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TITLE:

VEHICLE MODAL ACTIVITY ON FREEWAY LOOP ON-RAMPS: INPUTS TO THE DEVELOPMENT OF A RAMP DRIVE CYCLE TO DETERMINE THE VEHICLE EMISSIONS IMPACTS OF RAMP METERING

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ABSTRACT:

The goal of the study is to collect a comprehensive set of freeway and on-ramp operational data for the assessment of ramp metering systems. This paper is a presentation of data and initial findings for vehicle operations on loop ramps; a small subset of the larger project. The results reported here focus on the changes in modal activity (e.g. speed/acceleration) that occurred on two of the study area freeway loop on-ramps as a function of meter operation.

The study showed that vehicles on the two freeway loop on-ramps assessed in this paper displayed increase levels of modal activity that may result in associated increased levels of vehicle emissions. This analysis was limited to ramp activity and associated with only two ramp locations. Therefore, the extension of these results to other freeway on-ramps or to the evaluation of ramp metering systems as whole is also limited (the larger study will address overall system impacts and is due to be completed in April 2000). The analyses presented in this paper do provide initial evidence that ramp metering will impact vehicle activity on ramps and that the activity within each condition (metered versus non-metered) is reasonably consistent. This also provides the initial steps for developing a ramp drive cycle for use in the detailed modeling of freeway on-ramp emissions. Continuing research in the area will assess the specific emissions impacts and the system wide air quality effects.

KEY WORDS:

Vehicle Emissions
Freeway Ramp Operations
Ramp Metering
Drive Cycles

INTRODUCTION

In October of 1998, the Georgia Institute of Technology, School of Civil and Environmental Engineering began a 16-month comprehensive study of the Atlanta ramp meter system for the Georgia Department of transportation (GaDOT). The goal of the study is to collect a comprehensive set of freeway and on-ramp operational data and develop a traffic simulation model for these ramps. The simulation model will then be used to examine the effects of ramp meter operation and design policies on vehicle pollutant emissions. As will be discussed in some detail later, vehicle emissions are a function of both speed and acceleration characteristics of vehicle operations. Although the TRAF series of models typically provide good traffic flow data, previous Georgia Tech studies have identified deficiencies in the ability of the models to accurately simulate speed/acceleration profiles (Hallmark, et al., 1999). Hence, a primary goal of the study is to develop a calibrated model that accurately predicts not only the traffic flows on the links, but the speed/acceleration profiles for these vehicles. Ultimately, the simulation model will be linked with advanced motor vehicle emission rate models for estimating the impacts of ramp meter operation as a function of ramp meter design and operation.

For 18 days, vehicle speed/acceleration profiles were collected on ramp and mainline segments using laser rangefinders and probe vehicles. The focus of this study is on the data collected by the probe vehicles on the two loop ramps involved in the study. The results reported here focus on the changes in modal activity that occurred on these loop ramps as a function of meter operation. These results are initial findings from a much larger study on the impacts of ramp metering and management strategies. Once the analyses of vehicle activity data are completed for the freeway segments, the simulation model will be developed and comprehensive changes in modal operations for the entire system and fleet will be predicted. This study is a look at a small subset of the overall data collected as part of this project.

BACKGROUND

For years, ramp metering has proven to be a popular and effective means for major urban areas to reduce freeway traffic congestion. Ramp metering is an example of a transportation control measure designed to reduce congestion by improving traffic flow. Ramp meters restrict the rate and number of vehicles entering a freeway network from on-ramps, so that the induced congestion on the freeway is minimized. Without ramp metering, freeway on-ramp demand is usually accommodated at the expense of traffic already on the network. That is, the vehicles coming down the ramp force their way onto the system, reducing the available freeway capacity to handle the upstream traffic. When the freeway is operating under congested conditions (at lower levels of service), heavy on-ramp demand can force the upstream sections of the freeway into an unstable mode of operation, and upstream queues of very slow moving traffic can develop. The concept of ramp metering is to restrict on-ramp access in such a manner that the formation of unstable upstream flow is minimized. Vehicles are metered onto the system such that large groups of vehicles do not significantly disrupt existing flow patterns.

Ramp metering results in stop delay and higher fuel consumption for vehicles waiting for freeway access and accelerating to freeway speeds. However, because unstable flow on the freeway is avoided, fuel consumption is minimized for the very large numbers of vehicles on the freeway. Usually, traffic flow improvement measures result in concurrent motor vehicle emissions reductions. When traffic flow becomes more steady, motor vehicle emissions usually decline. However, ramp metering is an example where there is still a great deal of uncertainty in estimating the trade-off between increased fuel consumption and emissions on the ramps and decreased fuel consumption and emissions on the freeway.

