Headway and Speed Data Acquisition Using Video

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Accurate knowledge of vehicle speeds and headways on traffic networks is a fundamental part of transport systems modelling. Video and recently developed automatic data-extraction techniques have the potential to provide a cheap, quick, easy, and accurate method of investigating traffic systems. This paper presents two studies that use video-based equipment to investigate the character of vehicle speeds and headways. Investigation of headways on freeway traffic allows the potential of this technology in a high-speed environment to be determined. Its application to the study of speeds in parking lots enabled its usefulness in low-speed environments to be studied. The data obtained from the video was compared to traditional methods of collecting headway and speed data.

Digital image-processing applications offer the potential to automate a large number of traffic surveys. It is, therefore, not surprising that considerable interest has been directed at developing procedures for vehicle classification and number plate recognition (*1*, *2*). However, there appear to be several obstacles preventing these systems from being used regularly in traffic surveys. Some of these difficulties are the relatively high cost of the systems, problems of accuracy, quantity of data collected, and the time required to process the raw data. Fortunately, systems are being developed that can be used for specialized applications. This paper presents one such system. It is a video-based system that allows vehicle speed and headway data to be extracted.

Video-based techniques offer the means to overcome many of the difficulties of collecting information on speeds and headways. The basic idea is to create a video recording of traffic, then extract data from it. The video approach has a number of advantages including being unobtrusive and requiring a small labor component. Its major advantage is the production of a permanent, complete record of the traffic scene. This may be reanalyzed at any stage, and provides an account of each traffic event observed.

The oft-quoted disadvantage of the video technique is the large amount of time and effort needed for data extraction. The use of an automatic data-extraction (image processing) system can overcome this problem. The video vehicle detection system (VADAS) (*3*) developed by the Australian Road Research Board (ARRB) offers a sophisticated, high-technology system useful in data extraction. VADAS was developed for use in studies of the performance of unsignalized intersections, particularly roundabouts where complex traffic maneuvers take place. It had not been applied to a high-speed environment (such as a freeway) before this study, so there was an excellent opportunity to evaluate the system and suggest modifications to it. This equipment also made it feasible to investigate the relationship between vehicle speeds and location in car parks.

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THE VIDEO SYSTEM

Using film equipment to obtain a permanent record of vehicle movements is not a new concept. However, considerable recent developments have occurred in collecting data using video. In particular, ARRB has developed a trailer-mounted video recording system (*3*). This relatively new equipment has until recently experienced only a limited range of applications. It consists of a gas-operated extendible mast (with video camera attached), a power supply, and other video accessories concealed in an inconspicuous, covered trailer. A range of lenses is available that enable it to view various aspects and areas.

The extraction of the data from the video could be carried out by a human observer, but this is time consuming. A preferable method is to extract the data automatically. A procedure for carrying out this task has been developed by Troutbeck and Dods (*3*). The position of the vehicle is recorded as it passes through a particular point on the screen. These points, termed detection points, are identified in the data collection stage. The movement of a vehicle through these points is determined by a change in the intensity of the image and is recorded on computer tape for further analysis. The basics of VADAS are as follows. The image-processing system relies on the observation that most vehicles have a video illuminance level much greater than that of the road pavement on which they are traveling. The general luminance of the scene is monitored by locating a reference point just off the carriageway. Thus, changes in ambient light levels due to cloud cover and the angle of inclination of the sun can be accommodated.

Besides the reference point, VADAS allows the analyst to define up to 16 detection points within the video frame. The illuminance level at each point is then monitored by VADAS, and a change in luminance above a set threshold is taken to mean the passage of a vehicle over that point. The basic steps involved in data extraction using VADAS are the positioning of detection points on the screen and the adjustment of the sensitivity threshold. Once the data have been logged, they can be edited. The output from this process is a computer file of times and detector numbers that can be used in subsequent data analysis. The speeds and headways can be calculated from data on the times when vehicles were detected.

HEADWAY STUDY

A convenient way to describe the inherent variability within a traffic stream is to consider it as a stochastic process and examine the headways between vehicles in a traffic stream. Headways are defined as the time separation between the same point on two successive vehicles in a traffic stream. This definition holds for both single-lane and multilane traffic streams. Statistical distributions can be fitted to represent headways. The reciprocal of mean headway is equal to the mean flow rate.

Headways are perhaps the most important of all traffic variables since a large amount of traffic research and simulation exercises make use of headway models in the analysis of traffic problems. Buckley (*4*) stated that "headways are the building blocks with which the concepts of volume and capacity, and indeed the entire traffic stream are constructed." The ability of traffic models to replicate traffic systems realistically will be enhanced through more efficient and accurate techniques of collecting headway data.

A number of theoretical models of headways exist. Schuhl (*5*) and Buckley (*4*) provided some of the earlier research in this area. The most comprehensive theoretical study of headway distributions was provided by Cowan (*6*), who derived a family of four headway models. The first three members of this family are the negative exponential distribution, the shifted exponential distribution, and the mixed exponential distribution. These three models show increasing levels of sophistication from the simple random traffic model (the negative exponential distribution) through the shifted exponential distribution (which allows for the finite length of vehicles traveling in a single lane by imposing a minimum headway) to M3, which represents traffic as a mixture of free and following vehicles. Cowan fitted the models to data collected in a single lane on an arterial road. He concluded that the M3 model (and the fourth member of the headway model family, M4) could provide a reasonable description of traffic flow.

A number of problems emerge in the application of statistical distributions to traffic headways. There are two theoretical issues of importance. First, the models assume that mean flow rate (q), and hence mean headway, are constant over time (i.e., the traffic process is assumed to be stationary). Although this may not be unreasonable for short time periods, it can cause problems when collecting the large data sets needed to estimate the parameters for the theoretical models and to fit the distributions, particularly when using conventional data-collection methods. Second, the headway distribution models also assume that the headways are independent of each other.

Another difficulty is a practical one, of particular relevance to studies of multilane traffic flows. This is the problem of observing and assessing the full set of vehicle headways between lanes and within lanes. It is this difficulty that a video-based data recording method can help to overcome. In the past, most observational studies of headways [e.g., Cowan (*6*)] have concentrated on a single lane of traffic. The usual method of treating multilane traffic is to assume that vehicle arrivals are independently distributed and that a superposition of single-lane headways can be made. The validity of this approach could be questioned if vehicle arrivals are not independent. Miller (*7*) and Mahalel and Hakkert (*8*) found some evidence of correlations between vehicle arrivals in multilane traffic. Such correlations should be expected on arterial roads where there are signalized intersections. There is no clear evidence one way or the other for freeway traffic flows.

