ITS Devices Used to Collect Truck Data for Performance Benchmarks

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This paper documents the development of data collection methodologies that can be used to measure truck movements along specific roadway corridors in Washington State cost-effectively. The intent of this study was to design and test methodologies that could provide information to ascertain the performance of freight mobility roadway improvement projects. The benchmarks created would be used to report on speed and volume improvements that resulted from completed roadway projects. One technology tested consisted of Commercial Vehicle Information System and Networks electronic truck transponders, which were mounted on the windshields of approximately 30,000 trucks traveling in Washington. These transponders were used at weigh stations across the state to improve the efficiency of truck regulatory compliance checks. With transponder reads from sites anywhere in the state being linked through software, the transponder-equipped trucks can become a travel time probe fleet. The second technology tested involved Global Positioning Systems (GPS) placed in volunteer trucks to collect specific truck movement data at 5-s intervals. GPS data made it possible to locate when and where monitored trucks experienced congestion. With this information aggregated over time, it was possible to generate performance statistics related to the reliability of truck trips and even to examine changes in route choice for trips between high-volume origin–destination pairs. The study found that both data collection technologies could be useful; however, the key to either technology is whether enough instrumented vehicles pass over the roadways for which data are required.

Understanding changes in truck trip travel time and reliability due to roadway construction projects requires fairly extensive data collection. Unfortunately, data specific to truck movements can be difficult to collect, especially on urban arterials, where many truck-oriented projects are located. In fact, most traditional data collection systems cannot cost effectively provide information about changes in truck performance and route choice that result from construction projects. To address these data collection limitations, a project conducted by the Washington State Transportation Center tested two ITS technologies for collecting robust truck performance information along specific road corridors. These data were then used to develop a process for measuring freight mobility roadway improvements funded by Washington State's Freight Mobility Strategic Investment Board. The benchmarks created will be used to report on speed and volume improvements that result from truck-oriented projects.

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TRUCK DATA COLLECTION

For a data collection technique to evaluate a truck-oriented roadway improvement effectively, it must have benchmarks for both roadway volumes and travel reliability data. Measuring the volume of trucks on a roadway before the improvement gives a benchmark for the level of use before construction. Measuring volumes after the improvement has been completed describes the level of "current" use. However, it is not acceptable to simply subtract the "before" volume from the "after" volume and assume that the difference in volumes is caused by the improvement. In part, this is because changes in the economy can easily cause freight volume changes. It is also important to count truck volumes on parallel routes to determine whether overall truck volumes have actually increased or whether trucks have chosen to use the improved route in place of alternative routes.

The second major roadway performance benchmark is travel time. Two major components need to be measured to understand the effect of a freight mobility improvement. The first is the change in average travel times that trucks experience as they make routine trips. The second is how frequently trucks experience unexpected delays and the severity of those delays. Improved reliability of freight trips can be more important to trucking firms than travel speeds.

Average link travel times can be measured by running floating car surveys repeatedly over the improved roadway link, but this technique is not a practical method for collecting data to determine changes in the reliability of that trip. In addition, restricting the data collection effort to an improved roadway segment does not account for changes in travel time and travel time reliability that result from changes in route choice as truckers adjust their behavior to take advantage of the improved facility.

Therefore, this study explored more robust travel time benchmarks. In addition to the average travel time and reliability for the improved segment, the benchmarks reported on the average travel time and reliability of trips between key truck trip origins and destinations within the region, with emphasis on the origin–destination (O-D) pairs that might benefit from the selected roadway improvement.

DATA FROM COMMERCIAL VEHICLE INFORMATION SYSTEM AND NETWORKS DEVICES

Two existing ITS technologies were employed to collect the truck data used to develop freight mobility benchmarks. The first consisted of Commercial Vehicle Information System and Networks (CVISN) electronic truck tags, which are mounted on the windshields of approximately 30,000 trucks traveling in Washington. These radio
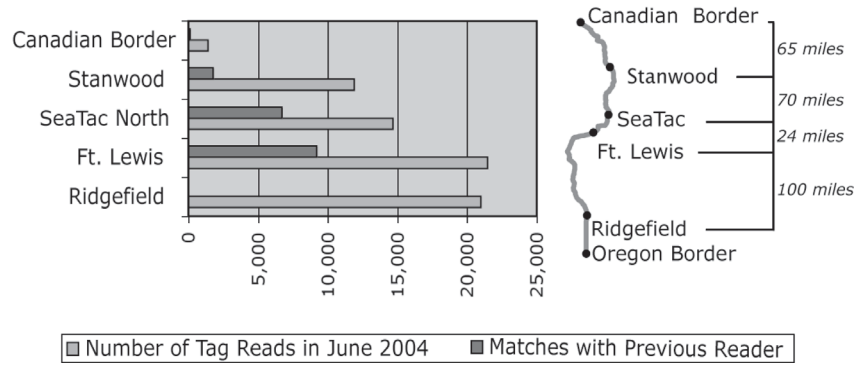
FIGURE 1   Typical CVISN tag segment statistics.

