Modal Activity Under Varying Traffic Conditions on California Freeways: Experimental Design and Data Collection Procedures

by

Troy Young
Institute of Transportation Studies
University of California
Davis, CA 95616
Ph (916) 752-8460; Fax (916) 752-6572
email: tmyoung@ucdavis.edu

Simon Washington
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0355
Ph (404)894-6476; Fax (404) 894-2278
email: simon.washington@ce.gatech.edu

Jan Botha
Department of Civil Engineering
San Jose State University
San Jose, CA 95192-0009
Ph (408) 924-3953; Fax (408) 924-4004
email jbotha@email.sjsu.edu

Daniel Sperling
Institute of Transportation Studies
University of California
Davis, CA 95616
Ph (916) 752-7434; Fax (916) 752-6572
email: dsperling@ucdavis.edu

Presented at the
TRB Transportation and Air Quality Committee
1996 Summer Conference
July 10-12, 1996
Beckman Center, Irvine, CA

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Troy Young
Institute of Transportation Studies, University of California, Davis

Simon Washington
School of Civil and Environmental Engineering, Georgia Tech

Jan Botha
Department of Civil Engineering, San Jose State University

Daniel Sperling
Institute of Transportation Studies, University of California, Davis

ABSTRACT

The current development of emission models is heading in a direction that will create a gap between regional transportation activity models and regional emission models. New generation emission models are being developed to predict emissions as a function of particular modes of vehicle operation. Hence, there is a need to forecast these modes of operation; namely accelerations, decelerations, cruises and idle periods.

This paper describes a project, funded by the California Department of Transportation (Caltrans), that aims to develop a method for collecting data and deriving speed-time profiles that represent 'typical' driving on different facilities and under varying traffic conditions. Such profiles, or driving cycles, will bridge the gap between current travel demand models and emerging *modal* emission models. The findings of this research will help to merge macroscopic outputs from travel demand models (traffic volumes and average speeds) and microscopic-level inputs required by modal emission models.

An initial data collection effort has been completed and the project team is in the process of analyzing data from three corresponding sources: loop detectors, instrumented vehicles, and video footage collected from helicopter overflights. This data collection effort was carried out on the Route 101 freeway in Marin County, San Francisco Bay Area. The loop detector data provide an estimate of facility traffic volumes and speeds (level of service), while instantaneous speeds and accelerations from the instrumented vehicles provide estimates of modal activity distribution by lane, time of day (traffic conditions), and driver characteristics. Video data were collected to estimate and compare speed-time profiles between the instrumented vehicle and surrounding vehicles.

This paper focuses on the data collection procedures, and some of the lessons learned during the exercise.

INTRODUCTION

The MOBILE and EMFAC models determine emission rates as a function of average link or trip speed. These models have been shown to underestimate emissions because they do not explicitly account for much of the critical *modal activity* (accelerations, decelerations, cruises, and idles) that make up the speed-time profiles of individual vehicles in a traffic stream; e.g. (*1*) and (*2*). Work is ongoing to improve the range of real-world modal activity accounted for in driving cycles used to obtain emissions data on which these models are based. However, future versions of MOBILE and EMFAC are still expected to determine emissions as a function of average speed.

The fundamental difficulty with the modeling methodology on which MOBILE and EMFAC are based, lies in the fact that two vehicle trips with the same average speed may have different speed profiles that consist of very different modal activity. Emissions have been shown to be highly dependent on high loads and power episodes, which are in turn highly correlated to modal activity, in particular high acceleration rates and high speeds. Hence, two trips that are similar 'on average' may generate different emissions profiles, to which model outputs are insensitive. This discrepancy, for example, is critical when modeling to determine the environmental impact of traffic control measures and intelligent transportation technologies that may provide flow smoothing benefits. Average speed-based emission models are not able to adequately assess the potential benefits of such transportation projects.

Current emission modeling work is focusing on the development of modal emission models, which explicitly account for the effect of the distribution of various driving modes. Most of this work is being undertaken at UC-Riverside (funded by the NCHRP), Georgia Tech (funded by the US EPA and the FHWA), and Los Alamos National Laboratory (funded by the FHWA and others). The research teams are taking different approaches in their model development, ranging from detailed second-by-second simulation to GIS-based disaggregate approaches.

