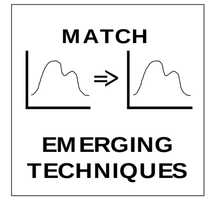


6 EMERGING AND NON-TRADITIONAL TECHNIQUES

The technology aspects of the test vehicle, license plate matching, and ITS probe vehicle methods of travel time data collection are fairly well established. This chapter presents other methods for collecting or estimating travel time that are considered emerging and/or non-traditional techniques.

Several of the emerging or non-traditional techniques are based on using “point” vehicle detection equipment, such as inductance loop detectors or video cameras. Travel time estimation algorithms have been developed based upon measurable point parameters such as volume, lane occupancy, or vehicle headways. Image matching algorithms are used to match vehicle images or signatures captured at two consecutive observation points. For the most part, these emerging techniques are still in developmental stages.

The available information is presented here for those interested in further research, development, or testing of these techniques. Because of the rapidly changing nature of these technologies, it may be appropriate to contact the associated authors or developers for updated information. This chapter does not provide information on comparative advantages and disadvantages because of the relative infancy of these techniques. The techniques discussed in this chapter include:

- **Extrapolation Method** - estimates average travel time by assuming that spot speeds (as measured by point detection devices) can be applied for short roadway segments between detection devices. This method is simplistic but can be used for applications that do not require high levels of accuracy.

- **Vehicle Signature Matching** - calculates travel time by matching (correlating) unique vehicle signatures between sequential observation points. These methods can utilize a number of point detectors such as inductance loop detectors, weigh-in-motion sensors, video cameras, and laser scanning detectors.

- **Platoon Matching** - estimates average travel time by matching unique features of vehicle platoons such as the position and/or distribution of vehicle gaps or unique vehicles. As with correlation methods, platoon matching uses point detection devices, such as video cameras, ultrasonic detectors, etc.

- **Aerial Surveys** - estimates travel time using aerial survey methods that measure vehicle density or track vehicle movement. Fixed-wing aircraft have typically been used for aerial surveys, but newer methods propose using weather balloons, satellites, and remote controlled gliders.

6.1 Extrapolation Method

The extrapolation method is a simple way of estimating average travel times because it assumes that a spot speed is applicable over short segments of roadway (typically less than 0.8 km, or 0.5 mile). Several planning applications that do not require high levels of accuracy, like demand forecasting model validation or system monitoring, could use the extrapolation method. Spot speeds are typically collected by a number of traffic monitoring devices that are considered intelligent transportation systems (ITS) components. Traffic monitoring devices that have marketed capabilities of collecting spot speeds include (1,2):

- inductance loop detectors;
- piezoelectric sensors;
- active and passive infrared sensors;
- magnetic sensors;
- video tracking and tripline systems;
- doppler microwave;
- passive acoustic sensors; and
- pulse ultrasonic detector.

An example of the extrapolation method is shown in Figure 6-1. In the figure, the point detection devices that measure spot speed could be any of the above-mentioned traffic monitoring devices.

The most common and widely implemented point detection device is the inductance loop detector. The most accurate method to measure vehicle speed with loop detectors is to place two detectors in series, which is referred to as a "speed trap" or "loop trap." The results of a Texas Transportation Institute study indicated that the accuracy of inductance loop speed traps were dependent upon the trap length, inductance loop wire type, and consistency in design and use (3). The study found that the optimal trap length, or distance between inductance loops, was 9 m (30 ft). The study authors also found average error ranges to be about 2.4 km/h (1.5 mph) by using identical make and model detector units.

Information gathered by California PATH researchers (4) suggests that calibrated inductance loop speed traps can achieve the following accuracy ranges:

- individual wire loops: low speed, 5 to 8 km/h (3 to 5 mph);
- individual wire loops: high speed, 16 to 19 km/h (10 to 12 mph);
- multi-conductor loops: low speed, 0.3 km/h (0.2 mph); and
- multi-conductor loops: high speed, 5 to 8 km/h (3 to 5 mph).

PATH researchers also report that speed traps can be separated by a distance ranging from 2 to 20 m, with 9 m (30 ft) being the optimal spacing.