frequency transponders are used at weigh stations across the state, some seaports, and the Canadian border to improve the efficiency of roadside regulatory checks. With software to link the time of arrival of individual trucks at adjacent roadside transponder readers, the transponder-equipped trucks can become a travel time probe fleet. The advantage of using the CVISN transponder readers is that the data are essentially free.

The process developed to collect CVISN tag data involved periodically polling Washington State Department of Transportation's (Washington State DOT) roadside readers through an Internet connection. The data obtained from a transponder read included each unique tag's ID, location, direction of travel, and a time stamp. Each tag's ID was then scrambled for anonymity. These tags were then matched from one reader to every other reader for the next 24-h period, and travel times and speeds between readers were computed for each pair of matched observations.

The resulting database could then be used to produce statistics about travel time between any pair of tag reader locations and for any given time period. Each selected reporting period, which was usually every 15 min, was associated with the upstream tag reader. The "fastest truck algorithm" was used to report travel time between readers. This algorithm assumes that if any one truck can make a trip between readers in a stated time, all other trucks can also make the trip in that time interval, and any truck traveling slower than this does so by choice of the driver. When truck volumes that passed

both readers were moderately high, the "fastest truck" algorithm was good at removing from the travel time data set those trucks that were slower then the fastest truck and that voluntarily stopped between readers. However, the fastest truck algorithm had limitations when truck volumes were light. At those times, slow travel times reported by the system could signify either that there was congestion or that the few (often singular) vehicles observed at both readers stopped at some point between those readers.

Figure 1 shows the typical matches for northbound CVISN roadside readers in June 2004 on Interstate 5. This major truck corridor is 280 mi (448 km) long and crosses Washington State from Oregon to the British Columbia border. The figure shows that for a major route such as I-5, enough transponder-equipped trucks are traveling to be able to compute roadway performance measures.

Analysis of a 24-mi (38 km) segment on I-5 northbound through the city of Tacoma and between the Ft. Lewis and SeaTac weigh station readers demonstrates the daily performance statistics that can be developed from transponders. In June 2004 this segment had an average of 220 transponder matches each day. Figure 2 plots the average number of matches by time of day for this segment and shows that tag matches were not evenly distributed throughout the day.

Travel times for the same segment are shown in Figure 3. The figure displays both average speed by time of day and the speed for the 85th percentile (slowest) travel time in May 2004. The travel times for each time period were computed with the fastest truck algo-
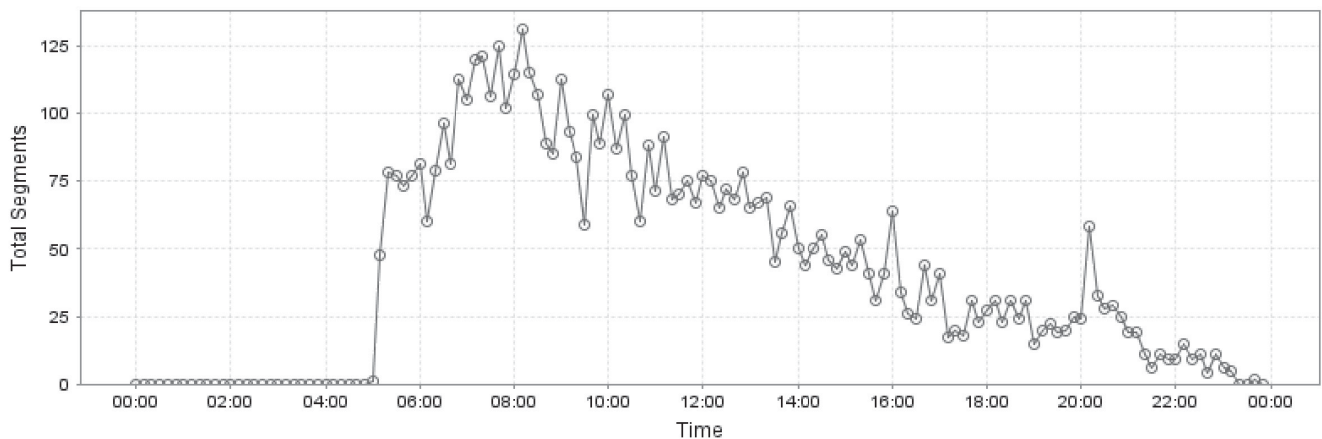