Recent vehicle emissions studies demonstrate that motor vehicle emissions under hard acceleration and high-speed moderate-acceleration conditions can lead to order-of-magnitude increases in vehicle emissions for some vehicle technologies (Kelly and Groblicki, 1993; LeBlanc, et al., 1994; LeBlanc, et al., 1995; Barth, 1996b; An, 1998; Guensler, et al., 1998; Fomunung, et al., 1999). Hard deceleration conditions also yield statistically significant carbon monoxide (CO), oxides of nitrogen (NOx), and hydrocarbon (HC) emissions increases (An, 1998; Fomunung, et al., 1999). The extreme non-linear relationships are particularly important for ramp meters, where traffic stops at the on-ramp and then accelerates to freeway speeds (sometimes over short distances). For the last few years, various representatives of federal and state agencies have advocated against ramp meter implementation due to the large expected increases in emissions on the ramps.

To analyze the net emissions effects of ramp meters and other flow-smoothing strategies detailed observations or accurate simulation models must be coupled with modal emissions and fuel consumption models. The analytical results can vary significantly as a function of network characteristics. Geometric parameters such as ramp length, grade, gore length, weave section characteristics, etc., can also significantly affect modal operations and therefore emissions.

Modal models are more complex than traditional emission rate modeling approaches. These models account for the interactions between vehicle technology characteristics and the vehicle operating modes. To apply a modal emissions model to such a ramp metering analyses, a variety of non-traditional data must be made available for analysis. That is, some vehicle technology groups experience significant increases in emissions under certain operating conditions, while others do not. Hence, to model the impacts of ramp metering where changes in operating modes are expected, modelers need roadway grade estimates, vehicle fleet characteristics, and speed/acceleration profile data for each scenario (Guensler, et al., 1998; Bachman, 1998).

As discussed earlier, the goal of the Georgia Tech/GaDOT ramp metering study was to collect a comprehensive data set that could be used in estimating the impacts of ramp metering through the application of the Mobile Emissions Assessment System for Urban and Regional Evaluation (MEASURE) modal model. The MEASURE model is a GIS based model emissions model developed at Georgia Tech. Road grade information for the study area is available through the Atlanta GIS system. Detailed vehicle fleet characteristics were collected by sampling vehicle license plates, translating plate numbers to vehicle identification numbers using a registration database, and decoding the VINs to provide vehicle technology group data. The speed/acceleration profiles were collected using laser rangefinders and probe vehicles. The results presented here focus on the changes in modal activity that occurred on the two loop in the study area ramps as a function of meter operation. Probe vehicles were used to collect all of the data presented in this paper (the research team is still processing laser rangefinder data). Once vehicle activity analyses are completed for the freeway segments, the comprehensive changes in modal operations for the entire system and fleet will be predicted using the MESURE model. The following are initial findings.

DATA COLLECTION METHODOLOGY

Probe Vehicles

Probe vehicles equipped with distance measuring instruments (DMIs) were used to collect the data for this study. Probe vehicles are advantageous for collecting vehicle activity on on-ramps, as it is safer and more convenient than other field instruments. This was particularly the case with the two ramps evaluated in this paper. That is, it was not possible to use the laser rangefinders to collect data at these locations due to the curved nature of the ramps.

The probe vehicles were used to collect vehicle modal activity (speed, acceleration, idle, etc.) data on the two freeway on-ramps (Northside Drive and West Paces Ferry) in the study area on I-75 northbound in Atlanta (map1.). Two probe vehicles were utilized for this data collection effort. Second by second vehicle speed data were downloaded from the DMI unit to a laptop computer operated by a data collector riding in the passenger seat. The data collector also maintained a field log to record additional information (time, plate number, data file name, etc.) for each probe vehicle run.

Equipment and field deployment tests started during the end of April, with full deployment commencing in May and June of 1999. The collection of the vehicle modal activity data was centered around the PM peak period when the ramp meters were in operation and under clear weather conditions. The data collection activities were carried out for approximately four hours per session from 3:15 PM to 7:00 PM on a typical day. The ramp metes were in operation from 3:45 PM to 6:30 PM. Data were collected for these two locations on eleven different days between May and July of 1999. During four of these days, the ramp meters were turned off during the entire peak period. A summary of the data collection activity is provided in the following table.