Another phenomenon of interest is the distribution of traffic between lanes on a multilane road. The conceptual model is that traffic uses (indeed, under some highway codes, should use) the outside lanes of a carriageway unless overtaking, when vehicles will use the inside (median) lane(s). Under light traffic volumes, this model works satisfactorily. But, as traffic volume increases, this flow regime breaks down. Vehicles in the outside lane that overhaul a slower vehicle in that lane and wish to overtake find increasing difficulties in changing lanes. For instance, Mahalel and Hakkert (*8*) examined traffic flows on a two-lane carriageway in Israel and found that the median lane carried more than 50 percent of the traffic flow for flow rates above 1,150 vph. Chen (*9*) found that the median lane attracted the largest volume of traffic on a three-lane carriageway in Ohio, for total carriageway flows exceeding 4,500 vph. This tendency for increased proportions of total flow to use the faster lanes as flow builds up leads to a greater tendency for bunching in that lane, and perhaps more instability in the traffic flow.

Although the negative exponential distribution has not proven to be a good descriptor of single-lane headways, there is a strong possibility that it could represent multilane traffic flows since headways close to zero are feasible. Buckley (*4*) and Gerlough and Barnes (*10*) both suggested that the negative exponential model could be used for multilane unidirectional traffic flow.

Given these observations, the data collection scheme was designed to include the defined flow regime; traffic volumes in the identified flow regime were spread out over different times of day and different days to account for the known variations in traffic flow levels over hours of the day and days of the week. Spreading the data-collection periods would provide the means to avoid misinterpretations based on fluctuations or deviations from the normal traffic pattern.

Theories of traffic flow and models of traffic system performance require comprehensive, accurate, and unbiased data for their appraisal. Much theoretical work has been directed at the case of uninterrupted flow, in which the performance and behavior of a traffic stream is dictated by the nature of the stream and the interactions between vehicles in the stream, free of outside influences. The traffic situation most closely approximating these conditions is probably freeway traffic. Data recording by conventional means, involving the placement of vehicle detectors on the carriageway, is difficult and impractical for freeway operations. Further, their presence on the roadway could modify driver behavior, producing biased results.

DATA COLLECTION

The primary objectives of the headway study were to examine the use of VADAS for automatic image processing in a high-speed traffic environment, as well as to fit theoretical headway models to freeway traffic data. In a series of experiments performed in 1986, data were collected using video cameras located at particular vantage points, e.g., freeway overpasses and pedestrian bridges on the Mulgrave Freeway in the eastern suburbs of Melbourne. The freeway section was that between the Springvale Road and Wellington Road interchanges (Figure 1). This section has two lanes for each direction of traffic flow. It was selected because of the considerable variations in the level and quality of traffic flow and the presence of the footbridge, which provided a convenient and inconspicuous high point to record the flow. This freeway section represented uninterrupted traffic, with no external influences on the flow.

This survey involved the collection of nine sets of data spanning three separate time periods on each of three days. The first six sets were about 15 min long, while the remaining three sets were about 30 min long. In all, a total of about 3 h of traffic flow was recorded, covering traffic demand from 8 a.m. to 5 p.m. Table 1 shows reference information for the data sets. Only the first six data sets were used in the analysis described in this paper.

The data covered a wide range of medium to high flows. Young et al. (*11*) proposed that different models should be applied to traffic under different flow regimes and that these regimes could be defined in terms of the flow-density diagram for a given road. They proposed three separate regimes: low, medium, and high flows.

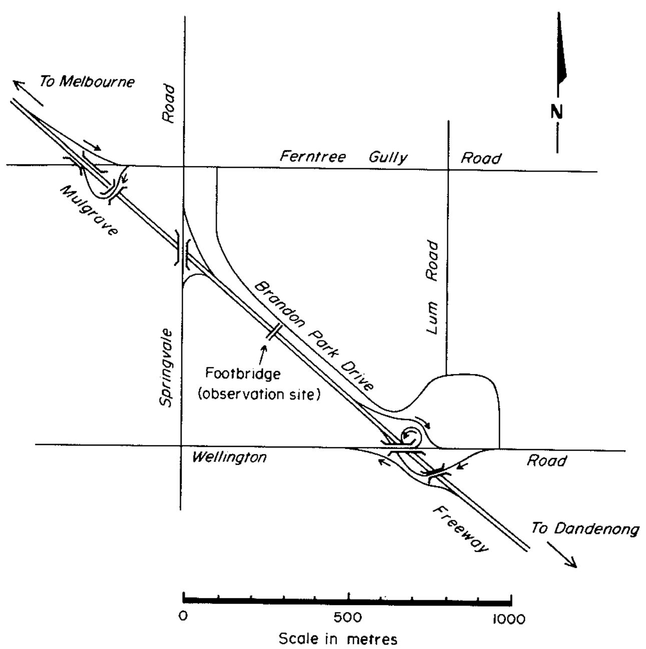

FIGURE 1 Freeway study area.

TABLE 1 DESCRIPTION OF MULGRAVE FREEWAY DATA

Data Set	Date	Time	Direction
1	7/8/86	9:14 a.m.	to city
2	7/8/86	12:00 p.m.	from city
3	7/8/86	3:36 p.m.	from city
4	20/8/86	10:24 a.m.	from city
5	20/8/86	11:46 a.m.	to city
6	20/8/86	2:21 p.m.	to city

DATA EXTRACTION

Two methods were used to extract numerical data from the video recordings. The first was manual extraction, and the second was automatic data extraction using VADAS. The manual method was included to provide a basis for evaluating the automatic procedure.

Manual Analysis

A stopwatch timer was included on the video record to assist in manual data extraction. The recorded tape was played at a quarter speed. An arbitrary mark was identified on the screen (e.g., a corner cube reflector or ceramic lane delineator). Each time a vehicle passed the mark, the time was noted. Different observers watched different lanes. The whole process took up to 90 min for 15 min of video recording. This process required extensive manipulation and was time consuming. The entire processing time (not including the time subsequently spent in data analysis) exceeded 3 hr (6 person-hr) per data set.