FIGURE 2   Segment matches by time of day for June 2004, Ft. Lewis to SeaTac North.
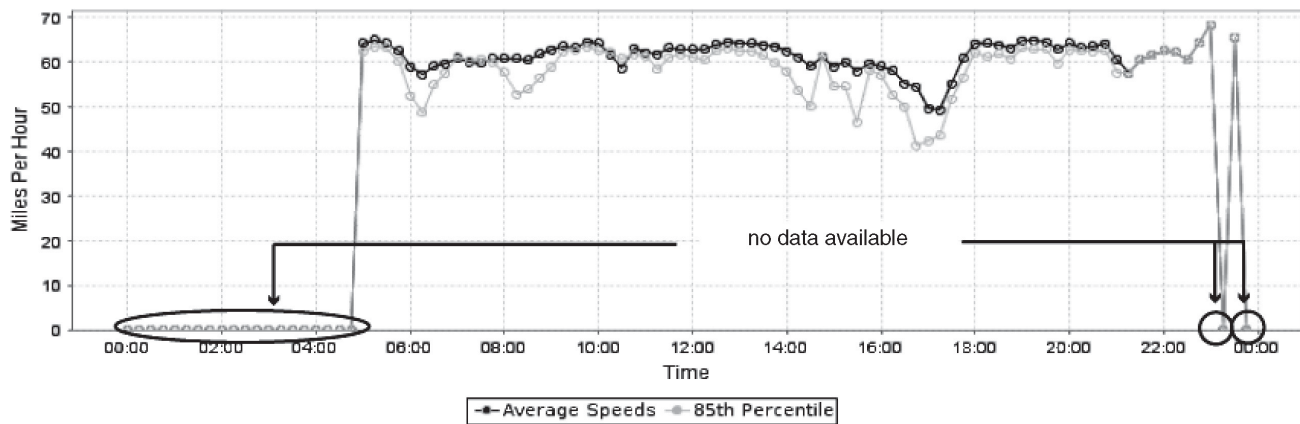
FIGURE 3   Ft. Lewis to SeaTac speed for mean and 85th percentile trip by time of day for all weekdays in May 2004.

rithm. Slowdowns routinely present in both the morning and evening commute periods are readily apparent. These delays that trucks experienced as they passed through the Tacoma metropolitan area demonstrate the type of information that can be extracted from this process. The 0 mph truck speeds for the late-night period in Figure 3 indicate that match data were not available.

Although such graphs are useful for analyzing the data collected and are necessary for understanding the strengths and weaknesses of the CVISN tag–based monitoring system, they were not the most usable freight mobility benchmark. Instead, an average day was divided into peak and nonpeak time periods with estimates of the "routine" conditions that could be expected by a truck driver traveling over the road segment during that period. These measures included average speed and the 85th and 95th percentile slowest travel times (converted to speed). Thus benchmark information could indicate, for example, that "the average travel speed on a segment during the PM peak is 52 mph, with the 85th percentile speed being 43 mph."

One potential bias needs to be considered. Travel time data through the urban area served by I-5 suggest that when a major incident creates very significant congestion, trucks may change their routes to avoid I-5 altogether. Thus the CVISN travel time data may have understated the "worst" travel time conditions.

These tests show that for routes with large numbers of CVISN tag–equipped trucks, it is possible to compute roadway performance with a reasonable level of accuracy. However, at this time only the major corridors in Washington State are equipped with tag readers and are also traveled by sufficient numbers of CVISN-tagged trucks for truck travel times to be accurately computed. This situation may improve as the number of transponder-equipped trucks increases and as Washington State DOT installs more roadside readers for both data collection needs and regulatory enforcement.

DATA FROM GLOBAL POSITIONING SYSTEMS DEVICES

Because of the limitations of CVISN readers, a second type of low-cost data collection technology, Global Positioning Systems (GPS), was explored as part of this effort. A number of studies have found that GPS devices have reasonable accuracy and are suitable for collecting travel time and trip data. Wolf et al., for example, found

GPS technology usable for accurate route choice data collection (1). Other efforts have determined that GPS data collection is an improvement over traditional manual travel time data collection procedures (2, 3).