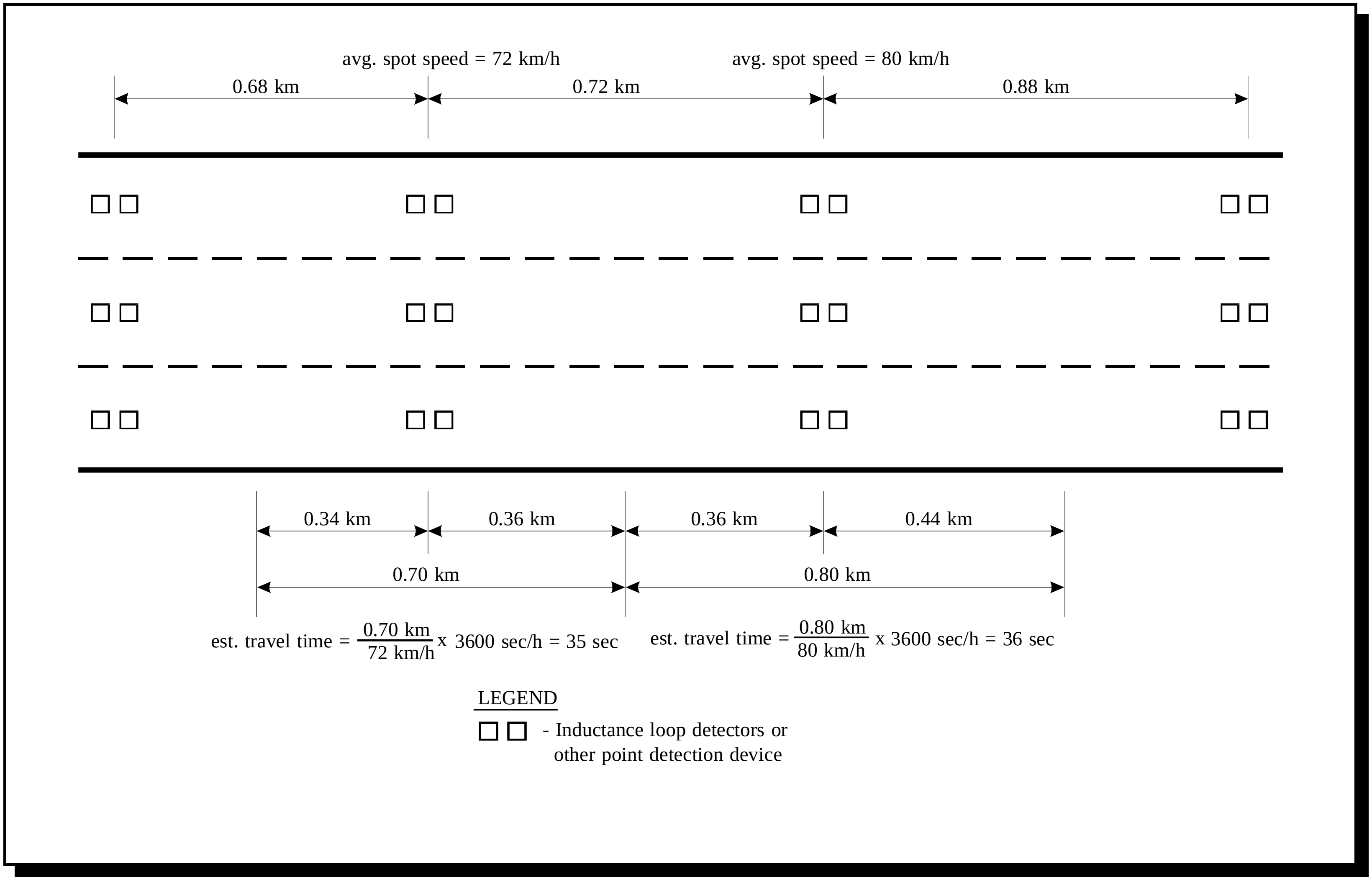


Figure 6-1. Example of Extrapolating Link Travel Times from Spot Speeds

Many inductance loop detectors currently in place are single loops primarily designed to collect vehicle counts and lane occupancy. Many attempts have been made to utilize speed-flow relationships to estimate vehicle speeds from single loop detectors. The following equations have been used to estimate spot speeds from single loop detectors:

$$spot\ speed = \frac{volume}{lane\ occupancy \times g} \tag{6-1}$$

where: g = speed correction factor (based upon assumed vehicle length, detector configuration, and traffic conditions).

The Chicago Traffic Systems Center assumes a vehicle length of 6.55 m (21.5 ft) and uses the following equation to estimate spot speed (5):

$$spot\ speed = \frac{volume \times 21.5\ ft}{lane\ occupancy \times 40.9} \tag{6-2}$$

Previous research (6,7) has identified several problems with these simplified relationships. These previous studies have shown that the accuracy of Equation 6-1 is a function of many factors, including location and weather, and may be prone to systematic bias with respect to lane occupancy.

Dailey suggests cross-correlation techniques that may provide more accurate link travel times from sequential single inductance loop detectors (8,9,10). Petty et al. also suggests correlation techniques for accurately estimating travel times from a single loop detector (11). Readers are encouraged to refer to these papers for more information about speed and travel time estimation from single inductance loop detectors.

Little or no information about the use or validation of the extrapolation method is contained in the literature, presumably because of its simplicity. The method could be easily tested for accuracy by comparing test vehicle or ITS probe vehicle travel times to travel times estimated by the extrapolation method. The accuracy of this method varies with several factors:

- type of facility (freeway versus arterial street);
- distance between point detection devices;
- traffic conditions (free-flow versus congested conditions); and
- accuracy of the device itself.

Traffic monitoring devices are often placed at 0.4- to 0.8-km (¼- to ½-mile) spacings on freeways for incident detection and devices at this spacing could be used for travel time estimation.

Inductance loop detectors on arterial streets are commonly placed at major intersections, where traffic conditions vary considerably throughout the traffic signal cycle. Mid-block system detectors on arterial streets would not include the stopped delay time associated with intersections, and would be less suitable than intersection detectors. The accuracy would presumably be less in congested traffic conditions, where stop-and-go conditions and rolling shock waves can significantly affect vehicle speeds over short segments of roadway.

Errors in measured spot speeds due to device inaccuracies would be reflected in any estimates of link travel time. There are ongoing efforts to evaluate the accuracy of various traffic monitoring devices. Minnesota DOT is testing several devices in normal and adverse weather conditions (12). Virginia Tech's Research Center of Excellence is also performing traffic sensor testing on a 9.6 km (6-mi) "Smart Road" (13). Ongoing FHWA efforts have focused on creating a National Vehicle Detector Test Center, and a Vehicle Detector Clearinghouse has been established at the Southwest Technology Development Institute of New Mexico State University (14,15).

CAUTION !!	Exercise caution when using point detection devices for estimating travel times. Freeway detectors may provide reasonable estimates in light traffic, but using detector estimates is not recommended in heavy congestion or on arterial streets.

6.2 Vehicle Signature Matching

Several research efforts are aimed at developing methods to capture unique vehicle features, or "signatures" and match these vehicle signatures between two consecutive locations to provide a link-based travel time and speed. These methods provide an anonymous alternative to ITS probe vehicle-based travel time measurement, in which a probe vehicle is identified and matched between two locations using a unique identification number. Vehicle signature matching is also regarded as implementable in the near-term using existing point detection devices. ITS probe vehicle-based systems require more extensive instrumentation and market saturation before useful results can be achieved for many areas.

Vehicle signature matching has been investigated using a number of different point detection devices, most noticeably with inductance loop detectors. Laser sensors, weigh-in-motion (WIM) sensors, and video cameras have also been tested using vehicle signature matching. Infrared and microwave radar sensors are also capable of extracting unique features of vehicles, and therefore capable of using vehicle signature matching for link travel times. The following sections discuss specific research related to the testing of inductance loop detectors, WIM sensors, and video cameras.