Table 1
Data Collection Summary by Location

LOCATION	Days of Data Collection	Hours of Data Collection	Approximate Number of Vehicle Runs	Metered Runs	Non-Metered Runs
Northside Drive Ramp	6	20	160	53	107
West Paces Ferry Road Ramp	5	18	91	28	61
TOTAL	**11**	**38**	**251**	**81**	**170**

Car Following Procedure

A target vehicle was selected from the traffic stream and then followed by the probe vehicle through the ramp cycle. To the degree possible, the probe vehicle would mimic the vehicle behavior of the target vehicle. If the target vehicle did not stop at the ramp meter red signal the probe vehicle driver was instructed to follow the vehicle through the signal. On occasion the probe vehicle was not able to identify and lock onto a target vehicle. In these cases, the probe vehicle driver was instructed to drive with the average flow of traffic. Two vehicles and six different drivers were used for the collection of data at these two sites over the eleven days.

Site Selection

The focus of this paper is on the analysis of the observed driving cycles on two freeway loop on-ramps. As mentioned earlier, the analyses are a subset of a much larger program to assess the air quality impacts of the enter ramp metering systems. The driving cycles reported here represent the average vehicle activity on pre-defined roadway segment, or the expected level of activity on this specific type of facility. It is anticipated that vehicle activity will be measurably different on loop ramps as compared to other ramp designs. The two ramps in this study are both part of the same ramp metering system, although they are not adjacent (there are two interchanges between the two study ramps). The two study ramps are significantly different from each other despite both being loop ramps. The Northside Drive location is on a negative grade and is an auxiliary lane. The second site at West Paces Ferry Road, has a larger radius than the Northside Drive ramp, is on a positive grade, and has a long taper as opposed to a short merge into a weave area. The metering rate for both locations varies between 13 and 6 vehicles per minuet. Both ramp cycle lengths were the same and the distance from the top of the ramp to the ramp meter location were similar (see Table 2).

Sub-Fleet Mix Data

To characterize the fleet in the study area, vehicle license pate information was collected for a sample of vehicles during the data collection period. Vehicle license plates were recorded by the data collector and enter on the field log. Additional plate data were collected at the two ramp locations by a remote sensing crew collecting vehicle emissions data as a related part of this project. This plate information will be associated with a VIN and decoded to provide detailed fleet information. The plate information, as well as, the vehicle emissions data had not been reduced at the time of this paper.

Traffic Volume Data

Concurrent with the collection of vehicle modal activity data, traffic volume data were also collected. Video cameras and Nu-Metric devices were used to collect the traffic count data. A combination of GaDOT TMC freeway surveillance cameras and portable Georgia Tech School of Civil and Environmental Engineering cameras were used to record the traffic movements during the data collection periods. The Nu-Metric devices were used on some ramp locations when cameras were not available or convenient to employ.

STUDY FINDINGS

The focus of this study was on the differential levels of activity on freeway loop ramps, under metered versus non-metered conditions. Due to the different configuration of the two ramps in the study, direct comparisons between the two ramps are limited. The essential findings are centered on the comparison of activity when the ramp meter was on verses when the ramp meter was off, on a site-by-site basis. This is not to say that general conclusions about all on ramps is not the ultimate goal, but that factors influence vehicle activity on freeway on-ramps are numerous, including metering cycle, grade, and geometric design. Since the ramp meters were turned off during a portion of this study, direct comparisons of activity during critical peak period times can be made on a ramp by ramp basis.

The findings are summarized by vehicle speed and acceleration, and other vehicle activity measures that are important to the level of vehicle emissions. Moreover, since the Atlanta region is an ozone nonattainment area with a focus on NOx reduction, variables that have been found important in the production of high levels of NOx in vehicle exhaust were emphasized. These measures are acceleration greater than 6 mph per second, deceleration greater than 2 mph per second, and inertial power surrogate (measured as velocity * acceleration) greater than 60 mph^2/sec (Fomunung, et al., 1999).

The following table shows general information and descriptive findings for the two on-ramp drive cycles examined in this study. The ramp cycle length for both locations was 1700 feet. The start of each cycle (i.e. distance = 0) was the beginning point of each ramp were it intersected the adjacent street.