For this study, 25 portable GPS devices, which cost approximately $500 each, were supplied to trucking companies recruited by Washington State DOT. The eight companies that were selected frequently traveled between the Port of Seattle and several major concentrations of warehouses in the south Puget Sound area. The in-vehicle GPS devices were connected to the cigarette lighter in the trucks, and they recorded the vehicle's position every 5 s while the vehicle's engine was on. Data were stored in the truck in a battery-powered "data logger." Each record stored on the logger contained an identification number, latitude, longitude, time and date stamps, and speed and direction of the vehicle when the data were recorded.

Every 3 weeks, the trucking firm's dispatch office replaced the data logger in each vehicle with a fresh data logger and mailed the full logger back to the project team for downloading.

With GPS position data being collected frequently, it was possible to gain an understanding of when and where monitored trucks were experiencing congestion. With GPS data collected during a large number of days and then aggregating the roadway performance information over time, it was possible to generate performance statistics related to the reliability of truck trips. To develop benchmarks, the analytical process illustrated in Figure 4 was undertaken. The analytical process followed two separate tracks: trip statistics and road segment statistics.

Truck Trip Statistics

The first task in developing trip performance measures was to identify "trips" in the GPS data set. Trips were defined by the locations at which trucks either picked up or delivered goods. To do this, the record for each GPS device was ordered by time of day and was read sequentially by a software program. The first point in the file for that device ID was assumed to be the origin of a trip. The remaining points were then scanned until a break in that record of 3 min or longer was found. At that point, the trip was considered to have ended, and the last point before the time break was recorded as the "trip destination." Once the vehicle started moving again,
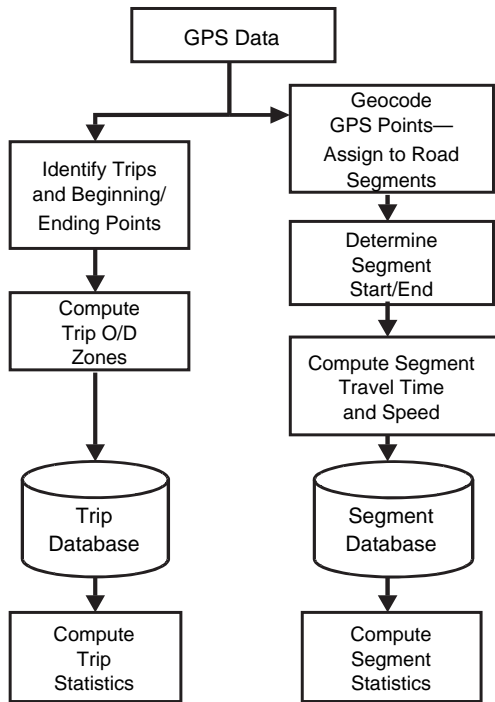
FIGURE 4   GPS data-processing flowchart.

that first point was considered the "origin" of the next new trip. This process continued until the entire GPS file was segmented into a series of trips. Under this 3-min process, most intentional stops to load or unload cargo or for lunch would start a new trip. Restarting a trip after these stops helped to ensure that the resulting data captured the performance of trucks only while traveling the roads. Some modifications to this process to account for unintentional

delays at railroad crossings and drawbridges were written into the software.

For each trip identified above, a single data record was written. It consisted of O-D points, followed by the coordinates traversed between the origin and destination for that trip. Total trip travel time was computed by subtracting the time at the origin point from the time at the destination point. The time the trip occurred was defined as the time at the origin point. Each trip was then assigned an identification number. The trip records were then read back into the geographic information system (GIS), in which the origin and destinations for each trip could be geocoded to the census tract level and saved as the "trip database." This file served as the primary input to analyses about trip-making behavior. Data that were extracted from the trip file included average speeds and the mean, median, and 80th percentile travel times. Figure 5 illustrates GPS truck trip data for three time periods for the approximately 15-mi (24-km) trip from a Kent Valley census tract that consists of a warehouse area to the Duwamish census tract containing many of the Port of Seattle's terminals.

Monitoring changes in these GPS statistics can allow analysts to track the effects of roadway improvements on the time taken to deliver goods, as well as on the reliability of the movements. It can also provide an understanding of the effects of traffic congestion on a company's ability to efficiently schedule labor and equipment. The 80th percentile travel time is a good descriptor of the travel time that a truck driver could be expected to exceed about once a week. Other ways to describe reliability are to examine the distribution of travel times associated with zone-to-zone movements.