6.2.1 Inductance Loop Detectors

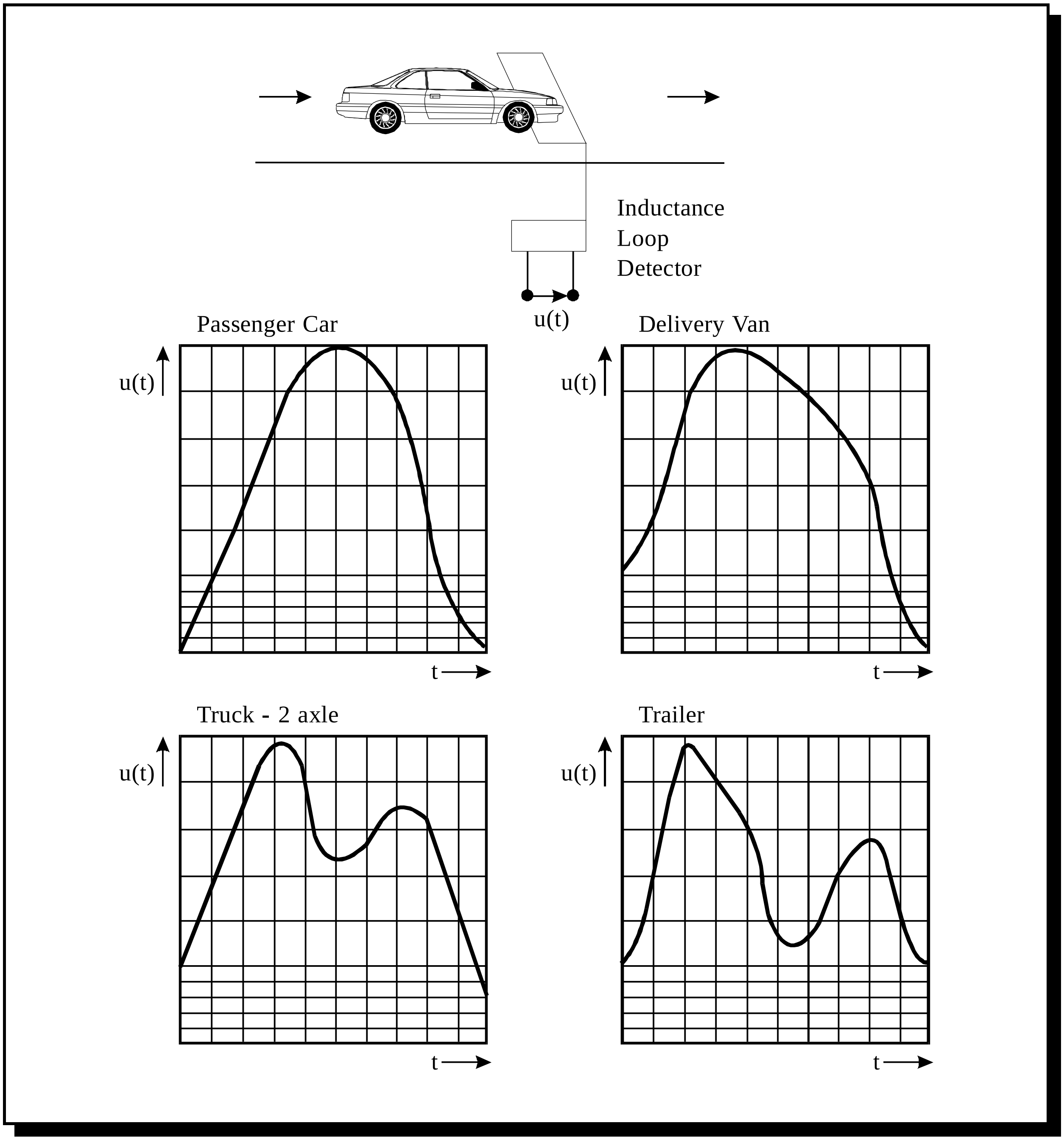
The testing of inductance loop detectors for vehicle signature matching has been thoroughly documented by Kühne et al. (see references 16,17,18,19,20,21,22). Kühne's technique relies on several algorithms to capture vehicle signatures from a loop detector frequency detuning curve. Different types and classes of vehicles provide somewhat characteristic detuning curves (Figure 6-2). The unique features of a vehicle signature (as seen in the detuning curve) are then compared to signatures within a given time frame at a downstream location. The signature is considered to be matched when a large number of feature correlations has been found within vehicle signatures at the downstream location. Figure 6-3 illustrates the features correlations, with the largest number of correlations (about 120) occurring with the matched vehicle signature. A lower number of feature correlations (less than 60) were found within other vehicle signatures, but can be discarded because of the relatively low number of feature correlations relative to the maximum correlation (about 120).

The vehicle signature matching technique does not match every vehicle signature captured, but can potentially match a large enough percentage as to be significant (estimated at 10 percent of the traffic volume). This use of inductance loop detectors has not been thoroughly tested, and no quantitative test data that details accuracy levels was available in the literature. The technique appears to be capable of providing estimates of link travel times for real-time traffic control. Vehicle signature matching appears most promising for areas that currently have an existing loop detector infrastructure with no plans for probe vehicle-based systems.

Recent research by Coifman (23) takes a slightly different approach by attempting to match a sequence of vehicle signatures between two sequential single inductance loop detectors. According to the research, the specific sequence of vehicle lengths is captured at an upstream detector and then re-identified at a downstream detector location. This vehicle length sequence method is capable of using commercially-available loop detector controllers (i.e., 170 controllers) with software developed by researchers at PATH and Caltrans. The author acknowledges that the accuracy of this method is not as great as matching actual vehicle signatures, but asserts that the necessary loop detector infrastructure is already in place. No recent field tests were available at this writing, but development on the vehicle length sequence method continues.