VADAS Analysis

Figure 2 shows the configuration of 11 detection points, in two bands across the carriageway, used in the data extraction. The detection points were a fixed distance apart, and the distance corresponded to that between consecutive corner cube reflectors in adjacent groups of the raised pavement markers that form the lane delineators for the freeway. Knowledge of this distance permits speed information to be computed, once the validity of the techniques has been properly established. The present discussion deals solely with headways.

Care was taken when positioning the detection points to ensure that any change in ambient light conditions, e.g., cloud cover or shadows from bridges or foliage, would affect all points equally.

Adjusting the sensitivity threshold for each detection point was vital. The sensitivity was set sufficiently high to detect as many vehicles as possible. This was found to be especially important for those high-speed vehicles with similar luminance to that of the road surface. However, when the sensitivity was too high, some vehicles were detected more than once. This phenomenon was especially pronounced for light-

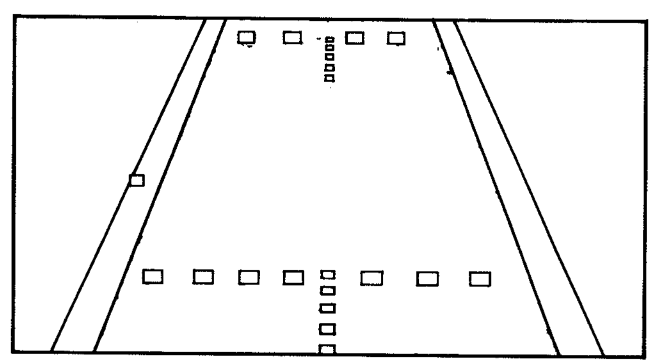

FIGURE 2 Location of VADAS detector points.

colored vehicles, which could trigger the detection point perhaps three times (hood-windscreen-roof). An optimum sensitivity was thus chosen, on the basis that all vehicles would be detected. False points triggered were then detected in the data-editing phase, using a series of logical tests of the time differences between successive events at the one detection point. The method is not perfect. Some false detections may still have been accepted while some genuine detections may have been missed. However, the procedure should be at least as good as manual observations based on viewing the video record at normal speed.

When the video signal at each detection point exceeds the upper and lower limits, an output is produced and read by the VADAS microprocessor (*3*). A preset time delay is used to prevent further detections at the detector. This was set at 70 ms for the freeway study to ensure that all vehicles could be detected. This, however, led to some multiple detections, as indicated above. Some problems were noted in recording motorcycles when these vehicles traveled between the detection points.

The time taken to extract the data from all the video tapes was approximately 5 hr. This involved an initial period of around 4 hr to set up and become proficient with the equipment. The processing of the tapes was completed within 1 hr. Obviously, if data was regularly processed using this technology, the time required for familiarization could be substantially reduced and the data extraction would become quicker. Further time was required for editing the data. The editing was carried out using a series of programs developed by Troutbeck and Dods (*3*). The editing for all the headway data took approximately 1 hr. It was therefore apparent that VADAS offers considerable time savings in headway data collection once users become familiar with the operation of this equipment.

The VADAS headway surveys described here were compared with manual methods. The comparison indicated a VADAS accuracy level of approximately 90 percent, which was generally attributable to the poor quality of the video camera used for the data collection. The accuracy of the VADAS system has also been tested in intersection surveys with results of approximately 95 percent being obtained (*3*).

RESULTS

The data extracted in this study were subjected to three separate analyses: a general view of the traffic flow for each data set and each lane and an examination of lane usage characteristics.

Traffic Flow Characteristics

Comparisons were made of east- and westbound flows for all nine data sets and the range of traffic flow conditions. The results of this comparison are shown in Table 2. This table shows a range of lane flows from 632 vph/lane to 1,476 vph/lane and a range of total flows from 1,420 vph to 2,676 vph. An important result is the consistent observation of small minimum headways (approximately 0.3 to 0.5 sec) for single-lane flows. No distinguishable differences were found between the characteristics of traffic in each flow direction. Figure 3 shows the coefficient of variation of headways plotted against the traffic flow rate, with the observations scattered about the horizontal line representing a unit coefficient of variation. There is a possible suggestion of differences between lane flows, with the outer (slower) lane showing coefficients typically less than unity, while the inner (faster) lane shows coefficients generally exceeding unity. More data are needed to pursue this observation, but it is interesting to reflect that a unit coefficient of variation is one analytical property of the negative exponential distribution. A further comment on Table 2 is the strong indication that trucks were largely confined to the outer lane.

TABLE 2 SUMMARY DATA FOR THE HEADWAY DATA SETS FROM MULGRAVE FREEWAY

	Data Set Number					
Description	1	2	3	4	5	6
Full Carriageway						
Sample size	550	356	668	364	381	375
Flow rate (vph)	2,200	1,424	2,672	1,456	1,524	1,500
Truck percentage	7.8	12.1	5.2	11.2	9.4	8.5
Minimum headway (sec)	0.0	0.0	0.0	0.0	0.0	0.0
Maximum headway (sec)	11.5	17.4	10.1	17.9	22.0	17.8
Outer Lane						
Sample size	245	198	300	204	206	209
Flow rate (vph)	984	796	1,200	820	828	840
Truck percentage	15.9	19.1	9.7	18.5	13.0	13.3
Minimum headway (sec)	0.3	0.2	0.2	0.5	0.3	0.6
Maximum headway (sec)	14.5	20.8	12.0	18.5	22.0	17.8
Median Lane						
Sample size	305	158	368	160	175	166
Flow rate (vph)	1,220	632	1,472	640	700	664
Truck percentage	1.3	3.2	1.6	1.9	5.1	2.4
Minimum headway (sec)	0.3	0.2	0.2	0.3	0.3	0.4
Maximum headway (sec)	18.2	39.5	19.9	41.5	40.0	45.9

Distribution of Lane Flows

Mahalel and Hakkert (*8*) reported Israeli data that showed that a majority of vehicles used the outer lane at low volumes. The reverse occurred at high volumes. This tendency has been observed in other studies from various countries, e.g., Chen (*9*), Lenz and Hotop (*12*), and Rorbech (*13*). A similar tendency was noted in this study. One possible explanation is given below, in terms of bunching tendency. Figure 4 shows the split of traffic between the two lanes of the carriageway. It suggests that equal lane flows occurred at about 1,550 vph. This is consistent with the results of the other studies cited above. Further data are needed to fully test this finding.