Figure 6 illustrates how travel times by time of day can be plotted to provide a more intuitive sense of the variability of travel time between two zones. Examining the actual distribution of travel times can be very helpful in understanding how often slow trips occur and how slow those trips are relative to the "routine" travel times that trucks experience. The main concern was whether the participating
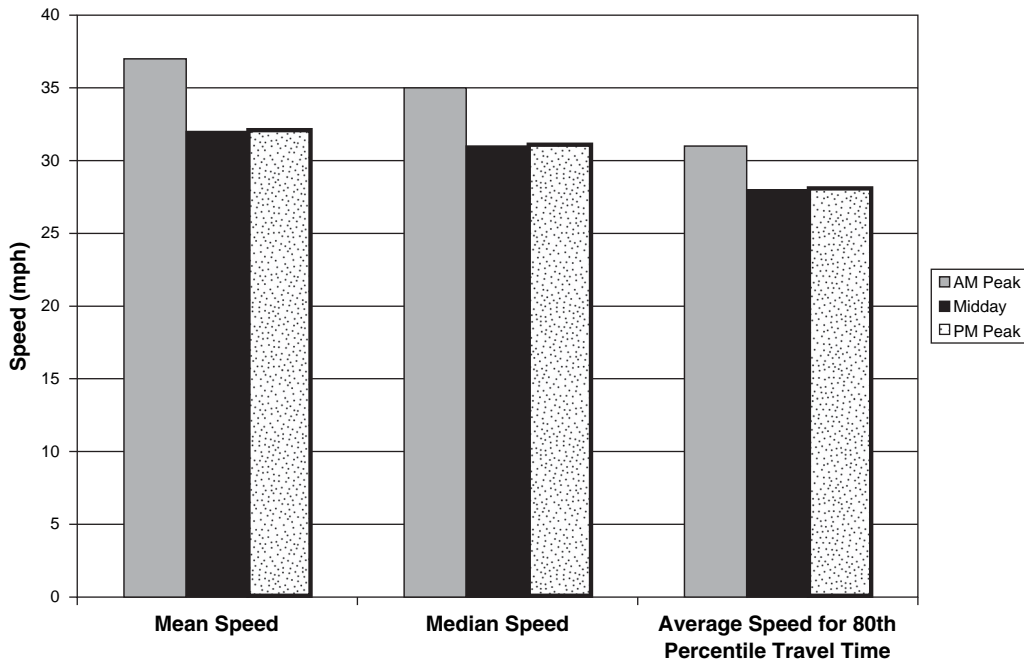

FIGURE 5   Mean, median, and 80th percentile travel times, Kent Valley to Duwamish area.
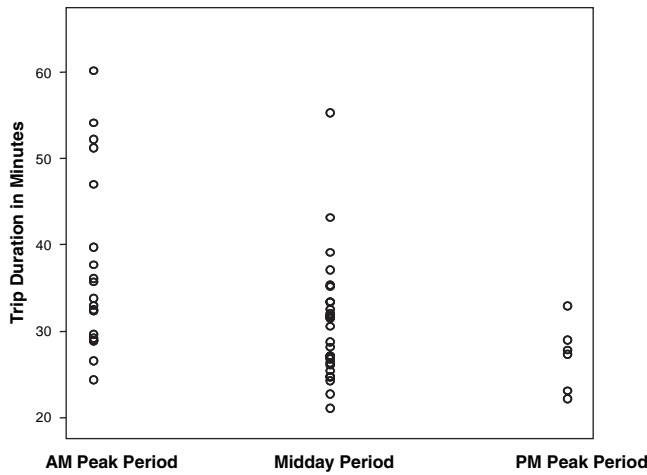
FIGURE 6   Distribution of travel times between Duwamish area and Kent Valley.

trucks actually drove often enough between key O-D pairs to provide reliable travel time estimates

One other concern was that zone-to-zone travel times would change slightly if the starting and ending points in the two zones were significantly different. However, just because the exact start and end point of trips can affect travel time and route selection does not mean that zone-to-zone travel times are not an effective measure of roadway performance. A variety of factors affect travel time, including congestion, traffic signals, and the availability of alternative routes.

If a representative sample of trucks was recruited to participate in the GPS data collection effort, the trip database could also be used to describe the geographic distribution of zone-to-zone truck travel in a larger region.