Table 2
Summary Statistics for Each Ramp Location for Metered and Non-Metered Conditions

MEASURE	Northside Drive Ramp Metered	Northside Drive Ramp Non-Metered	West Paces Ferry Road Ramp Metered	West Paces Ferry Road Ramp Non-Metered
Cycle Length (feet)	1,700	1,700	1,700	1,700
Distance to Ramp Meter Stop Bar (feet)	530	530	500	500
Average Speed (mph)	22.1	26.4	33.8	35.2
Maximum Speed (mph)	66	63	61	61
Maximum Acceleration (mph/sec)	11	7	8	7
Maximum Deceleration (mph/sec)	6	6	8	7

As would be expected, at both locations, the average ramp cycle speed was lower under metered versus non-metered conditions. Higher maximum acceleration rates were also observed for metered versus non-metered conditions. The following figures 1 and 2 compare the average speed traces over the ramp cycle for both locations. Note that for both study sites the average speed at the stop bar under metered conditions was approximately 10 mph. The expected value for this condition should be close to zero. The 10-mph figure is a result of the fact that few queues formed during the data collection period, some vehicles received a green signal upon approaching the stop bar, and not all vehicles obeyed the ramp meter signal. Figures 3 through 6 show the distribution of actual speed observations over all points down the ramp for both locations under both conditions. These figures show the spread of speed observations at different locations and how the variability in speed activity is greater under metered operations. In addition, these figures show the impact of vehicle queues on vehicle speeds through the ramp cycle. The individual speed data points observed at the beginning of the ramp vary as a result of the presence of a vehicle queue.

Figures 7 through 10 show the distribution of acceleration activity by location down the ramp for both locations and metered conditions. These figures show the high levels of deceleration and acceleration on either side of the ramp meter when it is in operation.

Figures 11 through 14 show the joint frequency distribution over speed and acceleration for both locations under metered versus non-metered conditions. These figures show the variability in acceleration for the metered conditions. In addition, the non-metered conditions reveal a much narrower distribution compared to the metered conditions. These figures also show the higher level of zero velocity activity (i.e. idle under the metered conditions).

Specific modal activity is important for estimating the level of various exhaust emissions. The percent of time a vehicle is operating in certain acceleration ranges and power demand ranges influence the level of NOx emissions. In the MEASURE aggregate modal model, acceleration rates greater than 3 mph per second, acceleration rates greater than 6 mph per second, deceleration grater than 2 mph per second, and an inertia power surrogate (measured as acceleration * velocity) greater than 60 mph^2/ second (Fomunung, et al., 1999) are critical variables. The following table shows the percent of the ramp cycle length spent in each of the above mentioned modes of operation.

Table 3
Percent of Modal Activity by Location and Metered Condition

MODAL ACTIVETY	Northside Drive Ramp		West Paces Ferry Road Ramp	
	Metered	Non-Metered	Metered	Non-Metered
Percent of Cycle with Acceleration Greater than 3 mph/sec	21	20	19	9
Percent of Cycle with Acceleration Greater than 6 mph/sec	3	.003	1	.001
Percent of Cycle with deceleration Greater than 2 mph/sec	14	3	10	5
Percent of Cycle in Idle	5	0	2	1
Percent of Cycle with IPS Greater than 60 power	25	31	32	32

The above table shows that most of the variables found to be important to predicting vehicle emissions are measurably different for the two conditions at both locations. Acceleration and deceleration activity and related power demand surrogates have been found to be significant modal activity variables for predicting vehicle emissions. As would be expected idling time increased under metered conditions, due to the development of queues behind the stop bar. Intuitively, idling would seem to be an important variable in predicting vehicle emissions. Although it may be a contributing factor, the percent of cycle under idle, is not a variable in the current modal model emissions rate algorithms. Based on these initial findings and the varying levels of modal activity observed under the metered versus non-metered conditions there is indication that vehicle NOx and other emissions may be higher under metered conditions on loop ramps sections. The scope of this report was limited to the modal activity on the ramps and does not consider the mainline conditions that may offset ramp emissions. Therefore, due to the limited scope of this analysis the comprehensive effects of ramp metering on vehicle emissions are inconclusive. This study does provide initial evidence that ramp metering will impact vehicle activity on ramps and that the activity within each condition (metered versus non-metered) is reasonably consistent. This also provides the initial steps for developing a ramp drive cycle for use in the detailed modeling of freeway on-ramp emissions.

Summary of Findings

The following is a summary list of the results of this study. These results are from data collected at the two study loop on-ramp locations and caution should be used when extending the findings to other freeway on-ramps.