This paper outlines a research project, funded by the California Department of Transportation, that aims to establish a protocol for developing driving cycles that represent vehicular activity on freeways and arterials under various roadway, traffic, and control conditions. The objectives of the project are presented, followed by a description of a trial data collection conducted on a freeway in the northern San Francisco Bay Area. This paper does not present detailed results of the ongoing data analysis from the field study. Some lessons learned from the data collection experience are used to make recommendations for the remainder of this research effort.

THE RESEARCH PROJECT: AIM AND OBJECTIVES

The project aims to provide a robust methodology for the development of driving cycles that will be related to specific facility types (namely, freeways and arterials) and traffic conditions, or level of service. Such driving cycles will bridge the gap between current travel demand models, such as MINUTP, TRANPLAN, EMME2, SYSTEM II, and QRS, and emerging modal emission models, as briefly described previously. The findings of this research will help to merge macroscopic-level outputs from travel demand models (e.g. traffic volumes and average speeds) with microscopic-level inputs required by modal emission models.

The project team has stated three separate research objectives for the development of driving cycles. The objectives are:

1. to measure representative modal activity on different facilities operating under different levels of service;
2. to adequately estimate traffic conditions (such as link speed, flow, and density), and relate these measures along with roadway and control conditions, to specific modal activity; and
3. to derive a defensible and repeatable methodology for measuring and then characterizing vehicle modal activity on California freeways and arterials.

An important sub-objective has been identified as part of objective 1: to determine whether instrumented vehicles driven in a traffic stream can represent the modal activity of all vehicles in that traffic stream. Previous research has utilized several different methods for obtaining driving pattern data with instrumented vehicles. These approaches range from using a laser range finder and a 'chase car' method (where the instrumented vehicle attempts to reproduce the driving behavior of randomly selected vehicles (*3*)), to using the 'floating car' method (where the instrumented vehicle moves with the general flow of traffic) in just the middle lane of traffic (*4*). However, evidence is lacking to support the assumption that these methods are capable of adequately representing the driving behavior and modal activity of all vehicles in a traffic stream, under a given set of conditions.

There are many factors that have the potential to affect driving patterns and the distribution of modal activity on freeways. These factors can be categorized as roadway conditions, traffic conditions, and control conditions. Roadway conditions include road grade, number of lanes, lane width, spacing of interchanges, presence of HOV lanes, and design speed. Traffic conditions include average speed, flow rate (on freeway and ramps), and proportion of heavy vehicles. Control conditions include posted speed limit and level of speed enforcement. The degree to which each of these factors will influence the distribution of modal activity is as yet unclear.

The remainder of this paper describes the trial data collection effort and briefly mentions some of the analysis methods being explored.

SCOPING STUDY FOR FREEWAY DATA COLLECTION

In May of 1995, a scoping study for freeway data collection was conducted on US 101 in Marin County of the San Francisco Bay Area. The selected freeway segment was between Rowland Boulevard and Manuel Freitas Parkway, a route of approximately six miles in each direction. The purpose of the scoping study was to run a 'mock' data collection effort, enabling the research team to test data collection methodologies and equipment, to test initial research hypotheses, and to more fully understand the complexity and interaction of the many technical issues surrounding the project. In addition, the scoping study allowed the research team to develop and test video coding software, to formulate working hypotheses prior to the full data collection effort, and to modify data collection methodologies and analyses procedures to facilitate attainment of the four research objectives.

This next section of this paper describes the overall data collection effort. This is followed by a more detailed description of the data collection methodologies for loop detector, instrumented vehicle, and video data. The kind of field data obtained are described, and some of the analyses being performed are discussed.

Data Collection Procedures

The data collection effort occurred over two days, with data collected throughout both the peak and off-peak periods. The data collection periods were: 6:20-7:25 am, 8:10-9:25 am, 10:30-11:40 am, 3:35-4:25 pm, and 5:00-6:00 pm on the first day; and 7:25-9:15 am, 11:00 am-12:35 pm, and 4:20-6:00 pm on the second day. There were three primary sources of data: loop detectors, instrumented vehicles, and video images captured from a helicopter. Data from all three sources were collected throughout each of these periods, with loop detector data collected continuously over the two days. Much of the first day was spent adjusting operational procedures and dealing with vehicle instrumentation problems; hence, there were no useful instrumented vehicle data collected for the first three periods of the day. In addition, instrumented vehicle data for some other runs were lost due to instrumentation failure or operator error. The purpose of the loop detectors was to provide traffic information (namely speed, volume, and occupancy) at several known locations along the route. The two instrumented vehicles were used to obtain second-by-second speed profiles for trips along the route in each lane, at various times of day, and under various traffic conditions. The video footage served as an alternative source for the collection of driving pattern data.