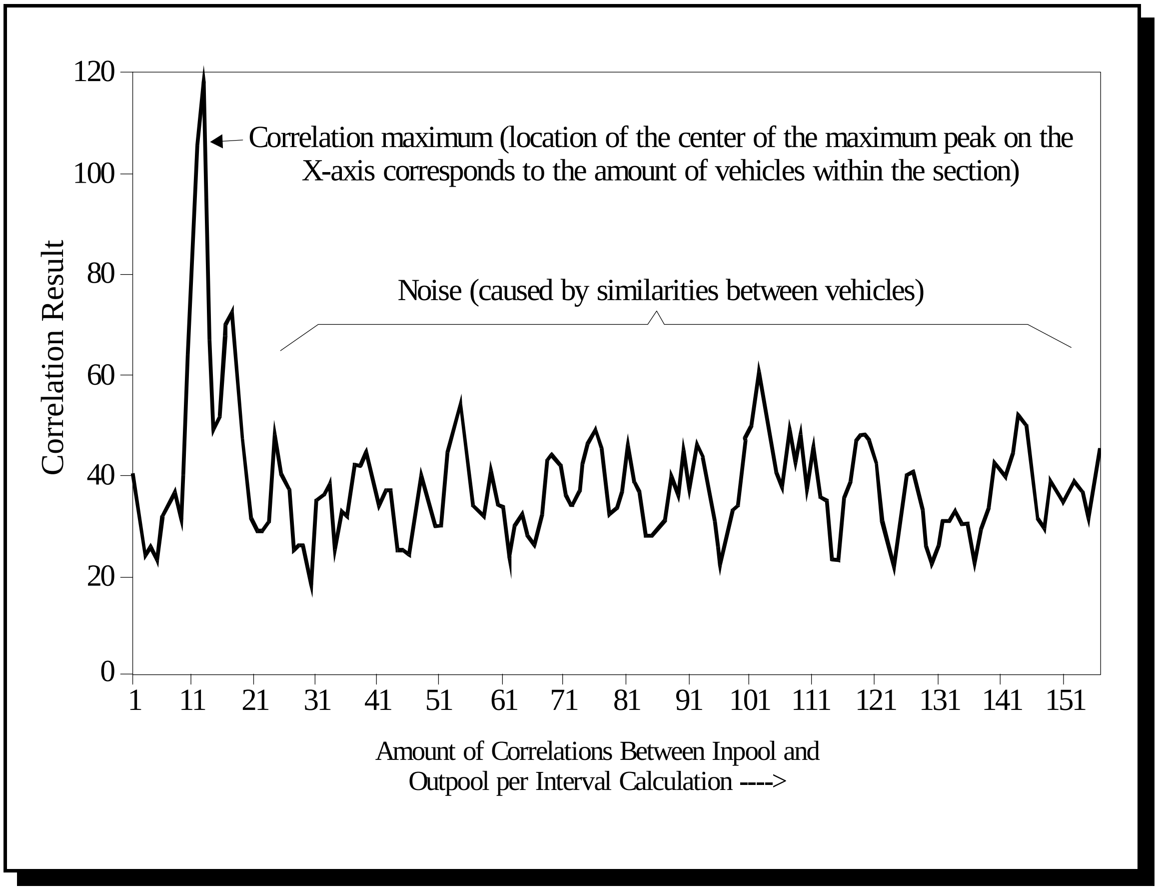
6.2.2 Laser Sensors

The vendor of a diode laser-based vehicle detector/classifier has developed matching algorithms that estimate link travel times using a laser rangefinder sensor (24). Two narrow laser beams are used to scan a moving vehicle and a three-dimensional profile is developed. The authors assert that height profiles can be obtained with considerable accuracy (± 76 mm or 3 in), and vehicle speeds can also be determined from the laser beams.



Source: adapted from reference (25).

Figure 6-2. Characteristic Detuning Curves of Inductance Loop Detectors



Source: adapted from reference (16).

Figure 6-3. Vehicle Signature Correlation Results

A structural matching algorithm is used to match the images constructed by the lasers at two consecutive locations. The algorithm reportedly can discern slight differences between similar vehicles using the spatial relationship of vehicle features. The algorithm's steps include (24):

- input image: obtain image from laser sensors;
- pre-processing: extract height and profile from image;
- develop model set: select set of vehicles from downstream location for matching;
- primitive extraction: extract characteristic features for matching;
- matching: compute a match score for all possible matches;
- matched pair pruning: select vehicle pairs with the highest matching score; and
- report: summarize matching results with link travel times.

The authors conducted a field test of this technique along SR 441 in Orlando, Florida, in which 50,000 vehicle images were collected. From these collected images, 500 sets of 100 vehicles each were chosen for matching purposes. From each set of 100 vehicles, match scores were computed for every possible vehicle combination and the matching algorithm was used to find those scores with the highest number of matching features. Then, a sample of 10 vehicles was chosen for computation of travel times. Of the 500 sets, 487 sets had all 10 sample vehicles matched correctly between the two locations. The other 13 sets had 9 of the 10 sample vehicles matched correctly. The authors reported a correct matching percentage of 99.7 percent (4,987 of 5,000 sample vehicles correctly matched).