- Average speed on ramps decreased under metered conditions
- The percent of cycle under "hard" acceleration (greater than 3 and 6 mph/sec) increased under metered conditions
- The percent of cycle under rapid deceleration (greater than 2 mph/sec) increased under metered conditions
- The percent of cycle under idle increased under metered conditions
- The maximum acceleration rate increased under metered conditions
- The maximum deceleration rate was consistent for both conditions
- The maximum speed was consistent under both conditions
- The percent of cycle under IPS greater than 60 (change in kinetic energy measured as power) was variable and inconclusive
- Speeds through curved sections of the ramps under metered and non-metered conditions are generally consistent. The average activity in the loop section is likely a function of radius and grade.
- The initial speeds entering the ramp and leaving the merge area (at the beginning and end of the cycles) are consistent for both conditions.
- It is evident that ramp meters influence driving behavior even when they are not in operation (i.e. some individuals stop or slow down at the ramp meter stop bar even if the meter is off). That is, there is likely a difference between a non-metered ramp and a metered ramp with the meter off.
- Differences in vehicle activity (e.g. acceleration) under each condition are likely to be greater on non-loop ramps as drivers would not be forced to decelerate if the ramp is not curved and the meter is off.

Limitations of the Data and Results

The study showed that vehicles on the two freeway loop on-ramps assessed in this paper displayed increase levels of modal activity that may result in associated increased levels of vehicle emissions. This analysis was limited to ramp activity and associated with only two ramp locations. In addition the use of probe vehicles for data collection limited the number of samples for use in this analysis. Therefore, the extension of these results to other freeway on-ramps or to the evaluation of ramp metering systems as whole is also limited. Continuing research in the are will assess the specific emissions impacts and the system-wide air quality effects.

Future and Forthcoming Research

Currently the Georgia Institute of Technology, School of Civil and Environmental Engineering is collecting and analyzing additional vehicle modal activity on other freeway on-ramps in the system and mainline sections. This fourth coming data will provide a more comprehensive and conclusive assessment of the emissions impact of ramp metering systems. The findings here are an initial look at a subset of the overall system activity. The expansion of the scope in both study locations and data collection intensity will provide for a much richer data set than is provided here. Future research will include not only more data, but simulation and validation studies.

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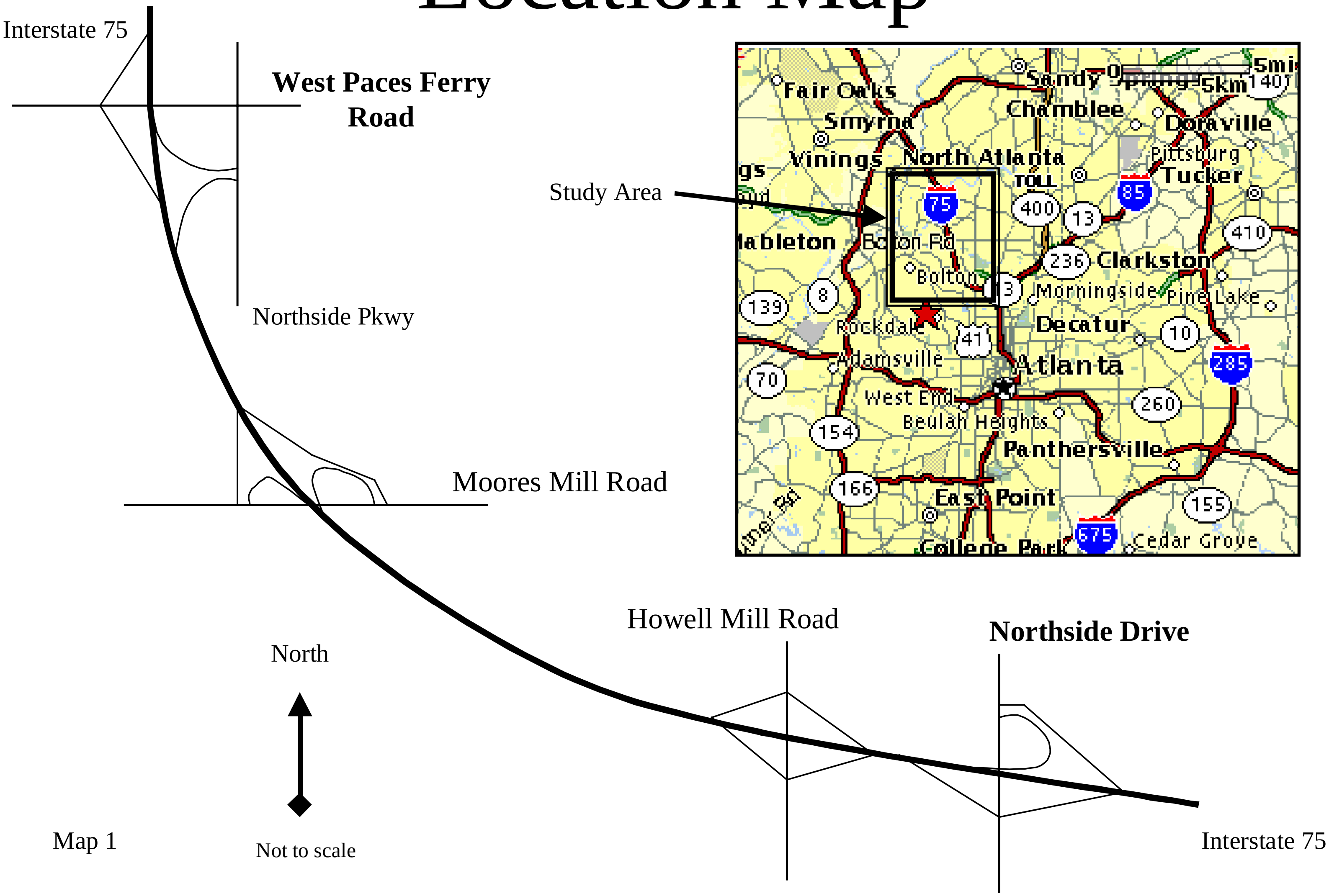
Location Map