Bunching Tendency

An examination of the coefficients of variation in headways (Figure 3) indicates some apparent differences between the patterns of traffic flow in adjacent lanes. In the outer lane, the coefficient was typically less than unity, while it exceeded unity for the median lane. This difference occurred at all levels of traffic flow. Figure 3 shows these results. There was a greater tendency for bunching in the median lane, with a bunching tendency exceeding that of Poisson flow. On the other hand, the vehicles in the outer lane were underdispersed in relation to Poisson arrival patterns. Similar results were reported by Mahalel and Hakkert (*8*). This difference is probably due to the presence of slower-moving vehicles (those with speeds well below the mean speed) in the outer lane. Under medium-to-heavy flows, there are limited opportunities for lane changing and overtaking. To maintain a reasonably constant speed and not be caught behind slow vehicles, drivers prefer to change lanes at the earliest opportunity while still some distance behind the slow vehicle. The long sight distances available on a freeway facilitate this maneuver.

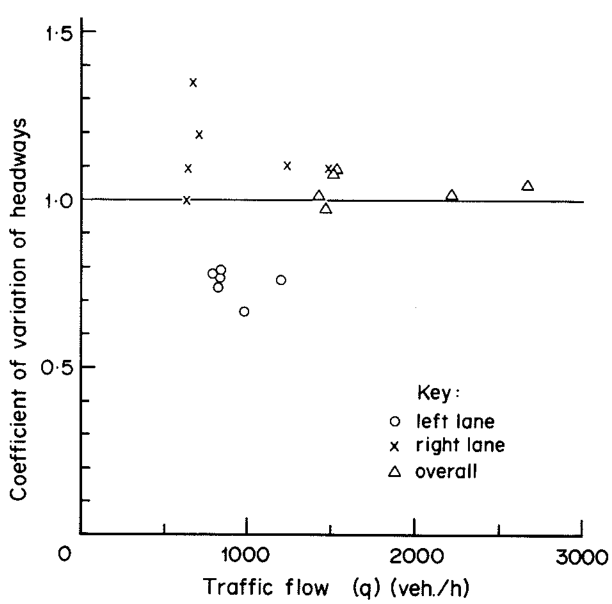

FIGURE 3 Relationship between coefficient of variation and traffic flow.

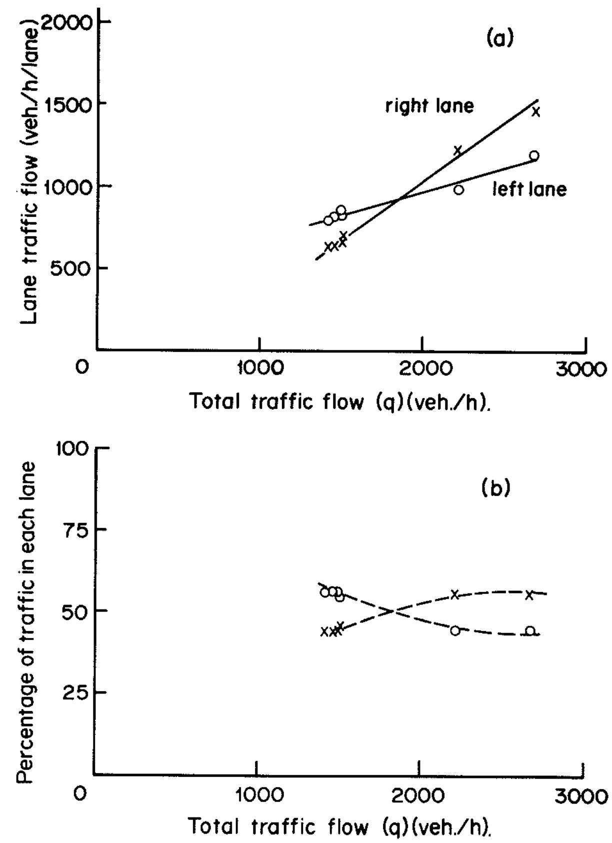

FIGURE 4 Division of traffic lanes.

This hypothesis is supported by the shift in the distribution of vehicles towards the median lane with increasing volume (see Figure 4). At higher volumes, the level of service is lowered to a point where the initiation of overtaking maneuvers becomes difficult. A large proportion of drivers then elect to stay in the median lane to achieve a smoother flow.

Distributions of Headways

Researchers have given considerable attention to headways and suggested many theoretical distributions. The problem with many of these models is that they often require complex iterative procedures to fit them to observed data. Rational subdivision and nonlinear least squares techniques have to be used, which are lengthy and at best approximate. As a result, only the common univariate models offered in the TRANSTAT distribution fitting package (*14*) were fitted to the headway data. The effort to estimate the additional parameters of mixed models is justified only if they substantially improve the fit to the data. Distribution fitting using TRANSTAT suggested that the exponential model best represented headways for the combined lanes, while the log-normal model best represented the individual lanes. Since a large number of the headway models fitted the data to a satisfactory degree, the mixed models, other than M3, were not investigated.

These general conclusions were not valid for all data sets, indicating that further work is required to investigate the conditions under which the different models could apply.

SPEED STUDY

The primary objectives of the speed study were to determine mean desired circulation speeds on parking circulators and aisles, as well as comparing two methods of speed data collection: radar and video.

Initial understanding of the specific nature of the data to be collected is an important component of any traffic survey (*15*). This is crucial in speed studies since the term "vehicle speed" is by no means a simple concept. It can refer to space mean speeds, design speeds, safe driving speeds, desired (free speeds), or spot speeds. In this study, several speed-related concepts are discussed. Space mean speed is the average speed of vehicles taken over a length of road at a particular point in time, whereas time mean speed is the average speed of vehicles taken at a particular point in space over a period of time.