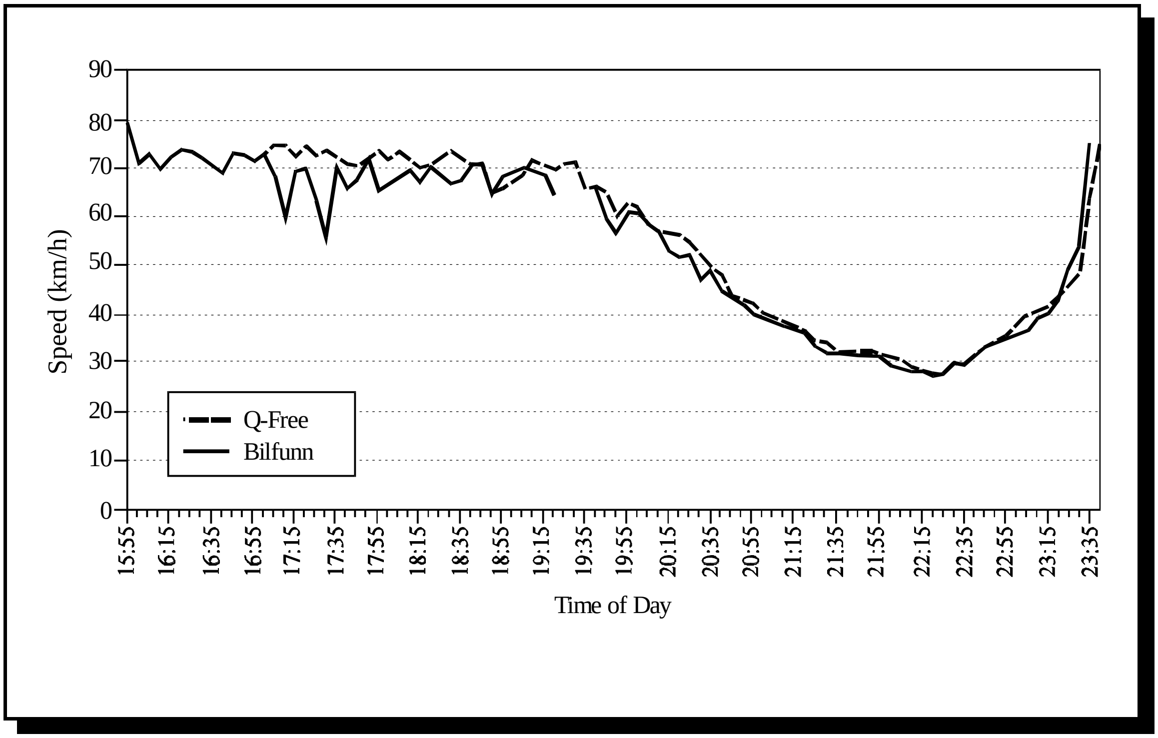
6.2.3 Weigh-in-Motion (WIM) Sensors

As with inductance loop detectors, WIM sensors also generate a vehicle signature based upon the axle weight and configuration. The Norway Public Roads Administration (NPRA) has experimented with using WIM sensors for link travel times on the Oslo Toll Ring (26,27). The Norwegian WIM system collects standard traffic parameters (e.g., volume, speed, lane occupancy) as well as axle configuration, axle distances, and axle weights. Accuracy of the WIM system is very high because the system is certified as an enforcement tool. Additionally, a prototype of the system was tested at the Winter Olympic Games in Lillehammer in 1994 and was later refined with more advanced matching algorithms.

The WIM system software uses axle configuration and axle weights to match vehicles between two different locations. Because of the high vehicle volumes and difficulty with similar vehicles, the system utilizes vehicles with unique axle configurations or weights (e.g., larger vehicles, trucks with trailers). Tracking of most standard passenger cars is difficult because of similar axle and weight configurations.

The NPRA tested the comparability of travel times collected through the WIM system to travel times collected by probe vehicles equipped with AVI transponders. WIM sensors were placed at AVI antenna locations, and travel times were compared. Figure 6-4 presents the results of AVI and WIM sensor travel times, and indicates that the two systems produce comparable travel times in both congested and uncongested traffic. The comparability was also significant because the AVI system typically measured passenger vehicle travel times, whereas the WIM system was more likely to measure travel times of large vehicles or trucks.

The Norwegian WIM system is currently being operated in real-time in an isolated fashion. Implementation of the WIM and travel time measuring system is expected in the southern parts of Norway in 1997. The NPRA hopes to be able to use the WIM system to overcome some privacy issues related to the tracking of AVI-tagged vehicles.



Source: adapted from reference (27).

Figure 6-4. Comparison of Travel Times Collected Using Norwegian AVI (Q-Free) and WIM (Bilfunn) Systems

6.2.4 Video

Video cameras are commonly used for a number of ITS applications, including incident detection and verification, sampling of traffic parameters like volume and spot speed, and monitoring traffic conditions. Several research efforts are trying to apply video cameras in the measurement of wide area traffic parameters like link travel time.

Early fundamental research examined the feasibility of capturing images of a moving vehicle, then segmenting and extracting relevant vehicle features for matching between several camera locations (28). The researchers used several steps in matching vehicle images:

- detection of moving objects: uses moving image analysis tools to detect the location of vehicle movement;

- color segmentation: divides the vehicle image into homogenous regions, or segments, using color information from the image;

- vehicle image extraction: extracts the moving vehicle from the background image based on the colorized segments; and

- matching features of individual vehicles: compute a matching score that quantifies the likelihood of a correct vehicle match.

Like other signature matching techniques, the researchers compute a match score that quantifies the likelihood of a correct match, then apply a logic algorithm to eliminate unlikely matches. In limited field tests of these techniques, it was possible to detect moving vehicles and identify unique segments of the vehicle, such as the hood, trunk, or wheels. The researchers proposed several refinements to the matching algorithms that could improve the accuracy of the technique. They also noted that multi-lane highways or congested traffic offered additional challenges because of several moving vehicles within the video camera field-of-view.

Several vendors claim they have developed a camera and machine vision system that is capable of tracking vehicles throughout the entire camera field-of-view (typically several hundred meters) (29) or calculating “wide area” travel times (30). The systems have reported capabilities of being able to “track” or correlate vehicles between several different camera locations and provide an estimated link travel time. Although no details are given on the matching algorithms, it is presumed that travel times are estimated by correlating distinguishable vehicle features between camera locations.