Map 1

Figure 1
Northside Drive Ramp
Average Speed over Distance

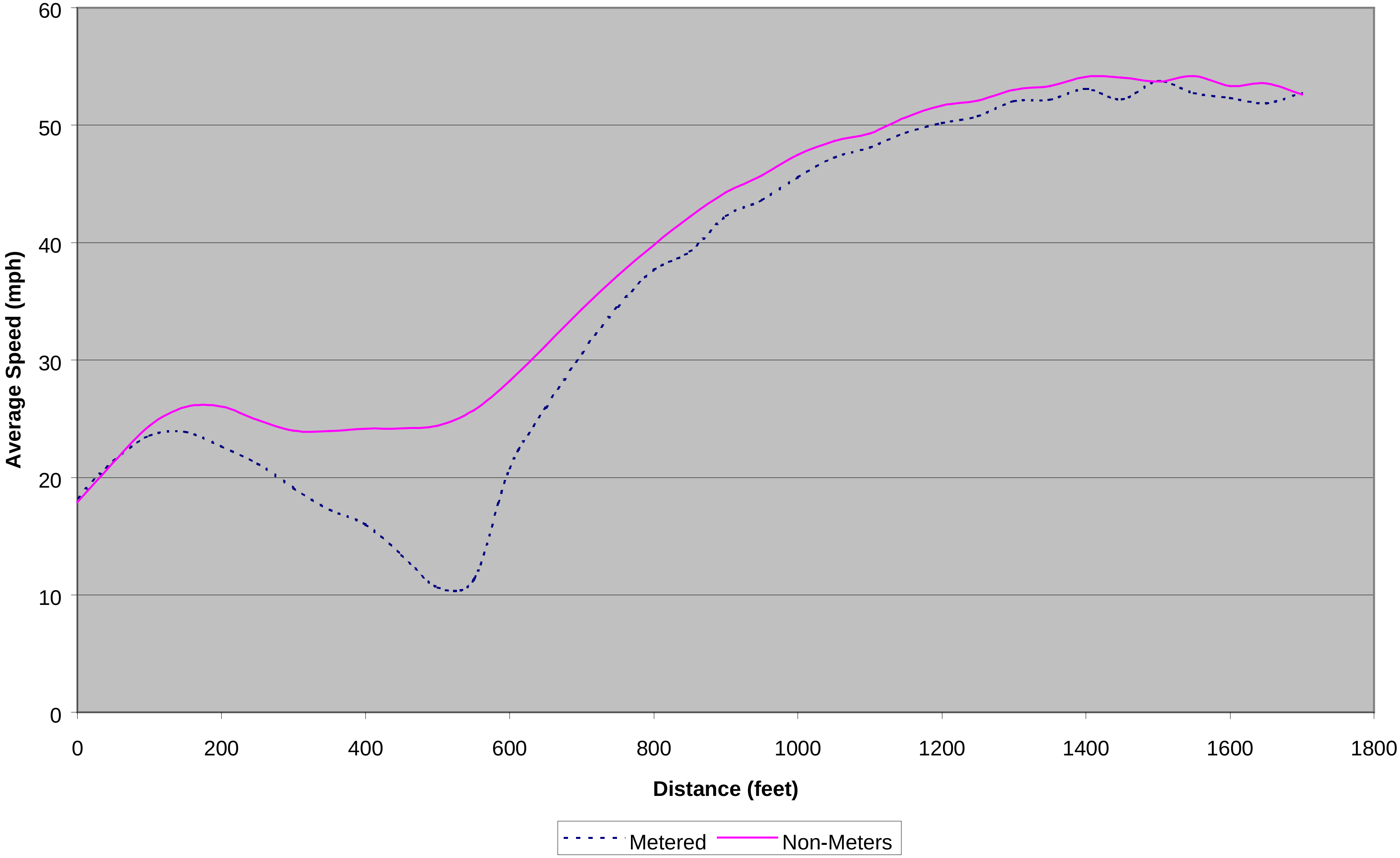


Figure 2
West Paces Ferry Ramp