The desired speed is the speed a driver will adopt if not hindered by other vehicles. It is often referred to as the free speed and is measured by observing the speeds of isolated vehicles and vehicles at the head of a platoon of vehicles, since vehicles in a platoon cannot adopt their desired speed. Methods to overcome bias in measuring free speeds are described by Taylor and Young (*15*). The definition of desired speed provides the impression that drivers are not hindered in their desire to travel at a particular speed. Drivers in parking lots are constrained by the geometric characteristics of the roads and their major purpose (looking for a parking space, leaving the parking lot, etc.). Therefore, they may never reach their desired speed. Possibly a more appropriate term would be "desired circulation speed." The desired circulation speed is the speed a driver will adopt when moving through the parking system. Vehicles that are not hindered can adopt this speed.

The spot speed is the speed of a vehicle at a particular point along a road. This speed can be measured using a radar gun. The interval speed is the speed over a small length (or interval) of road and can be determined using video-based equipment. It is calculated by dividing the time taken to traverse a small length of road by the length of the road. The average spot (interval) speed is the arithmetic mean of the individual vehicle speed measurements. Since the speed measurements in this study are taken at a spot (or interval), the average speed is a measure of the space mean speed. However, since the characteristics of the roads considered limit overtaking, the average spot speed is also a reliable estimate of the time mean speed.

A REVIEW OF GENERAL SPEED STUDIES

Knowledge of the speed of vehicles in parking lots is important in ascertaining the safety of the system and the effects of speed-control devices, and as an input into parking lot design models (*11*). Little attention has been focused on this parameter. This is difficult to understand given the considerable conflict between pedestrians and vehicles in parking lots, which is exacerbated by the relative speeds of vehicles and pedestrians. No reported studies of vehicle speeds in parking lots could be found. It is, however, informative to review studies of speed on other parts of the transport network (*16*).

In summary, considerable effort has been directed at the determination of vehicle speeds on urban arterial roads, rural roads (*17*), and residential streets (*18*). The impact of road design standards has also been investigated (*19*). All these studies used radar to collect the data.

SPEEDS IN PARKING NETWORKS

As discussed, no speed studies have been directed at vehicle speeds in parking lots. Therefore, before considering the studies presented in this paper, it is necessary to introduce the components of a parking lot and the concept of desired speed as it relates to vehicles in parking systems. Parking road networks can be likened to the urban road network where a hierarchy of roads are defined, each with different functions (*20*). The lowest level of the hierarchy in a car park is the aisle (*A*). It is the area of pavement used by cars to gain access to parking spaces. The upper end of the hierarchy is defined as the circulator (*C*). It is a roadway that provides access to parking aisles from ingress and egress points of the facility. Parking should not be provided on circulator roads.

As mentioned previously, drivers in parking lots are often constrained by other activities (e.g., looking for a parking space or exit). These constraints may not allow drivers to reach a desired speed. Therefore, this paper introduces the concept of circulation and refers to the desired circulation speed in parking lots. In parking lots, many of the roads are short, and a driver may spend all the time accelerating along the road rather than adopting a desired constant speed. The determination of vehicle speeds in parking facilities is complicated by the need to decelerate to park and carry out other maneuvers. The concept of a desired circulation speed may therefore not be appropriate since the vehicles may never reach a steady speed. Thus, the first step in this study was to study the character of speed profiles of vehicles traveling along roads in parking facilities. The determination of the steadiness of the vehicle speeds was studied in both circulators and aisles.

DATA COLLECTION AND EXTRACTION

The site chosen to conduct the data collection was Vermont South Community Shopping Centre, located on Burwood Highway opposite the Australian Road Research Centre. This site was chosen because it provided separate circulators and parking aisles with unimpeded views of at least two aisles from the video camera. The study was carried out on a Friday morning, since this provided high volumes of traffic. In fact, the car park was around 70 to 90 percent full when the readings were taken. The survey was carried out on a day with perfect weather conditions: sunny with light winds. This was advantageous since poor driving conditions may have affected the results.

Data was collected in two parts of the car park (Figure 5): a major circulator (Site 1) and a parking aisle (Site 2). The video recording system enabled changes in speeds along routes to be measured. By contrast, it is difficult to measure vehicle speeds at particular points along routes using a radar gun. Although radar can be used in conjunction with treadle systems to obtain speed profiles (*21*), the video allowed the

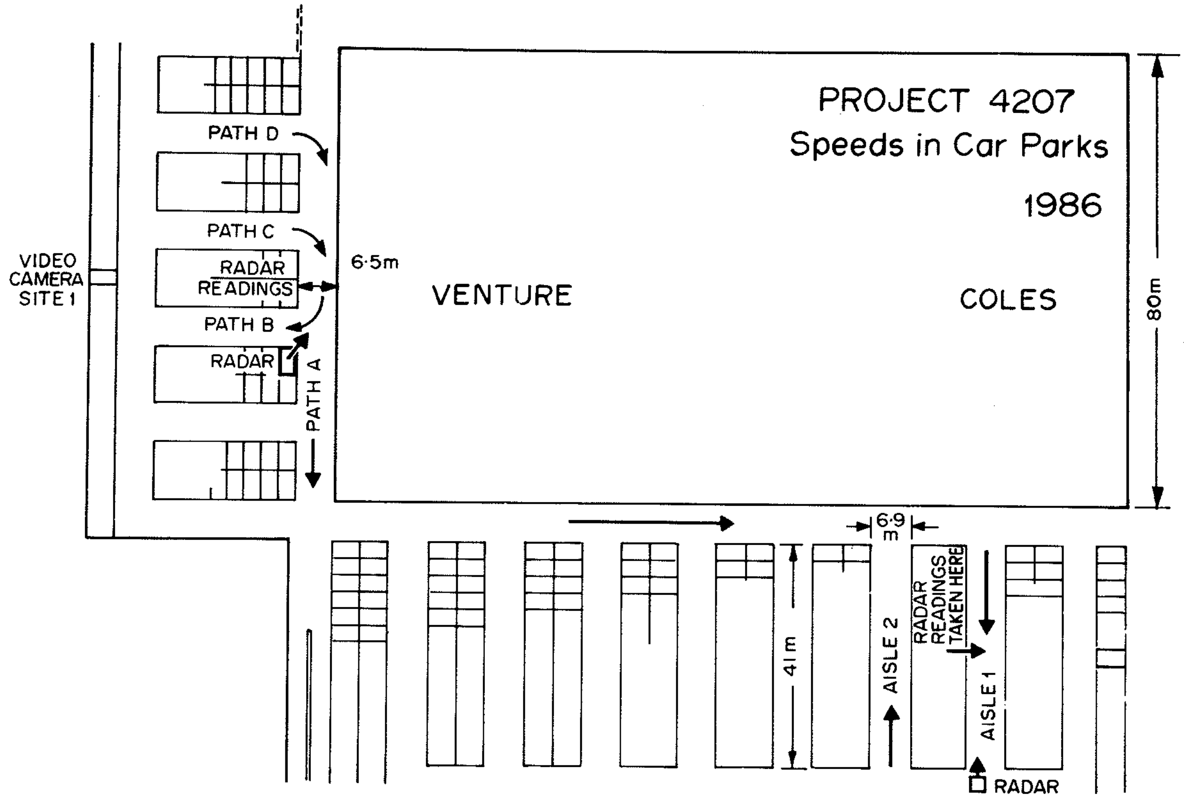

FIGURE 5 Vermont South parking lot layout.

