A GPS BASED APPROACH FOR THE ANALYSIS OF CAR FOLLOWING BEHAVIOR

Yilmaz Hatipkarasulu[1], Brian Wolshon[2], and Cesar Quiroga[3]

ABSTRACT
The study of car following behavior has been essential to the understanding of driver behavior and its effect on the interaction of vehicles on the highway. Car following studies conducted in the 1950's and 60's formed the foundation of today's microscopic traffic flow analysis techniques and provide the basis for many microscopic traffic simulation programs. The data collection techniques used in these early studies did not, however, allow for the collection of vehicle information under realistic highway conditions. Typically, data were collected under controlled conditions using complicated mechanical or electrical systems that limited the ability to collect and analyze data. Recent developments in the areas of global positioning system (GPS) and geographic information system (GIS) technologies and techniques now make it possible to inexpensively and accurately collect and analyze vehicle position and speed information under actual highway conditions.

The objective of this research study was to develop a GPS based methodology for the collection of car following data under actual highway driving conditions. The methodology involved the application of GPS hardware and software to simultaneously collect speed and location information for two test vehicles. Vehicle position information was then linearly referenced using a GIS. The data were analyzed using both numerical and graphical methods to examine the relationship between the relative positions, speeds, and accelerations of the vehicles. Based on this research a simplified, cost effective methodology for the collection, reduction, and analysis of car following behavior is presented.

Keywords: Car Following, Driver Behavior, GPS, GIS, Data Collection

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OBJECTIVES

The concept of car following theory was originated through studies to analyze and describe the way one vehicle follows another. The basic concept of car following theory is that the actions of a vehicle on the road are governed by the actions of the vehicle immediately preceding it. Flow elements such as vehicle separation, speed, and acceleration for one vehicle are the result of the actions of the lead vehicle. These factors also impact the reaction characteristics, or sensitivity, of following drivers

Researchers have employed a number of different data collection techniques that have resulted in a number of mathematical models that are used to describe car following behavior. Past practices used for the collection of data to study car following behavior have also demonstrated the need for improved data acquisition techniques. Data acquisition using many mechanical systems did not allow vehicles to be driven in actual highway driving conditions. Car following data collected on paper rolls, circular charts, and photograph film made the task of data reduction and analysis very cumbersome. Instrumented vehicles, while able to collect accurate data in different traffic stream conditions, proved to be costly to equip and data collection using this method also involved driver adjustment problems. Distance measuring instruments (DMI's) required frequent calibration. For these reasons a novel approach to the task of data collection for the study of car following behavior was sought.

Recent studies have demonstrated the robustness of global positioning system (GPS) based data collection systems [Guo and Poling, 1995] [Laird, 1996] [Quiroga, 1997]. GPS systems were shown to be relatively inexpensive, simple to operate, portable, and accurate. Based on

the results of prior research the use of GPS for the collection of car following data was suggested. Three primary objectives were addressed within the study. They were to:

1. Explore the feasibility of using GPS technology for the collection of car following data.
2. Develop a GPS based data collection method for the collection of car following information (i.e., speed and location for two separate vehicles)
3. Develop a system for the reduction of raw GPS to use for the analysis of the experimental results. The results of the study are detailed in the following "Approach" and "Application" sections of this paper.

LITERATURE REVIEW

The pioneering studies of car following theory were performed in the 1950's by Pipes and Reushel [May, 1990]. This work was followed by Chandler et al. who defined the first linear car following model in 1958 [Rothery, 1997]. In the Chandler model, the response of the driver in the following vehicle was dependent on the relative speeds of the vehicles.

In 1958, Herman et. al. initiated a series of studies at the General Motors Research Laboratories [Herman and Potts, 1961]. The studies conducted by GM research team resulted in the development of several models that have become the most commonly used of all car following equations. Five different models were developed from this research effort and are now referred to as the GM Car Following Models [May, 1990]. In each of these models, the behavior of the following driver takes the form of:

$$response = func\ (\ sensitivity,\ stimuli\ ) \qquad (1)$$

In this general equation, the response is an acceleration or deceleration of the following vehicle. The primary stimulus is the speed difference between the lead and following

vehicles. A sensitivity factor accounts for differences in the level of response during the various test experiments.

The final model that resulted from the GM research effort is known as the GM Fifth Model and is shown below [May, 1990].

$$\ddot{x}_2(t \,\square\, T) \;\square\; \frac{\text{V3}_{l,m}[\dot{x}_2(t \,\square\, T)]^m}{[x_1(t) \,\square\, x_2(t)]^l}[\dot{x}_1(t) \,\square\, \dot{x}_2(t)] \tag{2}$$

Where,

$x_1(t) =$ distance of the lead vehicle from the starting point at time t

$x_2(t) =$ distance of the following vehicle from the starting point at time t

$\dot{x}_1(t) =$ speed of the lead vehicle at time t

$\dot{x}_2(t) =$ speed of the following vehicle at time t

$\dot{x}_2(t+T) =$ speed of the lead vehicle at time (t+T)

$\ddot{x}_2(t+T) =$ acceleration of the following vehicle at time (t+T)

$T =$ time lag to respond for the driver in the following vehicle

$l, m =$ exponents of distance headway and speed of the following vehicle, and

$\alpha =$ sensitivity factor.