Average Speed over Distance

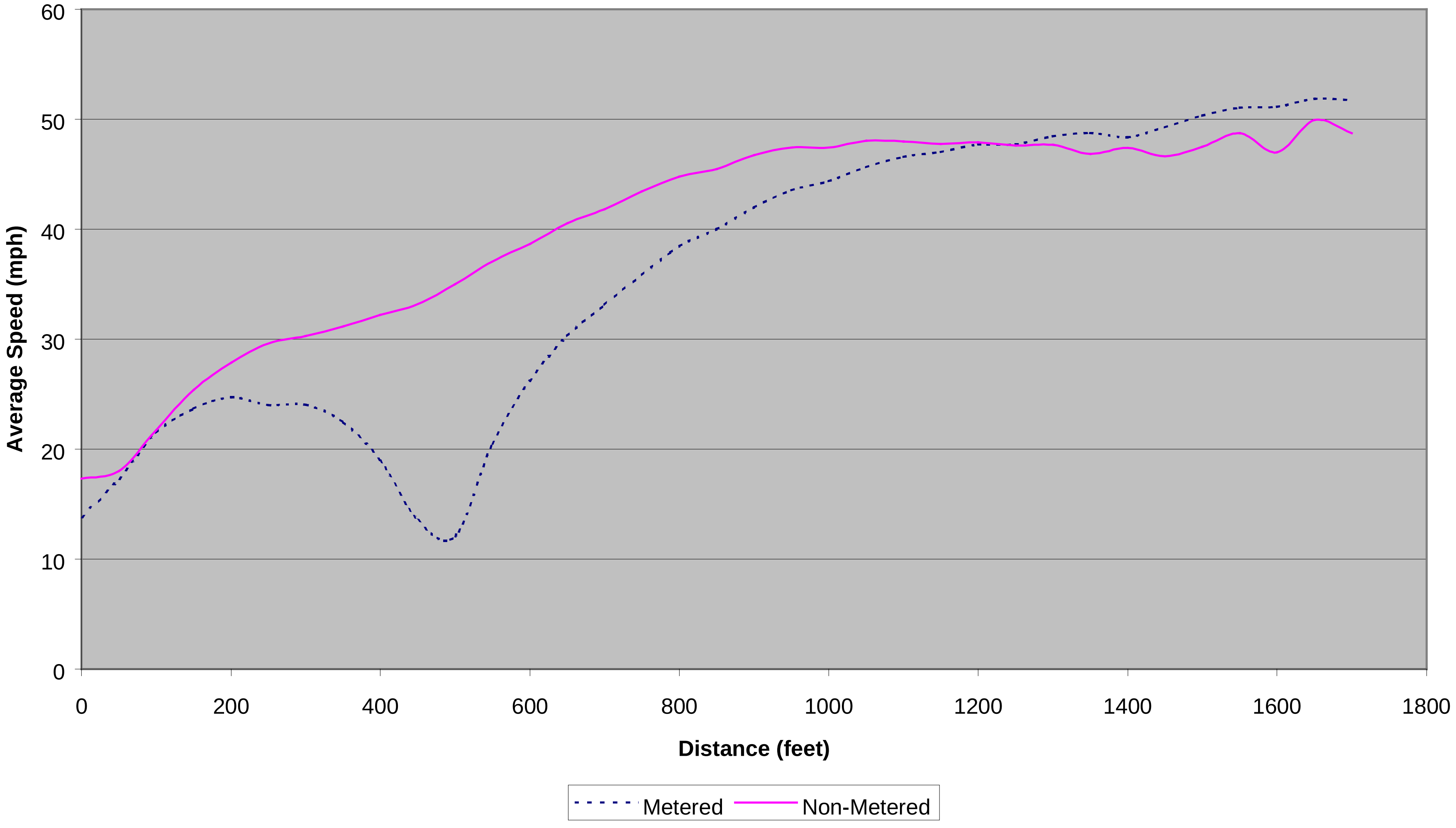


Figure 3
Northside Drive
Metered
Individual Speed Observations by Distance