One great advantage of the use of GPS for data collection is that if the distribution of trip start and end points does become a concern, the location of these points is known and can be accounted for through more detailed analysis of the truck routing. Figure 7 shows
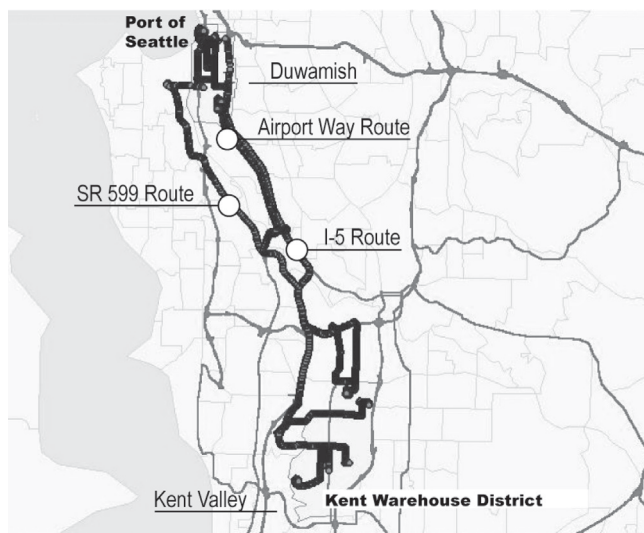

FIGURE 7   Three commonly used truck routes from Kent to Duwamish.

multiple routings the GPS recorded on trips between Kent Valley and the Duwamish area. This information could evaluate the regional impact of roadway improvements on truck routing, explore the effects on route choice of trip ends and starts in a zone, and help isolate portions of truck routes for evaluation.

Road Segment Statistics

In addition to providing information on total trip movements, GPS devices can be used to develop benchmarks for specific roadway segments to describe the localized performance changes that result from roadway projects. The raw GPS data were processed differently to compute segment statistics than they were to produce the trip database (Figure 4). It is important to note that every truck trip that traversed a specified road segment was included so that the segment database contained one record for each truck movement along a defined road segment of interest.

The initial step for creating the segment database was to read the "raw" GPS data point files into the GIS. GIS tools were then used to assign each GPS data point to a specific roadway segment. This step required considerable quality control. For example, some data points were assigned as "off network" and removed during this step because they were located too far from a road segment to be considered "on" that road segment. In most of these cases, the vehicle carrying the tag had entered a parking lot or was traveling a local road not included in the analysis network.

All data points were then exported to a segment file. Each reported truck location was a single record in the file, and that record included all data that described that location, including a road segment identifier extracted from the GIS. A program written in C++ identified when each truck passed from one road segment to another. Each time a vehicle passed onto a new road segment, the data from the previous segment were written onto a single record.

Consequently, each new record contained all the GPS data points on that segment for that specific trip by that specific truck, along with the road segment ID. Associated with each GPS data point included in the record were the latitude and longitude of that specific point, the time the truck was observed at that point, and the heading of the truck at that time.

From the data points stored on each record it was possible to compute the total distance the truck traveled while on that road segment for that specific trip. Accomplishing this required that the distance between each GPS data point be computed and that those distances be added together. These steps were necessary because the truck may have entered or exited the defined road segment at some point other than the end points of the segment. In addition, the road segment may have curved, making a straight line computation from the first data point to the last data point in the link a poor estimate of total distance traveled.

The total travel time the truck spent on that road segment was computed by subtracting the time the truck was first observed on the segment from the time the truck was last observed on that segment. Dividing the total distance traveled on the link by the total time on the link produced a measure of the average speed of the truck while on that link.

The result was a new segment database with records that described the performance of all truck trips along all the analysis's network roadway segments. To obtain performance information on specific segments it was necessary only to use the GIS to determine the ID of the road segment of interest, select the records that included this

identifier, and compute the statistics of interest from that sample of records.

The generated travel time benchmarks specific to roadway segments of interest included speed; mean speed; number of observations; and 5th, 25th, and 80th percentile speed. These statistics could be created for arterials that had the potential to fill major holes in Washington State's ability to monitor freight performance on roadways. However, the statistics generated were valid only if a substantial number of participating trucks used this roadway segment. Statistical confidence that differences in measured speeds accurately reflect real changes in roadway performance grows slowly with sample sizes larger than 30 trips.