Accompanying the development of theoretical equations to model the behavior of drivers was an effort to experimentally verify the results predicted by the models. Various field experiments were carried out to collect information such as speed, acceleration and positions of leading and following vehicles. Many innovative and novel approaches were developed to conduct these experiments. However, many of these experimental methods lacked the robustness required to conduct experiments under operational conditions.

The development of experimental data collection techniques and equipment took place primarily during two separate time periods. The first set of systems were developed in the early 1950's through the mid 1960's. These first generation systems involved the use of complex electrical and mechanical apparatus developed specifically for the task of car following data collection. Twenty years later, a second generation of data collection systems were developed by applying digital electronic equipment. These systems offered many improvements over the past techniques.

In 1956, Forbes et al. conducted the original studies in the field of driver reaction [Foote, 1964]. The purpose of these studies was to define the reactions of drivers under various operating conditions based on a set of standard changes in the behavior of a lead vehicle. A photographic data collection system was used to record intra-vehicle spacing. A specially equipped camera was mounted on the experiment vehicle, the third in a three-vehicle platoon. Driver responses to stimuli were analyzed by comparing of the photographic information recorded by the cameras at two second time intervals. From these photographs, speeds and spacing were calculated as a function of time. Additional studies were conducted to observe the relationship between the lead vehicle and other vehicles in the platoon.

A partial set of the data collected from this process was fitted to car following models derived by Helly [Rothery, 1997]. However, an in depth analysis of the data was hampered by accuracy problems associated with the vibration of the vehicle, light, and the clarity of the photo records. Forbes also performed follow-up experiments in tunnels in New York City in late 1950's. In these experiments data were collected from a following vehicle whose driver was instructed to duplicate the manners of the first vehicle [Foote, 1964].

The GM experiments performed by Chandler, Herman, Montroll, Potts, Gazis and Roherty in late 1950's and early 1960's were important because they made a significant contribution to the theory and the instrumentation [Gerlough, 1964]. The GM research team developed a cable system for data collection. The system consisted of a cable fastened on a reel between

two vehicles. Measurements of the movement of cable gave the distance between the lead and following vehicles. The speed of each vehicle was measured by a fifth wheel. The data recorded by this apparatus was printed on paper charts by a six-channel oscillograph.

Experiments using the cable system were limited to test tracks and vehicular tunnels because of the mechanical limitations presented by coupling two vehicles [Brackstone, McDonald, and Sultan, 1998]. This diminished the ability of the researchers to collect data in different highway environments. The oscillograph paper charts used in this data collection apparatus also presented difficulties during the data reduction and analysis phases of the study. Often, an analysis was limited to partial segments of the data [Foote, 1964].

A tachograph system was applied by Jones and Potts in the 1960's. In their car following studies, vehicle speed, distance, and engine operation data were recorded by tachographs mounted inside the test vehicles [Foote, 1964]. The data were printed graphically on circular charts. Although the results were better than those of the earlier cable based experiments, similar types of data accuracy and reduction difficulties encountered in the cable system limited the utility of data recorded in this way.

A set of car following experiments was also performed by the Port Authority in New York City in 1959 [Edie and Foote, 1961]. These experiments were conducted in the Holland Tunnel to evaluate platoon behavior and measure road capacity. An eleven-vehicle platoon was used and the motion of the last two vehicles were observed. The Port Authority also participated in the Forbes platoon studies, the Herman experiments, and Helly's car following study which used large scale computers to simulate tunnel traffic. While the experiments were useful, they did little to address the problems encountered in prior experiments.

Very little effort was made in the field of car following studies during the 1970's, although a renewed interest in the field was evident in the 1980's. This renewed interest initiated the development of a new generation of data collection methods. These second generation

techniques took advantage of electronic and computer technologies not available during the 50's and 60's.

Recent car following studies have involved the use of some sophisticated equipment. Instrumented vehicles have been developed to incorporate features like video cameras, radar, sensors, and digital computers. These vehicles were able to collect accurate data in a range of varying traffic stream conditions. However, data collection using these techniques often involved considerable expense.

Distance measuring instruments (DMI) are another form of equipment that have been used for the collection of highway flow data. DMI units have been in traffic analyses studies to record time, speed and distance information [Benz and Ogden, 1996]. However such units require frequent calibration and the synchronization of data from two DMI units is often very difficult. Synchronization is difficult because data is collected from two independent sources without a common point of reference. The use of synchronized data is critical for car following experiments. Information from two separate vehicles has to be "matched" so that cause and effect relationships can be identified.

Lately, systems originally developed for military applications have also been applied to the study of traffic flow. Most notable of these is GPS. GPS is positional and navigational system that allows an efficient way to locate objects on the surface of the earth. It is funded and controlled by US Department of Defense. The GPS system consists of twenty-four satellites; twenty-one navigational satellites and three active spares that circle the earth in twelve hour orbits [Dana, 1997]. Since GPS also incorporates features such as highly accurate time and speed functions it has also been used for a wide variety of purposes in addition to navigation. GPS satellites also rely on atomic clocks for time coordination. This important feature allows GPS data to be synchronized for the study of multiple independent moving objects. Specific applications of GPS technologies to transportation related projects

include traffic congestion monitoring [Quiroga, 1997] and traffic sign inventory studies [Smailus, Bullock and Besly, 1996].