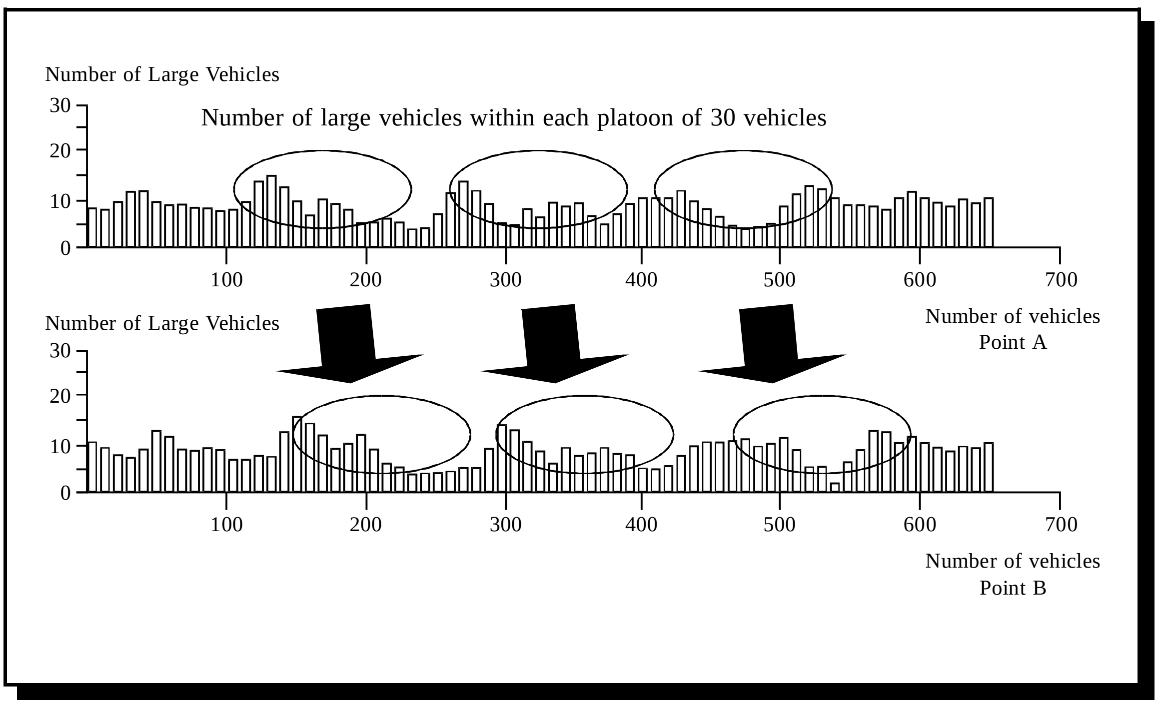
Field tests have been performed to validate point-based traffic parameters like volume and spot speed. The results of these tests have generally been comparable to other point detection devices. No documentation on the reported wide-area tracking and vehicle matching capabilities of these systems was found in the literature.

Research being conducted and coordinated by the Jet Propulsion Laboratory, California Institute of Technology, is also looking at matching techniques to measure link travel times and other traffic flow parameters (31). Color recognition technology is being used by the Massachusetts Institute of Technology and Northeastern University to identify and match individual vehicles between consecutive video camera locations. Several other commercially available video imaging detection systems will be tested and evaluated for their potential to measure and/or estimate link travel times.

6.3 Platoon Matching

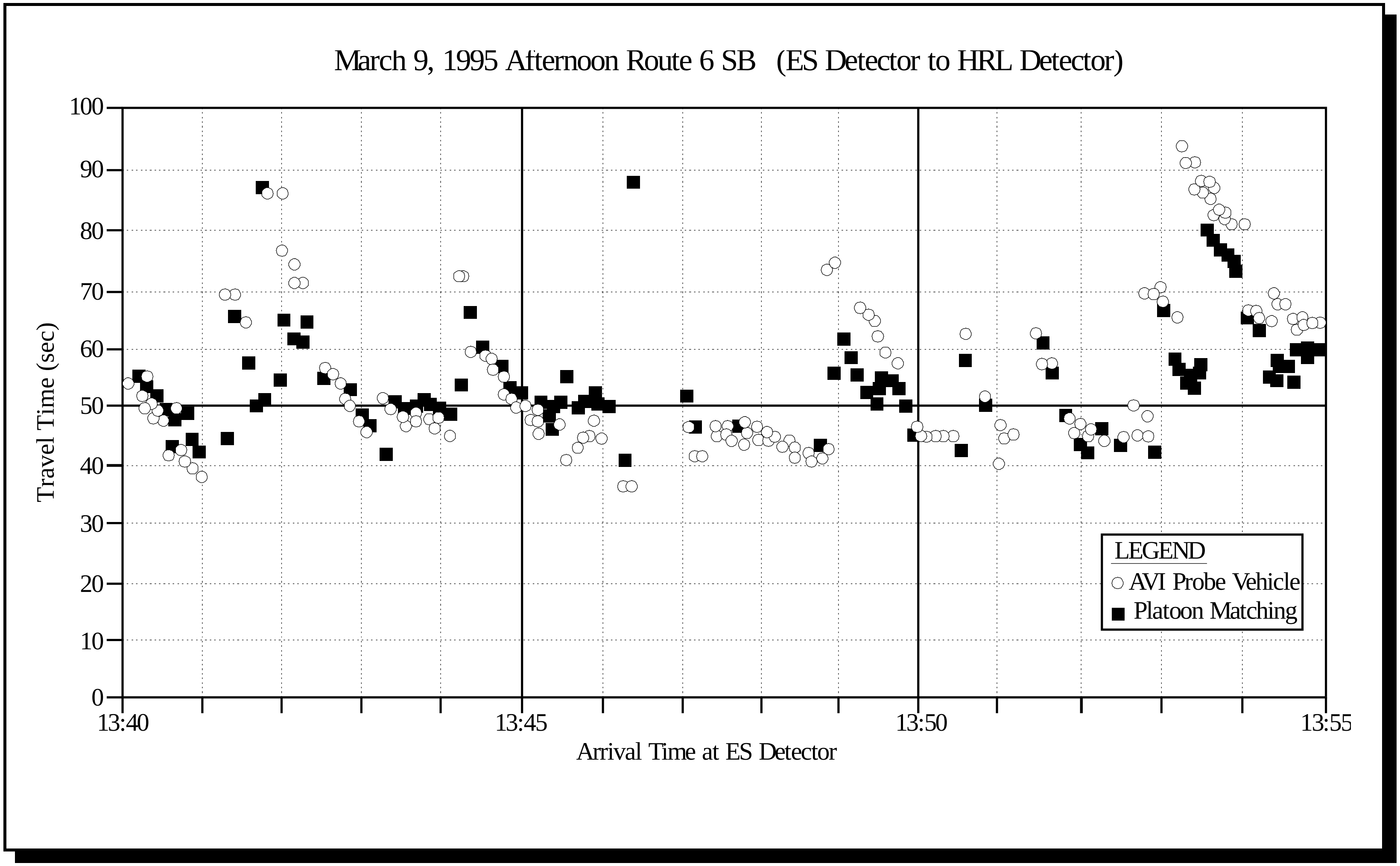
Platoon matching is similar to vehicle signature matching in that it relies on identifying, extracting, and matching unique features between two consecutive roadway locations. The underlying concept of platoon matching is based on identifying unique relationships between vehicles, whereas vehicle signature matching relies on the specific characteristics of a single vehicle or a sequence of vehicles.