The GPS data could also be used to examine where delays occurred for routine travel. Four of the GPS devices were placed in Boeing trucks moving 747 airplane components 75 mi (120 km) between a subassembly plant in southern Puget Sound (Fredrickson) and the final assembly plant in northern Puget Sound (Everett). Figure 8 illustrates monitored routes that were taken. In this figure, GPS data points are shaded to show the instrumented truck's speed at the time at which the GPS data points were collected. Darker shading indicates areas with slower speed. Such GPS data allow a quick determina-
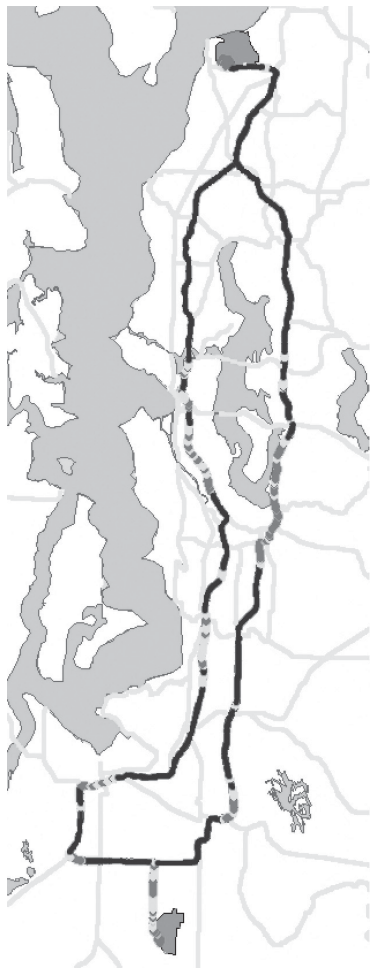

FIGURE 8 Locations of delays experienced between Fredrickson and Everett.

tion of where trip delays took place. However, some local knowledge must be used to account for situations such as slowed speeds due to traffic signals and to trucks entering and driving through the facilities on either end of each trip.

On the basis of data collected with both the CVISN and GPS technology, this effort developed recommendations for a truck-oriented freight mobility benchmark program. The following statistics should be developed both before and after a roadway improvement has been made:

- Truck volumes by day and by time of day,
- Mean travel times by time of day, and
- 80th and 95th percentile travel times by time of day.

Information on total trip reliability (origin to destination travel times and routes) should also be collected if the roadway improvement is likely to affect truckers' route selection. Both volume and travel time data should be reported for at least four time periods: morning peak period, midday, evening peak period, and nighttime.

For projects in areas with noncongested traffic, truck volume data can be accurately collected with automatic roadside vehicle classification counters. If automatic classifiers do not work, truck counts will have to be performed manually.

CVISN tags provide an almost free source of data, but they are limited by the number of transponder-equipped trucks and the locations of readers. Unless a freight mobility improvement will directly affect a major Interstate corridor, use of CVISN tags may require placing the portable CVISN tag readers at either end of the road segment for which monitoring will be required. And if not enough transponder-equipped trucks use the route, recruiting trucking firms that travel that route and supplying them with transponders may be required.

Several methods of GPS data collection are recommended to meet the benchmark reporting needs. For isolated improvements that are unlikely to cause changes in truckers' route choices, one of two data collection procedures can be used. First, if a limited number of trucks travel the facility, placing GPS devices on those trucks will provide an excellent measure of changes in the length and location of delays that result from the roadway improvement. Second, in cases in which the trucking population that travels the facility is diverse and not easily outfitted with GPS devices, a more conventional, and potentially expensive, floating car study will have to be performed. This will involve hiring drivers to follow trucks as they use the road and record their travel times. If truck trip reliability is one of the expected improvements of a roadway project, a fairly extensive number of floating car runs will have to be performed both before and after the improvement has been completed. If a significant percentage of trucks use weigh-in-motion transponders, portable roadside transponder readers can possibly be installed instead to collect travel time data.

A different data collection method is recommended to measure improvements to dense roadway networks that are likely to cause significant changes in truckers' route choices. In that situation, floating car runs may not provide a complete understanding of the truck travel time savings that result from an improvement. The diversity of trucks using such an improvement also may make it impossible to select a set of trucks that can be instrumented with GPS devices to effectively collect performance information. Consequently, it is recommended that the feasibility of implementing an ongoing regionwide truck performance data collection project be considered. Attention should be paid to recruiting trucking firms that operate over the improvements of interest.

TABLE 1 Example Benchmark Report for Road Segment Truck Travel Savings

Road Segment	Time Period	Mean Speed After Project	Before Travel Time (min)	After Travel Time (min)	Travel Time Savings (min)	Truck Volume (per hour)	Value of Truck Time (per year)
S. 180th	a.m. peak (6 a.m.–9 a.m.)	25.4	3.4	2.4	1	45	$62,331
	Midday (9 a.m.–3 p.m.)	34.7	2.7	1.7	1	45	$124,661
	p.m. peak (3 p.m.–6 p.m.)	21.5	3.8	2.8	1	45	$62,331
	Night (6 p.m.–6 a.m.)	40.1	2	2	0	5	$0
Total							$249,323

In any data collection situation, the use of GPS technology will require the cooperation of truck drivers and their trucking firms. This level of cooperation can be difficult to achieve and could be a considerable shortcoming. A key in gaining cooperation will be for trucking firms to understand the mobility benefits they might gain in return for their cooperation.