APPROACH

To address the objectives of the study a two-phase approach was developed. The first phase of the study addressed issues related to data collection. Several GPS based systems have been developed for use in various traffic related applications. However, issues associated with cost and accuracy were addressed relative to its application to car following. After it was determined that GPS presented a useful method for car following data acquisition, a test apparatus was implemented and utilized. The second phase of the study involved the development of a methodology to reduce and analyze the raw GPS data. The data reduction and analysis procedure involved the application of GIS software and an interpolation process to evaluate and utilize the GPS data files.

Use Of GPS For Data Collection

The data collection strategy developed in this study was based on the use of commercially available GPS equipment. There are a number of GPS systems on the market. Each of these systems has varying accuracy levels and costs as shown in Table 1.

Positional Acurracy	GPS Equipment Cost (approximately)
10m-100m	$1,000-$4,000
1m-10m	$1,000-$15,000
<1m	$5,000-$20,000

Table 1. Positional Accuracy and Estimated Prices of GPS Equipment [GPS World, 1998]
(note: price overlap in first two categories)

As shown in Figure 1 the data collection equipment used in this study included three primary components in each test vehicle: a GPS receiver, a differential correction unit, and a

notebook computer. The GPS receiver was a Trimble Placer 400 GPS receiver. The differential correction unit was an RDS 3000. The notebook computer was used primarily for data storage. Each set of collection equipment cost approximately $1,500 [Quiroga and Bullock, 1996].
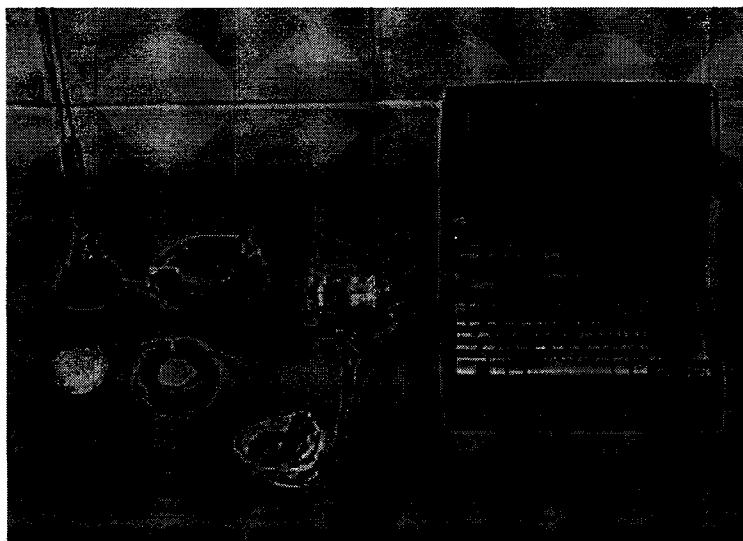

Figure 1. Experimental Data Collection Apparatus

Two of the advantages afforded by the GPS system are size and portability. Its portability allows the data collection system to be installed in virtually any vehicle and to be used under any operational traffic conditions. A vehicle equipped with a GPS receiver does not create any additional complications for the driver of the experimental vehicle. The collection of data does not require any operator interference nor is it distracting because of its size or placement. In a less obtrusive environment, it is expected that driver reactions will be closer to "normal" when compared to experiments conducted under controlled test track conditions.

One of the critical issues involved in any measuring system, including GPS, is accuracy. The accuracy of GPS is affected by several sources including systematic errors purposely introduced into the GPS satellite signals, atmospheric conditions, and the level of precision of

the GPS signal receiver. The levels of precision and accuracy of the experimental system, as well as the various error sources that make up the total GPS error budget, are described below.

A GPS receiver computes its position on the earth's surface based on the distances between itself and a constellation of GPS satellites orbiting the earth. To reduce risks to national security, the Department of Defense introduces an intentional system to lower the accuracy of non-critical (primarily defense oriented) GPS receivers. This system, known as selective availability (SA), prevents non-critical GPS users from knowing exact positions on the earth in real-time. SA purposely taints the satellite signal so that the exact position of the satellites and hence their distances to a receiver can not be determined. Without this information a commercial GPS receiver has an accuracy limitation of approximately 50 – 100 meters.

To overcome the problems caused by selective availability and other error sources such as atmospheric conditions, a system known as differential correction can be used. Differential correction takes advantage of an additional GPS receiver (commonly referred to as a base station) located at a known longitude, latitude, and altitude location. After a series of GPS data points are collected under SA conditions they can be compared to data collected at the base station during the same period. Using information provided by the United States government, the exact positions of the satellites during this period can also be determined to further increase positional data accuracy. Through a system of post-processing, the GPS data collected by the receivers are compared to both the base station location and the true satellite positions to recalculate their true position on the earth. This will produce a very accurate set of data (2-5cm).

Real-time differential corrections can also be performed. To perform real-time differential corrections, a radio receiver is used to collect information transmitted from the known base station. This information is then sent to the GPS receiver and uses to correct the GPS position information "on-the-fly." The resulting data is not as accurate as post-processing

differentially corrected data, but the accuracy achieved via this method were deemed to be acceptable for the purposes of this study. All of the data collected in this study was real-time differentially corrected.

The precision of the experimental data collection apparatus can be described in terms of a positional accuracy. The positional accuracy of this equipment was 2 to 5 meters, spherical error probability (SEP). (Note: SEP means the probability of a GPS positional record being in a sphere of a given radius is fifty percent.)