Japanese researchers have conducted tests of a platoon matching system that utilizes ultrasonic traffic detectors (32). The ratio of large vehicles within a platoon was the characteristic used to estimate link travel times between ultrasonic detectors. The system algorithm selects a platoon of 30 vehicles and records the number of large vehicles within that platoon (using ultrasonic detector data). The algorithm then attempts to match the histogram of the large vehicles in the platoon between consecutive detector locations (Figure 6-5). Limited field testing on a major arterial street indicated that the matching algorithm had the greatest error (± 10 percent of AVI probe measured travel times) in free-flow traffic conditions (Figure 6-6), where platoons were less stable and vehicles had the ability to maneuver. The platoon matching algorithms did perform better in more congested traffic conditions (Figure 6-7), with an error rate of about ± 5 percent of AVI probe measured travel times.



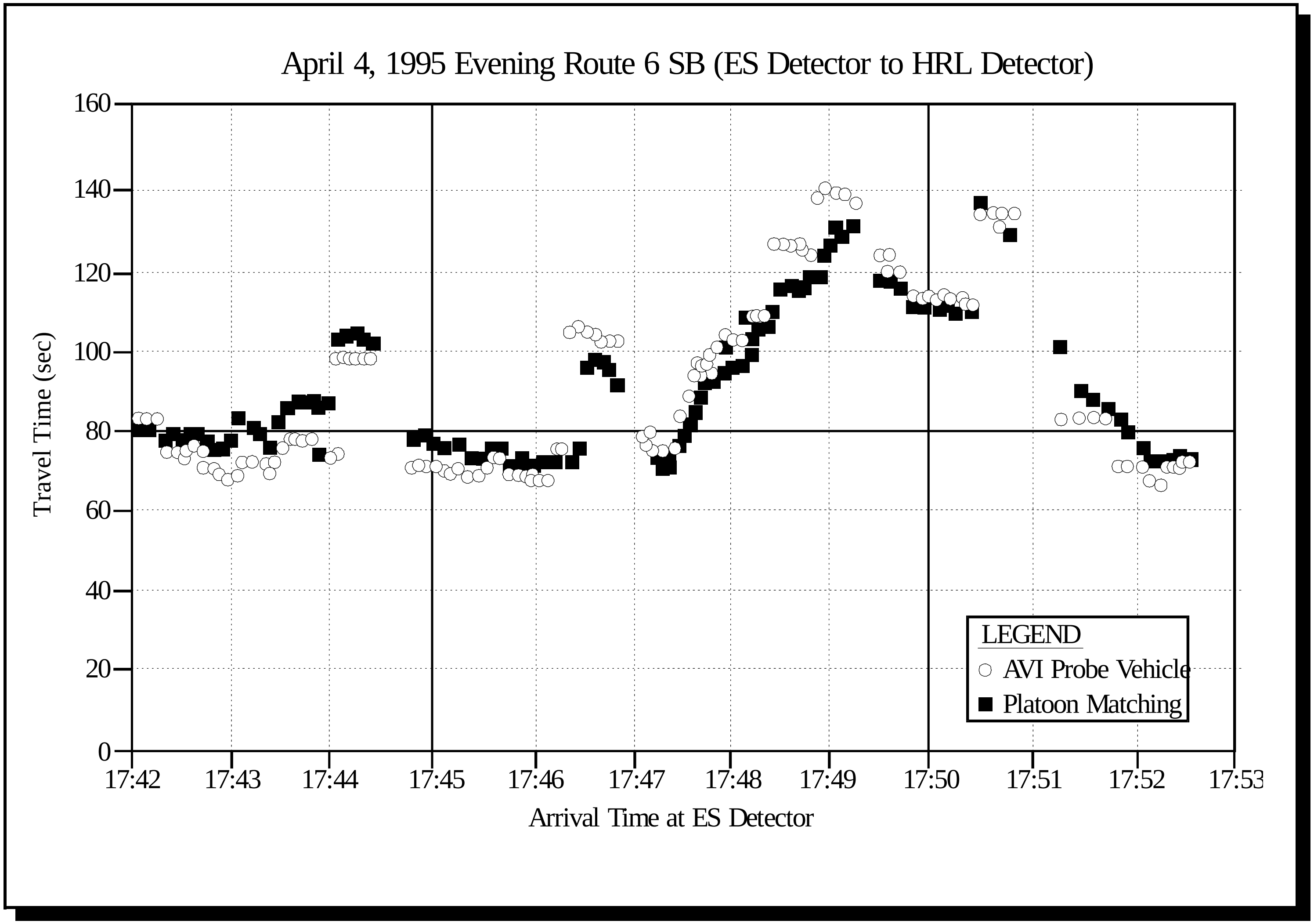
Source: adapted from reference (32).

Figure 6-5. Platoon Matching using the Ratio of Large Vehicles



Source: adapted from reference (32).

Figure 6-6. Comparison of Travel Times from Platoon Matching and AVI Probe Vehicle Systems in Free-Flow Traffic Conditions



Source: adapted from reference (32).

Figure 6-7. Comparison of Travel Times from Platoon Matching and AVI Probe Vehicle Systems in Congested Traffic Conditions

6.4 Aerial Surveys

Several types of aerial surveys have been used or tested to measure traffic flow and other parameters. These surveys can be conducted from fixed wing aircraft, helicopter, observation balloons, or even satellites. Examples of ongoing research in these techniques are discussed below.