Several report formats are suggested to effectively present the data from CVISN and GPS devices as part of a benchmark program. Table 1 illustrates how benchmarks calculated from GPS data show benefits that accrued to trucks using a roadway on which freight mobility improvements had been completed. The benefits are based on changes in average travel speed over the segment of interest. This same type of report could also be used to calculate benefits for daily truck trips attracted from other routes because of an improved road-

way. The difference is that trip benefits would be based on improved travel times between zones involved in key freight movements. Table 2 provides an example of a summary table describing the changes in travel time reliability that resulted from a roadway improvement. A standard, such as percentage of trips that require more than a 40-min travel time between zones, would allow for performance monitoring. The example illustrated in Table 3 is designed as if truck travel times were dependent only on travel route and reflect more regional impacts on truck travel due to roadway improvements.

For any format, ideally, enough data need to be collected to estimate trip travel times by route, by time of day. The problem with using travel time information by route by time of day is that it greatly increases the number of data required for before/after studies.

TABLE 2 Example Benchmark Summary of Improvements in Freight Reliability

Zone-to-Zone Movement	Time Period	New Mean Travel Time (min)	New Mean Speed (mph)	80th Percentile Travel Time (min)	95th Percentile Travel Time (min)	Percent of Trips That Require More than 40 Minutes
Kent to Duwamish	a.m. peak (6 a.m.–9 a.m.)	37	24.3	45	55	26%
	Midday (9 a.m.–3 p.m.)	32	28.0	34	39	2%
	p.m. peak (3 p.m.–6 p.m.)	33	27.7	37	42	7%
	Night (6 p.m.–6 a.m.)	27	34.0	28	30	0%
Duwamish to Kent	a.m. peak (6 a.m.–9 a.m.)	32	28.0	35	39	3%
	Midday (9 a.m.–3 p.m.)	33	27.4	36	38	3%
	p.m. peak (3 p.m.–6 p.m.)	39	22.8	43	52	24%
	Night (6 p.m.–6 a.m.)	27	34.0	28	30	0%

TABLE 3 Example Benchmark Report for Route Selection

Trip	Route	Before			After			Change in Mean Travel Time (min)	Change in Percent of Trips
		Percent of Trips	Mean Trip Time (min)	80th Percentile Trip Time (min)	Percent of Trips	Mean Trip Time (min)	80th Percentile Trip Time (min)		
Kent to Port of Seattle	4th Ave. S. Ramp	50	34.9	46.2	5	35.1	46.2	0.2	−45
	Atlantic Ramp	NA	NA	NA	58	34.1	41.5	NA	NA
	SR 599	35	36.4	50.9	30	36.2	50.3	−0.2	−5
	Airport Way	10	39.8	54.3	5	39.4	54.3	−0.4	−5
	4th Ave. S.	5	42	54.5	2	42.1	54.5	0.1	−3
Port of Seattle to Kent	4th Ave. S. Ramp	55	37.4	44.2	6	35.8	44.2	−1.6	−49
	Atlantic Ramp	NA	NA	NA	55	33.5	38.5	NA	NA
	SR 599	32	36.5	44.2	28	36.7	44.2	0.2	−4
	Airport Way	8	41	50.6	8	40.5	50.6	−0.5	0
	4th Ave. S.	5	44.5	51.3	3	44.3	51.3	−0.2	−2

SUMMARY

Results of the field tests indicated that it is possible to use both GPS and CVISN truck tag technologies to collect the truck movement data required to provide detailed descriptions of changes in truck performance that result from truck-oriented roadway improvements. CVISN tags provide an almost free source of data, but they are limited by the number of transponder-equipped trucks and the location of readers.

GPS devices provide highly accurate data on both travel routes and individual roadway segments used by trucks. The advantage of the GPS devices is that they can monitor the actual route taken by instrumented vehicles. This makes the GPS data set far more robust than the transponder data. The major problem with GPS is the difficulty in accessing more than a relatively few GPS-instrumented trucks and, therefore, in a large metropolitan region insufficient data may be collected on many routes unless a fairly large sample of trucks actively participates in the data collection effort. Unlike the CVISN tag reader system, the GPS data collection system requires considerable staff effort to coordinate. It is also necessary to have a mechanism for recruiting trucking company participation. This approach to data collection will not work without strong support from the trucking community.

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