More detail of the data collection methodologies for each data source is given in the relevant sections that follow, and a sample of the findings from the study and data analysis are presented.

Loop Detector Data

There were 10 loop detector stations in each direction along the selected route. The loop detector data were recorded in 30 second intervals, with each record containing the following data fields:

- detector station identification;
- date;
- time at the beginning of the period;
- flow rate in vehicles per hour for each lane (lane 1 closest to the median);
- average speed in mph for each lane;
- percent occupancy for each lane.

The data are being aggregated into 5 minute and 15 minute summaries for the purpose of defining the prevailing level of service at specific locations, and for specific periods of the day. The format of the recorded data is such that conversion from one sampling period to another is a difficult and time consuming task.

Unfortunately, loop detectors are often unreliable and the accuracy of speed measurements is questionable. Unreliability can be caused by loop detector failure, detector station controller failure, or communications error between a controller and the central computer. The controllers in use on the freeway segment for this study were capable of measuring the travel time between two detectors to the nearest 1/60 th of a second (time is recorded as the count of units taken at a frequency of 60 Hz). Though this seems like a small interval, when used to calculate the average travel speed over a distance of only 20 feet (center-to-center distance between two detectors in a lane), the potential error is significant. For example, a measurement of twelve 60 Hz units could be due to an actual time duration from just greater than twelve 60 Hz units to just less than thirteen 60 Hz units. This range corresponds to speeds between 101.4 and 109.4 km/h (63 and 68 mph). Fortunately, a reading of twelve 60 Hz units is actually recorded as 105.3 km/h (65.45 mph) and so the possible error is only 3.9 to 4.1 km/h (2.45-2.55 mph), rather than 8 km/h (5 mph). It is unclear whether errors of this magnitude are significant; this largely depends on both the sensitivity of modal activity to average speed (as a parameter to describe the traffic conditions), and the sensitivity of emission rates to variations in modal activity distributions. The first issue is being addressed in this project, and the second issue is being addressed in simultaneous research on modal emission modeling.

Errors of much greater magnitude than the instrumentation errors described above, were not uncommon. The set of loop detector data contained some average speeds as high as 225 km/h (140 mph) for 30 second intervals. This is clearly unrealistic; the highest speeds recorded with the instrumented vehicles were of the order of 137 km/h (85 mph). It is currently unknown whether these errors are due to corruption during data communications, or due to partial failures of a component of the system.

Instrumented Vehicle Data

During each data collection period, two instrumented vehicles were used to collect representative driving pattern data. The vehicle instrumentation recorded the time at the start of the run and the number of pulses received from the transducer every second. The number of pulses was related to distance traveled by a calibration factor, enabling second-by-second speed profiles to be obtained.

Data collection methodology

A staging area was set up near the beginning and end of the study segment, to enable start times to be synchronized and two-way communications to be established. For each run, one vehicle left the staging area, and the other vehicle followed approximately one minute behind. The target vehicle was marked with tape on the roof so that it could be tracked by the helicopter pilot and the camera man as it traveled along the length of the route. The vehicles alternated lead and follow positions so that for half the runs the second vehicle was following the target vehicle and the helicopter, and for the rest of the runs the second vehicle was in front of the target vehicle and unable to see the helicopter. The experiment was designed in this fashion so studies could be conducted to determine whether the presence of the helicopter had a measurable effect on the flow of traffic. The research team felt that the presence of the helicopter had the *potential* to affect the flow of traffic, or the behavior of individual drivers, due to drivers mistaking it for a California Highway Patrol speed enforcement helicopter or simply by looking at it.

For the first day and during the first two periods on the second day, data were collected for south and north bound runs, alternating between the three through lanes (excluding the HOV lane) after each bi-directional pair of runs. The drivers were instructed to drive with the flow of traffic, remaining in the designated lane for the length of the study segment. This is a form of the 'floating car' method, with the added restriction of remaining in a fixed lane. For the third period of the second day, drivers entered a previously designated lane (changed after each pair of southbound and northbound runs) and 'chased' the vehicle immediately in front. The drivers were given the freedom to change lanes, to follow the vehicle being chased, when deemed safe.