The experimental equipment also recorded speeds in addition to time and coordinate data. GPS speeds are computed using a pseudorange (distance from satellite to receiver) calculation process. The pseudorange data collection rate is completed at very short time intervals (approximately 1/10 second). The manufacturer of the GPS receiver used for data collection claims a speed accuracy of 0.1 mph (1 sigma) under steady state conditions. [Trimble, 1993] Under this system GPS speeds are essentially instantaneous and independent of position fixes. Thus, they are also more accurate than speeds calculated from a traditional space mean speed equation (i.e., using of two consecutive GPS positions and dividing the distance between them by the time interval.)

Figure 3 shows the primary errors associated with GPS data collection for car following experiments. Under normal circumstances (i.e., the vehicles are moving) the distance headway is usually large enough to avoid an overlap of the positional data error spheres.

Figure 3. GPS Positional Accuracy of Moving Vehicles
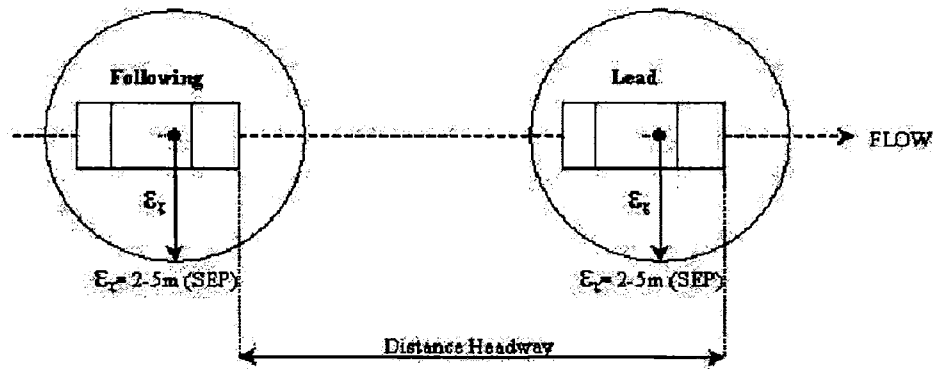
When the vehicles stop, however, the distance headway decreases to a point where the positional data error spheres had the potential to overlap. This scenario is illustrated in Figure 4. Although an error overlap possibility existed in the experiment, such situations were not encountered during the data collection phase.
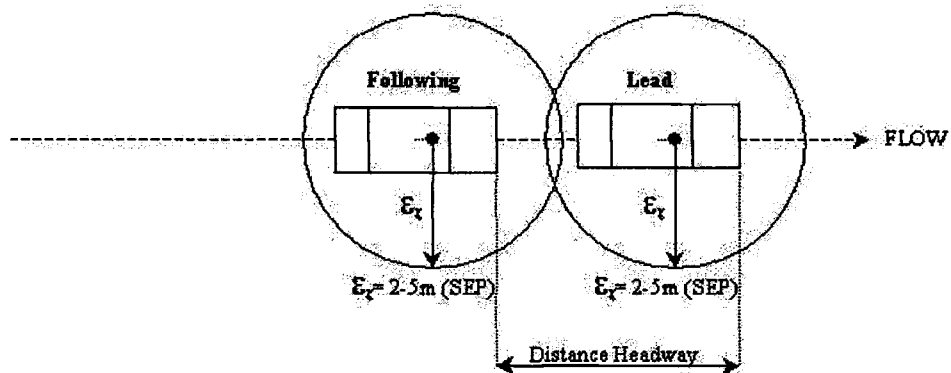

Figure 4. GPS Positional Accuracy of Stopped Vehicles

Data Collection

Next, a system for the collection of car following data was developed. Independent speed and location information for each vehicle was gathered for each vehicle. In addition to the collection of this basic movement information, it was also vital that these data were collected based on a synchronized time basis. Only through the use of a synchronized set of lead and following vehicle data could the speed and location of each vehicle be compared to one another on a cause and effect basis.

Two vehicles were equipped with separate GPS data collection systems. The vehicles drove in succession on a pre-designated two-lane highway route in Baton Rouge, Louisiana. The driver of each vehicle followed normal driving habits. All external stimuli and response resulted from the ambient traffic conditions. However, the primary goal of this study was to test the data collection methodology and not necessarily driver behavior. Therefore, the use of different drivers or multiple runs during different time of day or day of week traffic conditions were not completed.

The test vehicles were driven, one behind the other, for approximately one hour. This resulted in a single independent GPS point data set for each vehicle. Each file contained time stamps in Universal Coordinated Time (UTC), longitudinal and latitudinal coordinates, and instantaneous speed. Individual data points were recorded at a nominal interval of one second, the minimum time interval permitted by the equipment. Actual time intervals varied between 0.5 and 1.5 seconds, as shown in Table 2.

UTC Time (sec)	Latitude (°)	Longitude (°)	Speed (mph)
67469.75	30.411949	-91.190410	0.0
67470.25	30.411947	-91.190412	0.9
67471.25	30.411943	-91.190421	1.2
67472.00	30.411934	-91.190432	4.8
67472.75	30.411919	-91.190476	8.0

Table 2. Sample Data Segment

The one-hour data collection period resulted in two computer files containing 6,663 individual data points, each approximately 150 kilobytes in size. Each of these files was reduced and analyzed using a computer processing method developed specifically for this study.

