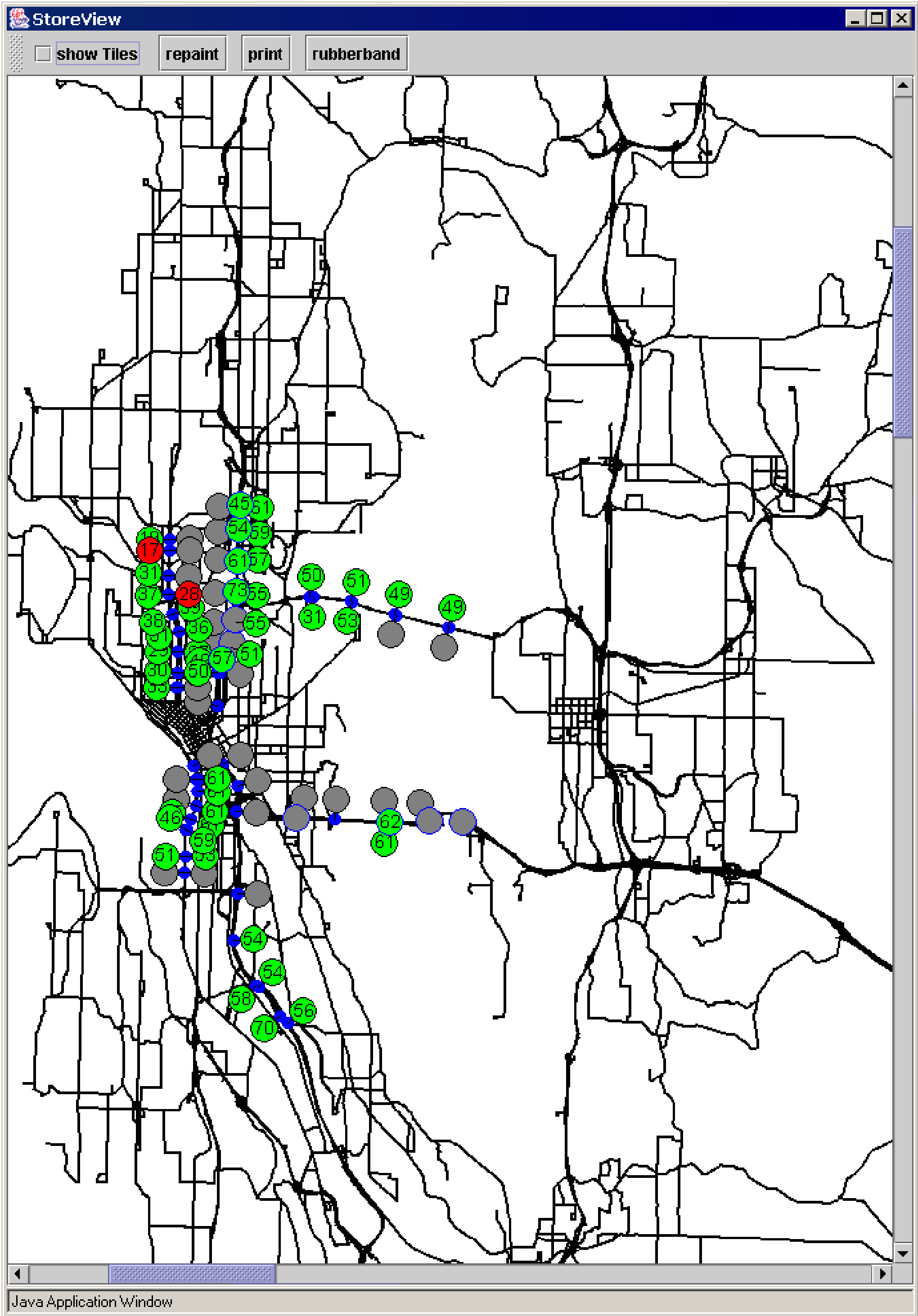

Figure 13: StoreView user interface

6. PICTOGRAPHIC MAP FOR VIRTUAL SENSOR SPEEDS

A second example of traveler information is the Traffic Map created with transit vehicles as probes on the freeways and arterials. The Pictographic Traffic Map is analogous to the traffic map found on TrafficTV. It is a GIF based on probe vehicles and includes SR 99 (http://www.its.washington.edu/probes_traffic/). This project interfaced both to the King County Metro AVL system and to the WSDOT TMS so that speed data from the probe vehicles could be converted into appropriate threshold values to indicate congestion and then input to the TMS for operator display and management functions. An example of a display congestion map containing both the freeways and SR 99, where there are no inductance loops, is shown in Figure 14.