The instrumented vehicle data are being analyzed to assess the variation in (1) the mean and standard deviation of speed for each run, and (2) the modal activity distribution for each run due to variations in:

(a) time of day (peak or non-peak);
(b) direction of travel (northbound or southbound);
(c) lane number (1, 2, or 3); and
(d) driver.

For the purpose of these analyses, the peak periods were defined as 7:00-9:00 am and 4:00-6:00 pm. Traffic lanes were numbered as follows: lane 1 is the lane next to the

HOV lane; lane 2 is the lane to the right of lane 1; and lane 3 is the rightmost through lane.

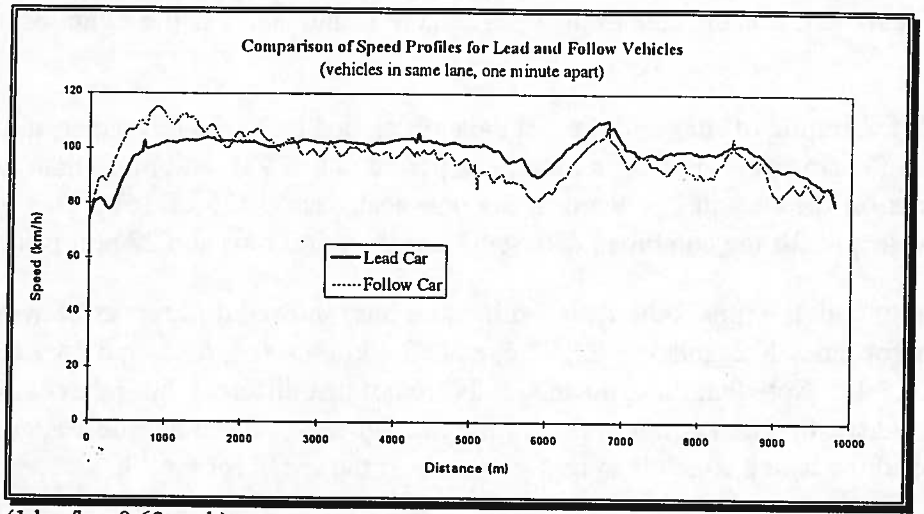
Due to the timing of runs and the lost data mentioned earlier in this paper, the majority of runs on the first day were during the peak period (21 of 23), and more than two thirds of the runs on the second day were in the non-peak period (25 of 36). This gave a more balanced split for the combined data set: 32 peak period runs and 27 non-peak runs.

Combining all the runs (both days, both directions) showed differences between the mean speeds for lanes 1, 2, and 3; 97.2, 92.6, and 88.4 km/h (60.4, 57.5, and 54.9 mph), respectively. Note that these mean speeds are not just different, but reflect an expected characteristic of freeway lanes; that is, the average travel speed of lane 1 is greater than the speed for lane 2 which is in turn greater than the speed for lane 3.

The differences in average speeds across lanes highlights the importance of collecting data from all lanes of the facility. Since traffic conditions can change quickly with time, it would be ideal to operate instrumented vehicles in each lane at the same time, hence capturing the driving behavior in each lane under the same conditions. If the average run speed varies across lanes, it should be expected that the distribution of modal activity will vary across lanes. This is being addressed in current analyses, as mentioned above.

One of the most interesting observations was the significant difference between drivers. As mentioned above, some of the data were collected with two vehicles following, one minute apart. Assuming that the traffic conditions were similar from one minute to the next (trip statistics such as average run speed have been used to show that this is a reasonable assumption), it was found that the driver-to-driver differences were statistically significant for each pair of lead-follow runs. The differences were tested using the non-parametric chi squared test at a 95 per cent confidence level. Figure 1 shows the speed profiles of two such runs and it can be seen that although the overall shape of the profiles is similar, the local variations in speed are greater for the follow car.

This finding has highlighted the need to develop an experimental design that will account for driver-to-driver variation, and help to build on the knowledge of its magnitude and significance. Current research in emission modeling is showing that throttle position, and the micro-accelerations that can result from small changes in throttle position, can significantly impact emissions. In this context, the findings here represent evidence that microscopic driver behavior differences can play a significant role in the production of emissions.