Data Reduction Process

Next, a procedure for data reduction was developed. The reduction procedure involved two steps, including data filtering and linear referencing. The filtering process was used to remove extraneous or unusable data. The linear referencing was used to provide a cumulative linear distance value to each GPS point. After all of the data were linearly referenced, vehicle position and speed data could be compared using numerical and graphical methods.

The data collected during the experiment contained GPS data points for short time periods when neither vehicle was moving. These segments occurred at stop and signal controlled intersections. In the analysis of car following behavior such data are of little value, so a procedure was created to remove them from the data pool. To analyze the characteristics of each vehicle while it was in motion (i.e., between stops) the two overall data files were segmented into smaller data subsets. A typical data subset started when the lead vehicle initially began its movement and ended when the following vehicle came to a stop at the next stop location. Zero speed data points were removed by searching for the first and last zero speed points in each subset. Figure 5 shows a graphical example of an overall data stream containing a typical car following segment for a lead and following vehicle.
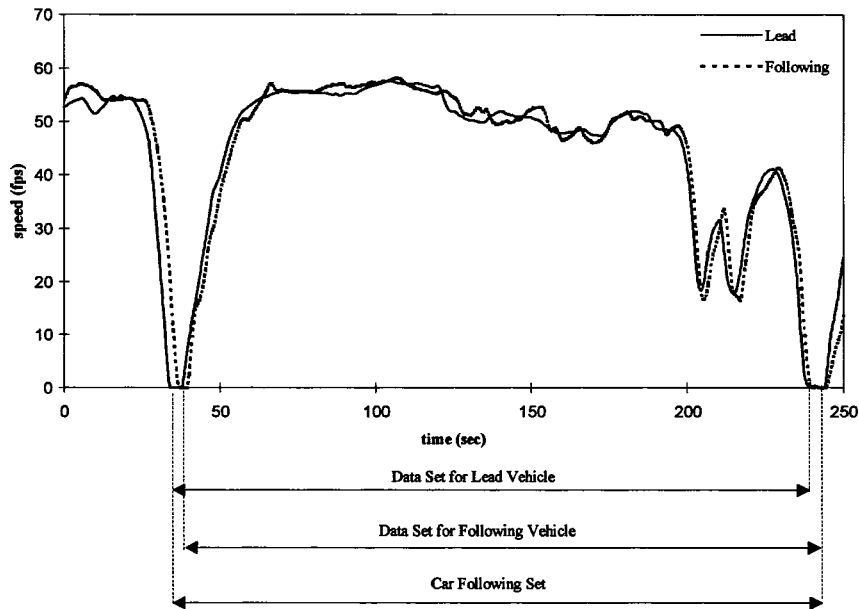
Figure 5. Reduction of Data Sets and Car Following Sets

Finally, to ensure consistency between lead and following vehicle data files, the lead and following vehicle data subsets were matched. The matching process ensured a synchronized relationship between the actions and reactions of the lead and following vehicles. These final matched and reduced data sets were referred to as "car following sets." A car following set included synchronized sets differentially corrected GPS data for lead and following vehicles while in motion.

After the data files were reduced into usable sub-data sets, the task of reducing the raw GPS points into usable information was completed. This was completed through a process of linear referencing. First, zero speed points were used to define the start and end points of the route. Next, distances from the start point of the route of the each GPS point were calculated. For this calculation, each GPS point was mapped to the closest link. Figure 6 shows a sample

segment of data showing the linear referencing of GPS points to a link. In the study, TransCAD was used to facilitate the task of linear referencing.

FLOW
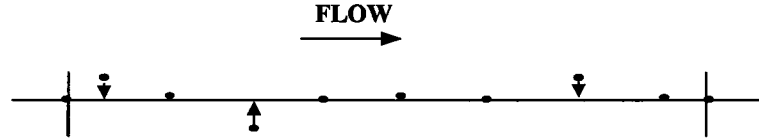
Figure 6. Linear Referencing of GPS Points

In addtion to time stamps and coordinates, vehicle speeds were also collected by the GPS equipment. As a result speed could also be used to provide a data quality control to the linear referencing process. Using equation (3), the cumulative linear distance for each GPS point can also be calculated by using speed and time data, where Δt is the time interval between two GPS points.

$$x(t) = x(t - \Delta t) + \frac{x(t - \Delta t) + x(t)}{2} * \Delta t \tag{3}$$

The criterion used for the control and adjustment process was that the difference between the distance calculated by linear referencing and the reference distance (calculated by Equation (3)) should not be greater than two meters. If the difference was greater than two meters, the reference distance was used as the distance value. In this calculation, the distance information calculated by linear referencing process for the first point of the data set was assumed to be true. Table 5 illustrates how the control and adjustment of cumulative linear distances was done.

Time	Speed	Linear Distance (ft)		
(sec)	(fps)	TransCAD	Speed*Δt	Adjusted
67471.75	0.00000	1.58400	1.58400	1.58400
67472.75	2.64000	8.03733	2.90400	8.03733
67475.25	9.38667	24.17067	17.93733	17.93733
67476.25	13.34667	30.62400	29.30400	30.62400
67476.75	13.78667	37.48800	36.08733	37.48800
67478.25	16.72000	44.35200	58.96733	58.96733

Table 5. Control and Adjustment of Linear Distances for a Sample Data

Once the linearly referenced data had been adjusted, the vehicle position data was interpolated. In prior studies it was suggested that the calculations for car following studies should be completed in 0.1 second intervals [Gerlough and Huber, 1975]. Since the time between GPS records was nominally one second, vehicle position data was interpolated at 0.1-second intervals. In this study, all data were interpolated linearly. Interpolation by cubic splines was also attempted. However, the curvature property of the cubic splines resulted in erratic predictions of vehicle movements, including decreasing values of cumulative linear distance.