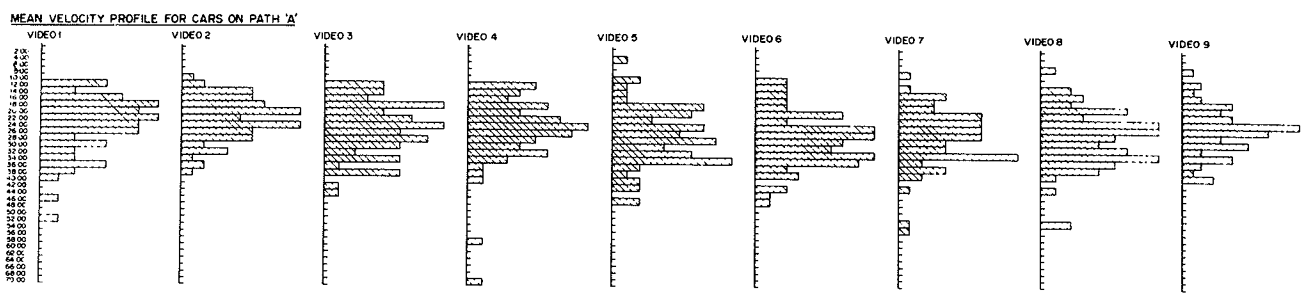

FIGURE 6 Speed profiles for vehicles traveling along circulator (Path A).

flexibility to adjust the location of detectors and to relate vehicle speeds to trip characteristics (e.g., whether or not the vehicle was parking). The trailer housing the video camera was positioned and stabilized perpendicular to the vehicles' movement path. The camera was then focused and raised to the top of the mast (10 m). After the camera had begun recording, the aisles and circulatory roads were marked by witches' hats at 5-m intervals so they could be located when the video tape was processed.

The extraction of the data from the video could be carried out by a human observer, but this is time consuming. A preferable method is to extract the data automatically. VADAS was used to extract the vehicle headways. In this system, the speeds are calculated by measuring the times the recording points are activated and dividing the difference into the distance between detection points. To determine the desired speed, it was assumed that any headway between two cars of less than 5 sec represented car following. In such cases, the second car was rejected.

RESULTS

The vehicles moving along the circulators were divided into four groups (Figure 5): those vehicles that did not enter an aisle (Path A), those that entered Aisle 3 (Path B), and those that exited Aisles 1 (Path C) and 2 (Path D).

The speed profiles of the vehicles that did not enter an aisle (Path A) are shown in Figure 6. The average (space) speeds of these vehicles fluctuated between 21.2 km/hr and 25.2 km/hr. The general evenness of the speed profiles indicates that the drivers do in fact have a desired circulation or cruising speed, which fluctuates at about 23.2 km/hr. The vehicles in this lane are moving toward another part of the parking lot or are using the parking lot as an alternate route to bypass the adjacent arterial road system. The speed profiles for those vehicles exiting an aisle (Paths C and D) showed that there is a pattern of steady acceleration toward the desired speed similar to those of vehicles moving through the system (*16*).

Vehicle speeds in aisles varied considerably. There are two types of vehicles that use aisles: those that find a parking space and those that are looking for a space. Vehicles of the first type slow down as they approach the parking space (Figure 7). Vehicles of the second type travel along the aisle looking for a parking space or leave the parking lot (Figure 8). A comparison of the speed profiles for both parking aisles showed that there is a slight difference in both the shape of the speed distribution and the mean velocity for each aisle. This could be due to a number of aisle characteristics, including differences in the grades between these aisles and differences in the proportions of the stalls that were used in each aisle.

An important point to establish in the interpretation of speed profiles is whether or not the driver reaches the desired circulation speed. By looking at the evenness of the profiles, it is reasonable to conclude that desired speeds are reached.

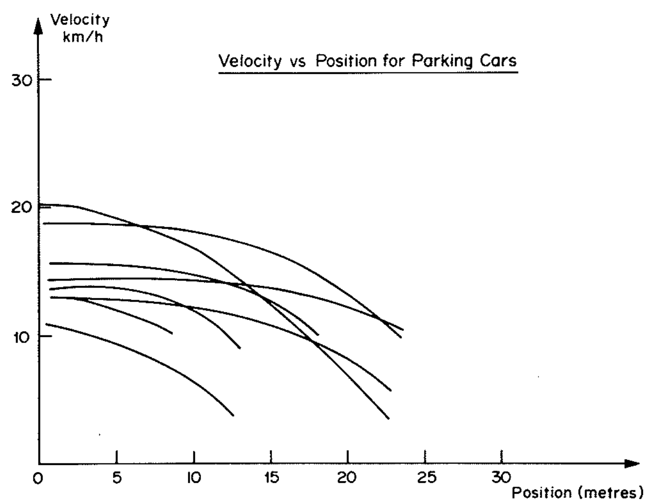

FIGURE 7 Speed profiles for vehicles parking in aisles.

For the aisles, these speeds were around 14 to 15 km/hr; for the circulator, they were around 21 to 25 km/hr.

A difference means test was used to test the difference in speed of vehicles turning from a circulator into an aisle. These two means showed no significant difference, even though they were not on the same road. The mean desired circulation speed of a car turning the corner from a circulator into an aisle was 13 km/hr.