(1 km/h = 0.62 mph)

Figure 1 - Lead and Follow Vehicle Speed Profiles

Video Data

During the preliminary study, several hours of video footage were collected with a camera operated from a helicopter. The helicopter tracked a target vehicle (one of the instrumented vehicles, marked for easier identification) along the length of the route. Runs were performed at different altitudes and with different camera focal lengths to determine the most suitable image size for post-analysis. The aim was to find a balance between capturing driving patterns for as many vehicles as possible and yielding an image clear enough to facilitate accurate analyses.

A substantial amount of emphasis has been placed on development and testing of a video analysis system to obtain individual speed-time profiles from the video footage collected in the preliminary study, and for future data collection efforts. The video analysis system is comprised of an IBM compatible PC installed with a high quality video card and frame grabber board, a time-base corrector, a video cassette recorder, and a video monitor.

The analysis system operates by digitizing the video frames so that distance measurements can be made by counting the pixels corresponding to the vehicle movements. A calibration process determines the relationship between the pixels on the screen and the distance on the ground, by using two fixed points with a known distance between them in the video image. At the beginning of a time increment, the position of a vehicle relative to a fixed point is established. Then the video is advanced for a period of time (e.g. one second, to obtain second-by-second speed profiles) and the relative position of the vehicle is measured again. It is necessary to re-calibrate the ‘ruler’ at each measurement interval to account for changes in altitude of the helicopter and changes in camera focal length. This, along with locating the ends of the ruler accurately between the reference point and the edge of the vehicle, makes the analysis process time consuming and prone to human error.

One of the uses of the video data is to determine whether instrumented vehicles can be driven in such a fashion as to statistically represent modal activity of the traffic stream as a whole. Since the video image captures the target instrumented vehicle and the vehicles surrounding it, speed-time profiles of both the instrumented vehicle and the other vehicles in that portion of the traffic stream can be obtained. Then, the composite modal activity distribution of the vehicles in the traffic stream can be compared with the distribution of modal activity for the instrumented vehicle. This will also help to determine whether the 'floating car' method represents typical driving behavior better than the 'chase car' method.

Further development of the video software is essential to enable the research team to make these important determinations. In particular, the video analysis process needs to be refined to make it more efficient. Currently, although the measurements and calculations are performed by the analysis software, there is still substantial user interaction in the analysis process which needs to be at least partially automated. Enhancements also need to be made to improve the level of accuracy of the analysis software.

CONCLUSIONS

This paper describes a preliminary study in which real-world driving pattern data, along with measures of levels of service, were collected with the use of loop detectors, instrumented vehicles, and a video camera operated from a helicopter. The data collection effort has highlighted several issues that need to be addressed by the research team.

Loop detectors provide a means of estimating traffic conditions; namely speed, volume, and occupancy. However, the preliminary study revealed that problems occur when relying on this data source for the required information. These problems include limited availability of loops that are on-line, and unreliability due to the potential failure of several components of the detector systems.

The use of instrumented vehicles, although widely used in previous studies, has some limitations. At this stage, the research team has not determined whether an instrumented vehicle can be operated in a manner that will ensure that the modal activity measured is representative of the modal activity of the traffic stream as a whole. This concern will be addressed later in this research effort, by continued analysis of data from the preliminary study.

The concerns about the use of instrumented vehicles highlight the benefits of a video-based method for obtaining driving pattern data. Collecting video footage from a helicopter allows the driving behavior of a large sample of individual vehicles to be obtained. The video data analysis system being developed shows much promise, and the research team is confident of further refinement. In particular, efforts will focus on improvements to the efficiency of the analysis process.

This research aims to fill a void between regional transportation activity models and regional emissions models. Since models that predict motor vehicle emissions as a function of particular modes of activity are currently being developed, there is a need for methods to help predict these modes of activity. The particular emphasis is on improving the understanding of how vehicle modes of activity (namely acceleration, deceleration, idle, and cruise events) occur under different roadway, traffic, and control conditions and on different facility types. A better understanding of this relationship will enable development of methods to forecast the activity necessary to input directly into 'modal' emission models for improved emission inventory estimates. Since current transportation activity models can only provide estimates of average travel speeds on network links—barely sufficient for today's regional emissions models, let alone the complex modal-based models of tomorrow—this research will help to fill a serious modeling deficiency.

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ACKNOWLEDGEMENTS

The authors acknowledge both the financial and technical support, provided for this project, by the California Department of Transportation. In addition, the authors acknowledge the contributions of Christie-Joy Brodrick of ITS-Davis, and Yuk Dia and Michael Wilson of San Jose State University to this research effort.