APPLICATION

To illustrate the experimental methodology, the reduction of a sample set of data is presented in Table 6. The data were collected in Baton Rouge, Louisiana. Figure 7 shows a linear referencing map of GPS data for both lead and following vehicles for the twenty second time segment shown in Table 6.

LEAD VEHICLE						FOLLOWING VEHICLE				
UTC Time	Coordinates		Speed	GPS		UTC Time	Coordinates		Speed	GPS
(sec)	(°)	(°)	(mph)	Status		(sec)	(°)	(°)	(mph)	Status
70418.25	30.4311029	-91.1912206	0.0	3D		70419.75	30.4310481	-91.1912303	0.0	3D
70419.25	30.4311101	-91.1912160	1.2	3D		70420.75	30.4310517	-91.1912268	1.3	3D
70420.25	30.4311166	-91.1912139	2.1	3D		70421.25	30.4310552	-91.1912254	2.7	3D
70421.75	30.4311275	-91.1912100	1.4	3D		70422.25	30.4310652	-91.1912229	2.5	3D
70422.25	30.4311299	-91.1912095	1.0	3D		70423.75	30.4310783	-91.1912208	1.9	3D
70423.75	30.4311356	-91.1912085	1.2	3D		70424.75	30.4310860	-91.1912194	2.0	3D
70424.25	30.4311389	-91.1912079	2.0	3D		70426.25	30.4311044	-91.1912162	4.6	3D
70425.75	30.4311609	-91.1912029	5.4	3D		70426.75	30.4311151	-91.1912141	6.1	3D
70426.25	30.4311735	-91.1911998	7.1	3D		70427.75	30.4311459	-91.1912079	9.4	3D
70427.75	30.4312319	-91.1911853	12.3	3D		70429.25	30.4312085	-91.1911953	10.9	3D
70428.75	30.4312862	-91.1911730	15.0	3D		70429.75	30.4312312	-91.1911907	12.0	3D
70429.75	30.4313505	-91.1911592	17.3	3D		70432.25	30.4313842	-91.1911620	18.8	3D
70430.75	30.4314233	-91.1911414	19.5	3D		70432.75	30.4314230	-91.1911536	20.2	3D
70432.25	30.4315472	-91.1911094	22.2	3D		70435.25	30.4316465	-91.1910963	24.2	3D
70432.75	30.4315921	-91.1910990	23.0	3D		70436.25	30.4317463	-91.1910748	26.0	3D
70433.75	30.4316868	-91.1910798	24.5	3D		70437.25	30.4318540	-91.1910556	27.9	3D
70435.25	30.4318408	-91.1910533	26.7	3D		70437.75	30.4319109	-91.1910469	28.8	3D
70435.75	30.4318949	-91.1910444	27.3	3D		70439.75	30.4321560	-91.1910132	32.0	3D
70436.75	30.4320066	-91.1910263	28.5	3D		70440.75	30.4322865	-91.1909955	32.9	3D
70438.25	30.4321838	-91.1910005	30.3	3D		70441.25	30.4323530	-91.1909861	33.3	3D

Table 6. GPS Data for Lead and Following Vehicles

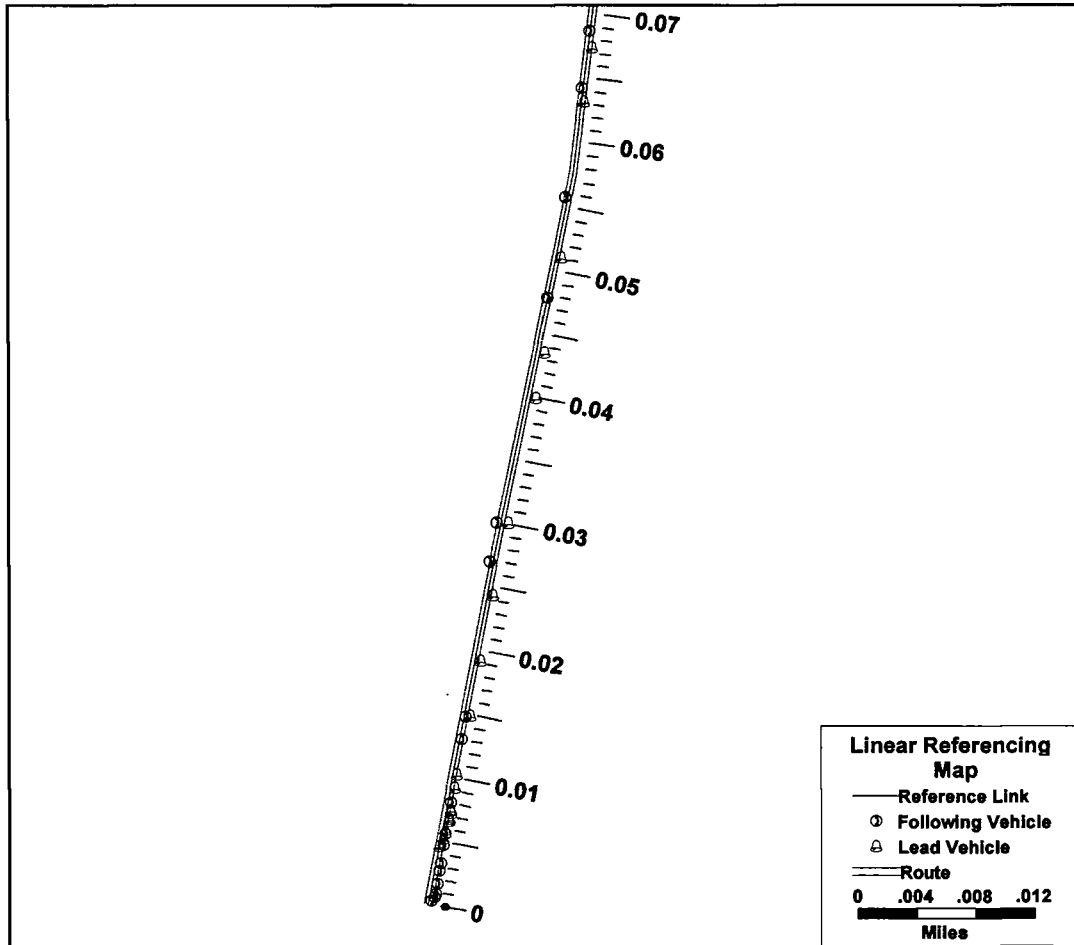**Figure 7.** Linear Referencing Map for Lead and Following Vehicles