COMPARISON OF RADAR AND VIDEO DATA

Video has a considerable advantage over radar in that it is located perpendicular to the vehicle's motion. Thus, it can record speed readings along a length of road easily, and variations in the speed of the vehicle along the road can be measured. The radar unit is located ahead of the car, which creates problems in locating the position of the vehicle. Further, radar and video measure different speeds. Video measures a speed over a given length of road (space), whereas radar measures it at a particular point (spot). Comparison of the two methods therefore involves the assumption that the speed measured by video is constant over the length chosen. Comparison between the two approaches was required, therefore, to determine if they produced similar results.

Data Recording Technique

Vehicle speeds were also measured with radar using a Kurston H.R. 4 handgun, which had been adjusted to measure low speeds accurately. The radar unit was set up in direct line with the vehicle's path. Two observers were required to collect the speeds of the cars using the radar. One paid particular attention to when the car passed the data collection point and noted the speed at that instance; the other observer recorded the speed of the cars on paper as well as noting the time of occurrence and occasionally noting an identifying characteristic of the car. This enabled the radar measurements to be matched to the same vehicle's speed recorded using the camera.

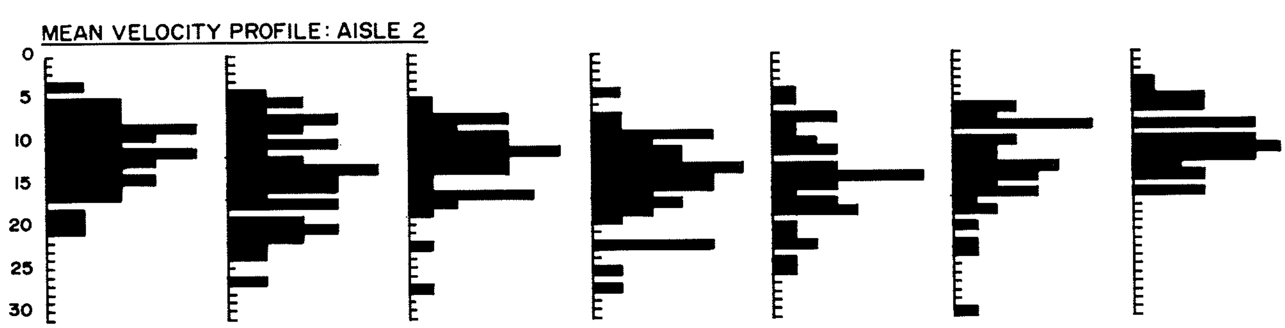

FIGURE 8 Speed profiles for vehicles in aisles.

Data Analysis

Data analysis was carried out by comparing the speeds of the vehicles provided by the radar and the video at the same point. These methods ideally should produce similar results, since they are both measuring the same vehicle speeds. Two tests were conducted to compare the two data sets. One test compared the overall means of each sample, while the other compared the individual data between the two samples.

The comparison of the means is shown in Table 3. The significance of the difference of the means is shown using the probability value. It is the significance level associated with a significant difference in the means. The first probability value indicates the difference in the location of both speed distributions by comparing the sample means. It can be seen that there is little difference at the 1 percent level. The second probability value refers to the paired means test. It indicates whether the difference in the mean differences of individual speeds is not equal to zero. At the 1 percent level this is in fact the case for all but Path B. There is therefore little evidence to support the hypothesis that the individual speeds measured by the two methods are the same. However, the overall mean from the two data sets shows no difference. This is consistent with arterial road speed studies (*3*).

Another comparison of individual speeds was made using regression. If, as assumed, the video and the radar give similar results, the linear regression should give a 45° line with an intercept at the origin. The results of four comparisons are given in Table 4.

The correlation between the two data sets is high, indicating a strong relationship between the radar and the video readings. However, as with the pairs *t*-test, the individual readings are not directly comparable. The video tended to underestimate the low radar speeds and overestimate the high radar speeds. The lack of agreement between the individual readings discussed earlier was therefore confirmed.

Comparison of the radar and the video speed readings indicated that the overall mean speed did not vary but the individual speed readings were not consistent. However, a significant difference in statistical testing may have little practical impact. The magnitude of the differences in the mean speed using the two measuring techniques is 1.17 km/hr with a standard deviation of 3.30. The accuracy of both the radar and the video is approximately 1 km/hr. In the light of the measurement error in the two techniques, a 1.17 km/hr difference is, for practical purposes, small. Due to the small sample sizes of these surveys, further studies would be needed to confirm these initial conclusions.

A comparison of the time taken to collect and extract speeds using video and radar was also undertaken. The radar survey required two people for the duration of the survey (4 hr) to collect the data. The video, once set up, can be left unmanned, and therefore requires only one person for an initial period (approximately 1 hr) to ensure that the trailer and unit are positioned and recording correctly. The data-extraction times for VADAS were similar to that of the headway data (around 6 hr) but would be considerably lower if the equipment was used regularly. The radar data was quickly transcribed into the computer (around 1 hr) due to the small amount of data. It therefore appears that both methods require about the same time to collect and code speed data. The VADAS system would be considerably faster once the users were familiar with the equipment.

AN APPRAISAL OF THE DATA COLLECTION AND ANALYSIS TECHNIQUE

A number of points should be considered when collecting data using the video:

- The position of the sun and its intensity play a significant role in the quality of the recorded image. Glare tends to confuse distant images, and the contrast between the image being observed and the background must be great enough to register a difference when the data is analyzed.
- It may be difficult to determine movements associated with vehicles obscured behind larger vehicles. The positioning of the camera should consider this possibility.
- The area the video can cover is restricted by the lens used in the camera; however, distortion error may result from the curvature of the camera lenses. Consideration should be given to the need to have a site that will allow the video to cover the full study area.
- Parallax errors will also result from the use of the camera since the camera image is two-dimensional while the actual situation is three-dimensional. This two-dimensionality could cause errors in the distance traveled between the two markers on the screen. Corrections must be made.
- Although the extendible mast allows the camera to look down on the traffic flow for near sites, vehicles at distant sites must be viewed somewhere between a top view and a profile. This may cause a problem since the profile of a vehicle is not square and, since vehicles do not always follow the same path, the detector points may be activated by the hood or bonnet, or missed altogether. In such a case, some of the detector points may have to be adjusted to detect the same point on the vehicles consistently.
- Dark cars and motorbikes were very difficult for the data logger to detect because a change in brightness is required to activate the detector. Another effect of dark vehicles is that the blimp may not be activated when the first part of the car passes the blimp.
- Quite often, a car passed through a detector and caused the detector points to flash until the car was totally past. This caused a succession of times to be recorded. In this case, the first time would be considered the correct time.
- The sensitivity of the data logger was continually adjusted by the brightness of the sun. This was a problem in cloudy conditions, for the brightness changed every time the clouds cleared. For the purposes of data logging, it would thus be preferable to collect data on a bright, sunny day. This would also cause more of the darker cars to be detectable due to the sun's reflection off their body panels.