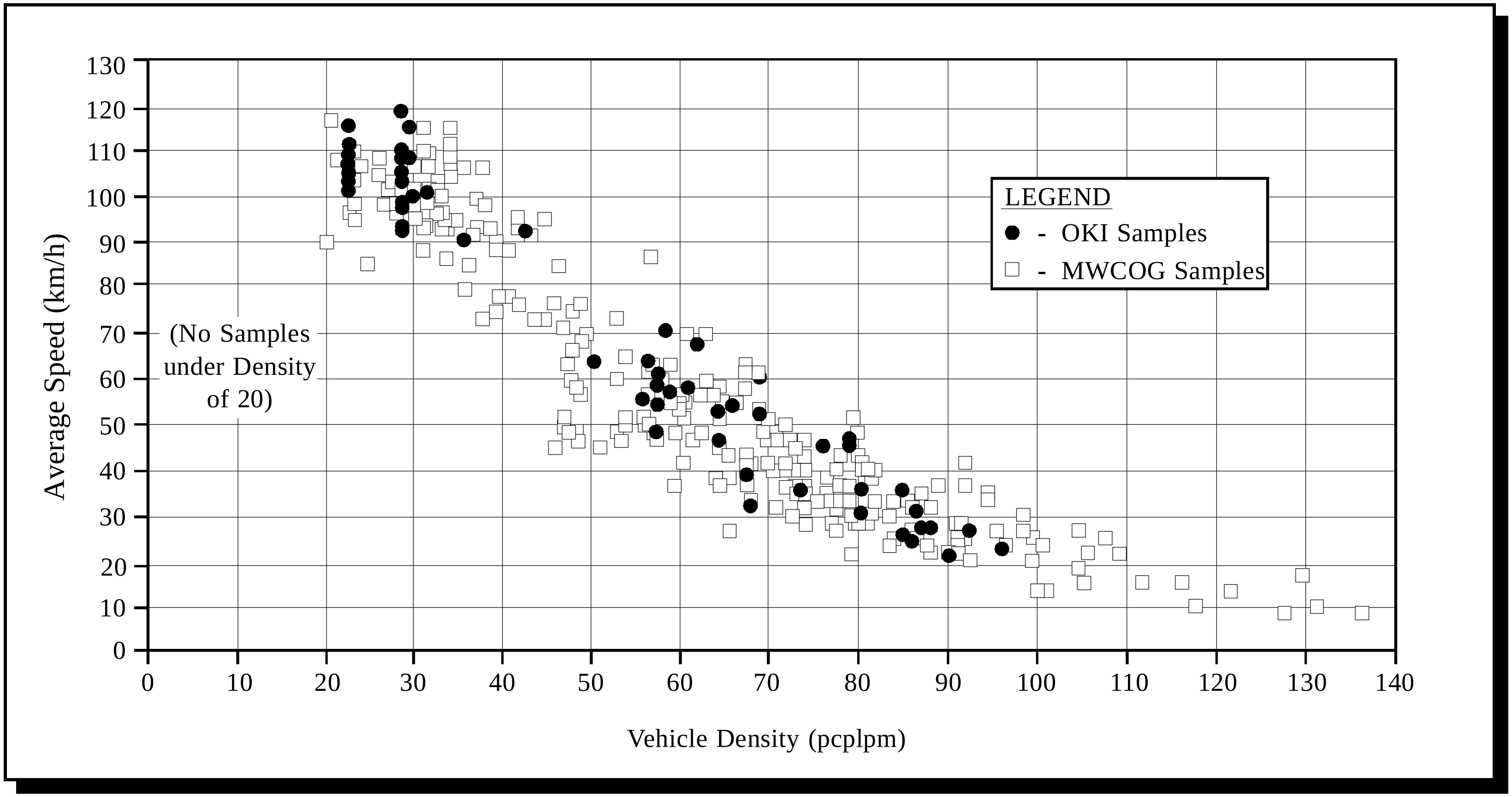
A transportation consultant in Maryland has been using a fixed-wing aircraft (and previously a helicopter) to collect congestion and traffic information as early as 1965 (33,34). In recent studies, the consultants have measured traffic densities and estimated speeds and levels of service on freeways and arterial streets. Traffic densities along freeways are easily obtained by collecting consecutive aerial photographs as the plane flies along the study corridor. Vehicles within a given section can then be counted from the aerial photos, and using known ground distances, traffic densities and corresponding levels of service can be computed. Alternatively, trained observers estimate the density and corresponding level of service without calculating actual vehicle densities.

Several efforts have focused on validating these qualitative level of service ratings collected by trained observers with satisfactory results. One such study compared aerial traffic density and estimated link speeds to average vehicle speeds being collected by test vehicles in the same traffic flow. Figure 6-8 presents the results of this comparison and shows that the aerial survey speeds correspond to vehicle speeds collected on the ground. The consultant has also considered the potential of collecting video from a fixed-wing aircraft for use in tracking vehicles along a particular section but has not pursued any extensive development or testing.

Researchers from the University of Karlsruhe in Germany examined the matching of vehicle images from aircraft in 1987 (35). The system was tested in Austria, with some problems due to curvature and slope of the area. Although the authors claim that "good results" were obtained, they suggested several improvements for the system. No recent mention of this system or subsequent research was found in the literature.

Two papers presented at the 1996 National Traffic Data Acquisition Conference discussed the potential of using observation balloons and satellite imagery for collection of traffic data (36,37). These two efforts focused primarily on collecting traffic volume and density statistics, as well as observations of congested traffic conditions. Although the papers include no mention of link travel times, the potential does exist to perform image matching and correlation. The estimation techniques and matching algorithms would presumably be similar to other methods discussed earlier in this chapter, with the exception that images would be captured from a vantage point high above the roadway.

The Georgia Tech Research Institute is testing a traffic surveillance drone that can relay video images from 8 to 16 km (5 to 10 mi) via a spread spectrum link. Prototypes will cost approximately $60,000 and be capable of 30 minutes of flight at a maximum speed of 30 knots (38,39).



Source: adapted from reference (34).

Figure 6-8. Correlation of Aerial Survey Densities (OKI Samples) to Ground-Collected Speeds (MWCOG Samples)

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