To control and adjust the linear referencing process, linear distances were also calculated by using speed and time data. The linear distances were adjusted if the difference between the linearly referenced distance and the distance calculated using speed was greater than two meters. Table 7 shows the control and adjustment process.

LEAD VEHICLE				
UTC Time (sec)	Speed (fps)	Linear Distance (ft)		
		TransCAD	Speed*Δt	Adjusted
70418.25	0.00000	20.5920	20.5920	20.5920
70419.25	1.76000	23.2320	21.4720	23.2320
70420.25	3.08000	25.8720	23.8920	25.8720
70421.75	2.05333	30.0960	27.7420	30.0960
70422.25	1.46667	31.3960	28.6220	31.3960
70423.75	1.76000	32.4360	31.0420	32.4360
70424.25	2.93333	33.7920	32.2153	33.7920
70425.75	7.92000	42.2400	40.3553	42.2400
70426.25	10.41333	53.4300	44.9387	(obscured)
70427.75	18.04000	65.4320	66.2787	65.4320
70428.75	22.00000	89.2320	86.2987	89.2320
70429.75	25.37333	112.9920	109.9853	112.9920
70430.75	28.60000	139.9200	136.9720	139.9200
70432.25	32.56000	186.3840	182.8420	186.3840
70432.75	33.73333	202.7520	199.4153	202.7520
70433.75	35.93333	238.1280	234.2487	238.1280
70435.25	39.16000	295.1520	290.5687	295.1520
70435.75	40.04000	314.6880	310.3687	314.6880
70436.75	41.80000	355.8720	351.2887	355.8720
70438.25	44.44000	421.3440	415.9687	421.3440

FOLLOWING VEHICLE				
UTC Time (sec)	Speed (fps)	Linear Distance (ft)		
		TransCAD	Speed*Δt	Adjusted
70419.75	0.00000	0.0000	0.0000	0.0000
70420.75	1.90667	1.5840	0.9533	1.5840
70421.25	3.96000	3.1680	2.4200	3.1680
70422.25	3.66667	6.8640	6.2333	6.8640
70423.75	2.78667	11.6160	11.0733	11.6160
70424.75	2.93333	14.7840	13.9333	14.7840
70426.25	6.74667	20.5060	21.1933	20.5060
70426.75	8.94667	25.3440	25.1167	25.3440
70427.75	13.78667	36.4320	36.4833	36.4320
70429.25	15.98667	60.1920	58.8133	60.1920
70429.75	17.60000	68.1120	67.2100	68.1120
70432.25	27.57333	137.0320	123.6767	(obscured)
70432.75	29.62667	139.3920	137.9767	139.3920
70435.25	35.49333	222.8160	219.3767	222.8160
70436.25	38.13333	259.7760	256.1900	259.7760
70437.25	40.92000	299.9040	295.7167	299.9040
70437.75	42.24000	320.4960	316.5067	320.4960
70439.75	46.93333	410.7840	405.6800	410.7840
70440.75	48.25333	439.8000	453.2733	(obscured)
70441.25	48.84000	483.1200	477.5467	483.1200

Table 7. Control and Adjustment Process for Lead and Following Vehicles

The adjusted data were then linearly interpolated to 0.1-second time intervals. Table 8 shows the linearly interpolated and adjusted data for both the lead and following vehicles.