CONCLUSIONS

Video-based data collection systems allow data to be collected that have previously been unavailable using traditional tech-

TABLE 3 COMPARISON OF VIDEO AND RADAR DATA

	Video		Radar		Prob. Value	
Path Type	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Paired Means
A	25.9	7.5	24.7	6.7	0.33	0.0032
B	14.6	4.4	14.5	4.6	0.49	0.4700
C	13.4	3.1	—	—	—	—
D	22.9	5.5	20.3	5.3	0.18	0.0001
Aisles	14.9	4.3	14.4	4.3	0.27	0.0056

TABLE 4 REGRESSION RELATIONSHIPS BETWEEN RADAR AND VIDEO DATA

	Intercept				Slope			
Path Type	Sample Size	Estimate	Standard Error	Sign	Estimate	Standard Error	Sign	Correlation
A	62	3.92	1.34	0.005	0.80	0.05	0.00	0.90
B	14	0.01	1.30	0.99	1.00	0.09	0.99	0.96
D	13	−0.76	1.55	0.63	0.95	0.07	0.25	0.97
Aisles	10	0.01	1.20	0.98	0.95	0.06	0.25	0.95
Total	99	1.58	0.56	0.006	0.88	0.03	0.00	0.95

niques (e.g., headways on multilane freeways and desired circulating speeds in car parks). This technology provides the traffic researcher with an unobtrusive method of observing traffic movements. Video tapes of traffic events contain much more information than manual recorders can collect. The additional information becomes invaluable when modeling complex traffic movements. The flexibility of being able to position the on-screen detector points allows a wide range of traffic parameters to be collected.

The VADAS system offers a reasonably fast method of collecting and extracting traffic survey data. Editing programs are necessary to ensure that the data extracted are accurate. Considerable time savings occur when operators become experienced with this technology. The technology also offers reasonable accuracy compared with traditional techniques, provided weather is appropriate and an adequate vantage point can be found.

REFERENCES

1. M. R. Wigan. Some Investigations of Image Processing Techniques Applied to Road Problems. *Proc., 1st International Conference on the Applications of Advanced Technology in Transportation Engineering*, ASCE, San Diego, Calif., 1989, pp. 424–431.
2. R. Troutbeck and M. R. Wigan. *Workshop on Visual Data Acquisition and Application*. Report ARR 151. Australian Road Research Board, Vermont South, Victoria, 1988.
3. R. Troutbeck and J. Dods. Video-Based Traffic Data Collection. In *Traffic Analysis: New Technology and New Solution* (M. A. P. Taylor and W. Young, eds.), Hargreen Publishing Co., Melbourne, 1988.
4. D. J. Buckley. Road Traffic Headway Distributions. *Proc., 1st ARRB Conf.*, Vol. 1, 1962, pp. 153–183.
5. A. Schuhl. *Poisson and Traffic*. Eno Foundation for Transportation, Saugatuck, Conn., 1955, pp. 59–74.
6. R. J. Cowan. Useful Headway Models. *Transportation Research*, Vol. 9, No. 6, 1975, pp. 371–375.
7. A. J. Miller. An Empirical Model for Multilane Road Traffic Flow. *Transportation Science*, Vol. 4, 1970, pp. 164–186.
8. D. Mahalel and A. S. Hakkert. Traffic Arrival Patterns on a Cross Section of a Multilane Highway. *Transportation Research*, Vol. A 17A, No. 4, 1983, pp.263–270.
9. C-C. Chen. Lane by Lane Speed-Volume Studies on a Six-Lane Freeway. *Proc., 13th ARRB Conf.*, Vol. 13, No. 7, 1986, pp. 1–13.
10. D. L. Gerlough and F. C. Barnes. *Poisson and Other Distributions in Traffic*. Eno Foundation for Transportation, Saugatuck, Conn., 1971.
11. W. Young, M. A. P. Taylor, and P. Gipps. *Microcomputers in Traffic Engineering*. Research Studies Press, Letchworth, 1988.
12. K. H. Lenz and R. Hotop. Some Results Derived From Automatic Traffic Monitoring. *Strassenverkehrstechnik 1*, 1970.
13. J. Rorbech. *The Multilane Traffic Flow Process*. Ph.D. dissertation. Ministry of Public Works, Copenhagen, 1974.
14. R. G. Thompson, M. A. P. Taylor, and W. Young. TRANSTAT: A Microcomputer Program for Fitting Probability Distributions to Traffic Data. *Proc., 14th ARRB Conf.*, 1988 (in press).
15. M. A. P. Taylor and W. Young. *Traffic Analysis: New Technology and New Solutions*. Hargreen Publishing Co., Melbourne, 1988.
16. W. Young. *An Exploratory Study of Speeds in Parking Lots*. Report AIR 466-1. Australian Road Research Board, 1987.
17. M. A. P. Taylor and W. Young. The Distribution of Speeds and Gaps in Traffic Studies. In *Traffic Flow Theory* (P. G. Gipps, ed.), Department of Civil Engineering, Monash University, 1984.
18. M. Armour. Vehicle Speeds in Residential Streets. *Proc., 11th ARRB Conf.*, Vol. 11, No. 5, 1982, pp. 90–205.
19. J. R. McLean. *Two-Lane Road Traffic Flow and Capacity*. Report AIR 359-6. Australian Road Research Board, 1982, chap. 10.
20. *Car Parking Facility: Off-Street Parking*. Standards Association of Australia, AS 2890.1, 1986.
21. M. A. P. Taylor and L. M. Rutherford. Speed Profiles at Slow Points on Residential Streets. *Proc., 13th ARRB Conf.*, Vol. 13, No. 9, 1986, pp. 65–77.

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