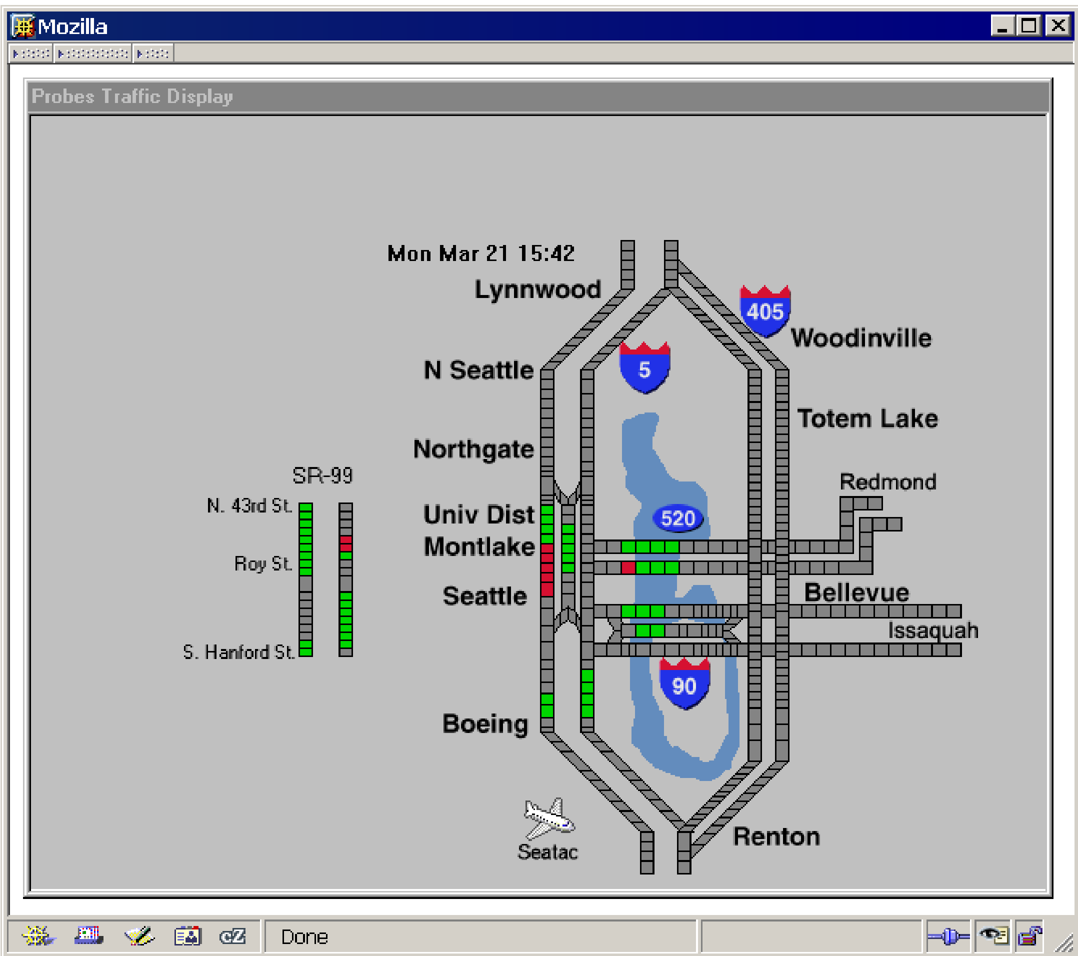

Figure 14: Virtual sensor traffic congestion map based on the use of transit vehicles as traffic probes

7. CONCLUSIONS

The WSDOT operates a central traffic management system (TMS) for both day-to-day surveillance and traveler information. Past efforts developed the ability to create real-time traffic speed information by using virtual sensors based on transit vehicle tracking data. In order for this new information source to be merged into the TMS, a number of issues, such as probe density in time and space, had to be resolved. In addition, the validity of using virtual sensors based on transit probes was quantitatively evaluated by using inductance loop/radar speed traps. This comparison included several months of data.

This report presents the solution developed at the University of Washington (UW). This solution provides real-time congestion information from I-5, I-90, SR 520, and SR 99 to WSDOT's TMS by using the ITS Backbone. This project harvests existing AVL data from within King County Metro Transit and transports the raw data to the UW, where a series of operations converts the data into roadway speed information. This roadway speed information is color coded on the basis of specific, localized conditions for the arterials and freeways to reflect traffic congestion. The resulting traffic data product is then provided to WSDOT as a data source for virtual sensors located in roadways where currently there are no inductance loops.

In addition to creating the infrastructure for an AVL-equipped fleet to serve as probe vehicles, this project created several user interfaces for traveler information. One is "StoreView," a Java application that displays the spatial and temporal average speeds of transit vehicles as bubbles on a map of the major arterials and freeways. The bubbles are color coded to reflect local traffic conditions. This application can be found at http://www.its.washington.edu/storeview/storeview.jnlp.

Another type of traveler information, analogous to TrafficTV and WSDOT's pictographic traffic maps, is also available. This interface can be found at http://www.its.washington.edu/probes_traffic/.

This report documents both the technical issues addressed in creating a virtual sensor data stream from probe vehicle data and the creation of a set of real-time traveler information applications. In addition, this report presents a quantitative evaluation of a probe vehicle system. This probe vehicle system senses traffic over a large geographical area and on a variety of roadway layouts. Quantitative metrics are presented for representative roadway topologies. WSDOT, the regional and state traffic management agency, has accepted speed traps constructed from either inductance loops or radars as the “gold standard” for traffic sensors deployed in support of the TMS. To validate the use of probe vehicles as an input to the TMS, the performance of the virtual sensors, created by using transit vehicles as probes, was compared to speed trap results.

7.1 Implementaion

This work demonstrated the creation of a set of practical real-time virtual sensors based on probe vehicles. Furthermore, it identified a framework in which an existing transit fleet can be used as probe vehicles. It created the software to implement this new data source within the existing TMS at WSDOT’s Traffic Systems Management Center (TSMC). WSDOT personnel at the TSMC are presently evaluating the use of probe data to populate a traffic map for Aurora Avenue (SR 99).

7.2 Recommendations

The set of applications and interfaces documented in this report demonstrates the viability of using an AVL-equipped fleet as a regional traffic surveillance system suitable for both traveler information and traffic management. While these ideas were implemented in King County with the King County Metro transit fleet AVL system as input, the underlying concept may be generalized to any area where a fleet of vehicles is tracked in real time. At the time of this writing, Sound Transit, Community Transit, and Pierce Transit are planning the installation of AVL on their respective fleets. This will expand the possible application of this technology to the tri-county area. In addition, some large metropolitan areas such as Chicago have implemented many of the underlying components discussed in this report by adopting the MyBus derivatives for their transit information systems. With more of these types of deployments, this technology could generalize nationally.

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