	LEAD VEHICLE			FOLLOWING VEHICLE		
Time (sec)	Accel. (ft/sec²)	Speed (fps)	Distance (ft)	Accel. (ft/sec²)	Time (sec)	Distance (ft)
0.00		0.0000	20.5920		0.0000	0.0000
0.10	1.760	0.1760	20.8560	0.000	0.0000	0.0000
0.20	1.760	0.3520	21.1200	0.000	0.0000	0.0000
0.30	1.760	0.5280	21.3840	0.000	0.0000	0.0000
0.40	1.760	0.7040	21.6480	0.000	0.0000	0.0000
0.50	1.760	0.8800	21.9120	0.000	0.0000	0.0000
0.60	1.760	1.0560	22.1760	0.000	0.0000	0.0000
0.70	1.760	1.2320	22.4400	0.000	0.0000	0.0000
0.80	1.760	1.4080	22.7040	0.000	0.0000	0.0000
0.90	1.760	1.5840	22.9680	0.000	0.0000	0.0000
1.00	1.540	1.7600	23.2320	0.000	0.0000	0.0000
1.10	1.320	1.8920	23.4960	0.000	0.0000	0.0000
1.20	1.320	2.0240	23.7600	0.000	0.0000	0.0000
1.30	1.320	2.1560	24.0240	0.000	0.0000	0.0000
1.40	1.320	2.2880	24.2880	0.000	0.0000	0.0000
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
18.60	1.760	41.9760	360.2370	2.787	39.8053	285.4370
18.70	1.760	42.1520	364.6020	2.787	40.0840	289.4500
18.80	1.760	42.3280	368.9660	2.786	40.3627	293.4620
18.90	1.760	42.5040	373.3310	2.787	40.6413	297.4750
19.00	1.760	42.6800	377.6960	2.713	40.9200	301.4880
19.10	1.760	42.8560	382.0610	2.640	41.1840	305.6060
19.20	1.760	43.0320	386.4260	2.640	41.4480	309.7250
19.30	1.760	43.2080	390.7900	2.640	41.7120	313.8430
19.40	1.760	43.3840	395.1550	2.640	41.9760	317.9620
19.50	1.760	43.5600	399.5200	2.494	42.2400	322.0800
19.60	1.760	43.7360	403.8850	2.346	42.4747	326.5940
19.70	1.760	43.9120	408.2500	2.347	42.7093	331.1090
19.80	1.760	44.0880	412.6140	2.347	42.9440	335.6230
19.90	1.760	44.2640	416.9790	2.346	43.1787	340.1380
20.00	1.760	44.4400	421.3440	2.347	43.4133	344.6520

Table 8. Interpolated Data for Lead and Following Vehicles

CONCLUSIONS

The purpose of this study was to develop a GPS based methodology for the collection, processing, and analysis of car following behavior data. The new procedure provides an alternative to past methods used for the study of car following behavior. While it is not perfect, the procedure may be applicable to the completion of similar types of traffic oriented studies.

The approach presented in this paper represents an improvement over prior car following data collection techniques in a number of ways. The data collection methodology has been demonstrated to be effective for use in car following experiments in actual highway conditions. Thus, it permits the collection of speed and vehicle spacing, to be collected outside of test tracks and without simulators. This is significant in that real conditions can now be used to evaluate the results of past car following studies and verify the car following models that form the basis of many microscopic traffic simulation programs.

The experimental system is relatively simple to operate and can be set to collect data free of operator interference, throughout multiple field test trials. The data collection apparatus is also portable, allowing it to be moved from one vehicle to another as needed. Since it is small and portable the collection equipment is less also obtrusive to test drivers. Drivers can be tested with their own vehicles under realistic conditions or in a pre-set "random" fashion without the knowledge of drivers as to when or where the data is actually collected.

The methodology presented in this paper made use of several specific techniques, equipment, and computer software packages. It may also be adjusted to meet the specific needs or accommodate particular equipment capabilities of a user. The flexibility of this general GPS/GIS data collection and analysis process can also be applied to the study of any form of surface travel mode including rail and water transport.

The data reduction and analysis procedures describe a method for relatively quick and accurate data reduction. The entire process can be further refined and accelerated with the application of specific use computer programs written to search data files for the presence extraneous or unusable speed, time interval, or GPS data points.

While the methodology presented in this paper has demonstrated an efficient and accurate procedure to collect and process car following data, it is not perfect. The linear interpolation

procedure developed in the study produced levels of positional accuracy between actual GPS data points that are acceptable for the study of car following behavior. The interpolation procedure incorporated a 0.1 second level of resolution for the data. This was based on the findings of prior research. The study did not, however, address in detail the suitability of level of resolution in the experiments. In addition the study did not address the possible use of other forms of interpolation. Interpolation using cubic splines was attempted. However, cubic spline interpolation resulted in backward movement in the following vehicle in some slow speed instances. Further work to determine an "optimal" procedure for interpolation between data points could increase the level precision in the data reduction procedure.

Other questions associated with the system hardware could also be addressed. The most obvious is the need to evaluate the use of more accurate (and more expensive) GPS data gathering equipment. In theory, the use of more sophisticated equipment would also permit shorter sampling intervals, thereby increasing the resolution of the data and reducing the need for interpolation between wide data gaps.

Future applications for the data collection and processing methodology are numerous. The next logical step of this technique is to apply it to an actual car following study. Specific studies are currently underway to compare the results of data collected under this system to that collected in prior experiments. Another project under development will compare the results of field testing to the car following behavior simulated by microscopic traffic modeling software like CORSIM. Additional areas of application also lie in the study of multiple vehicle platoon behavior as well as the examination of the relationship between different vehicle (car/truck) and driver types (male/female older/younger). It has been suggested that the procedure could also be applied to the study of the behavior of drivers impaired by drugs or alcohol.

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