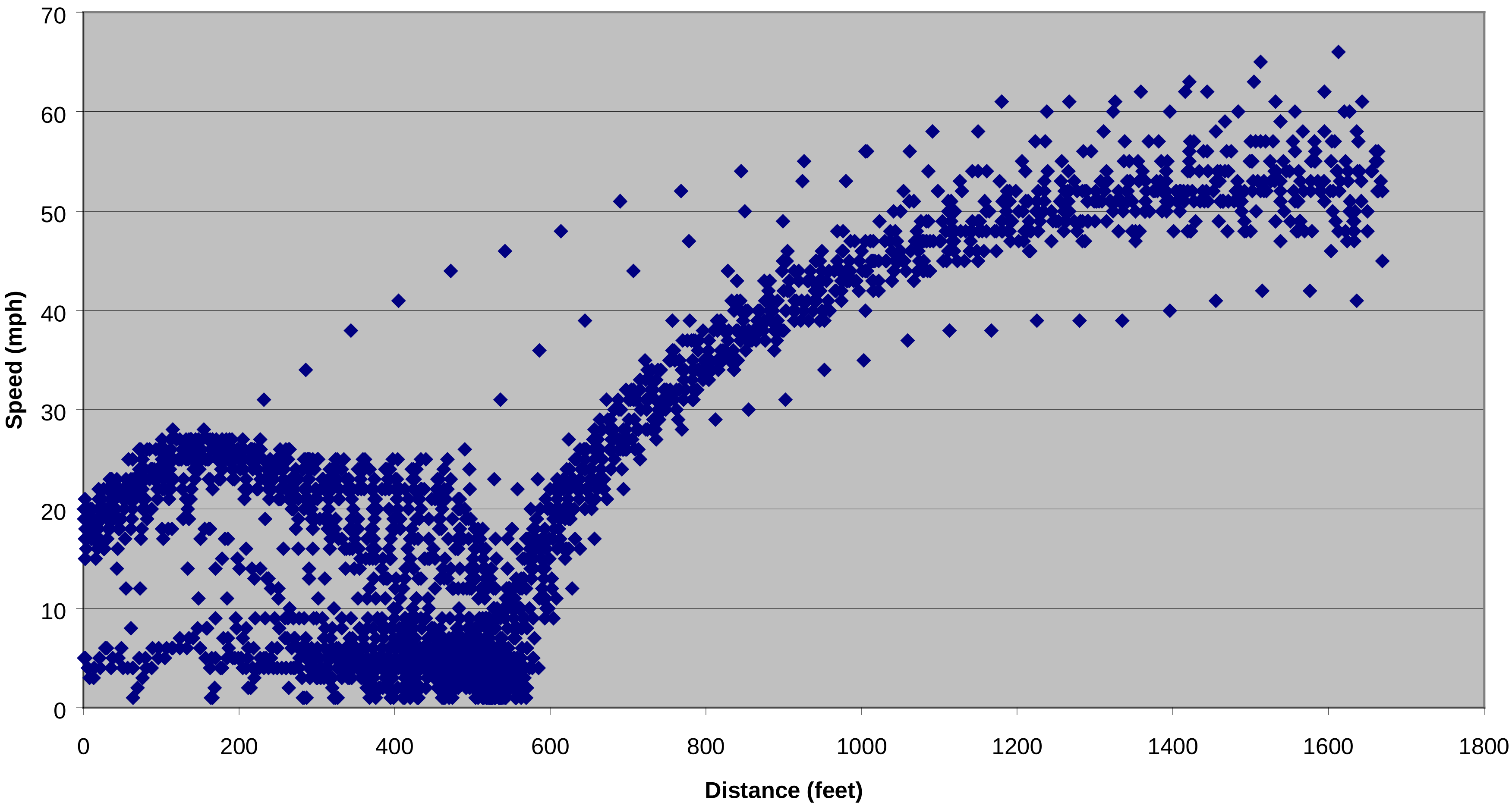


Figure 4
Northside Drive
Non-Metered
Individual Speed Observations by Distance

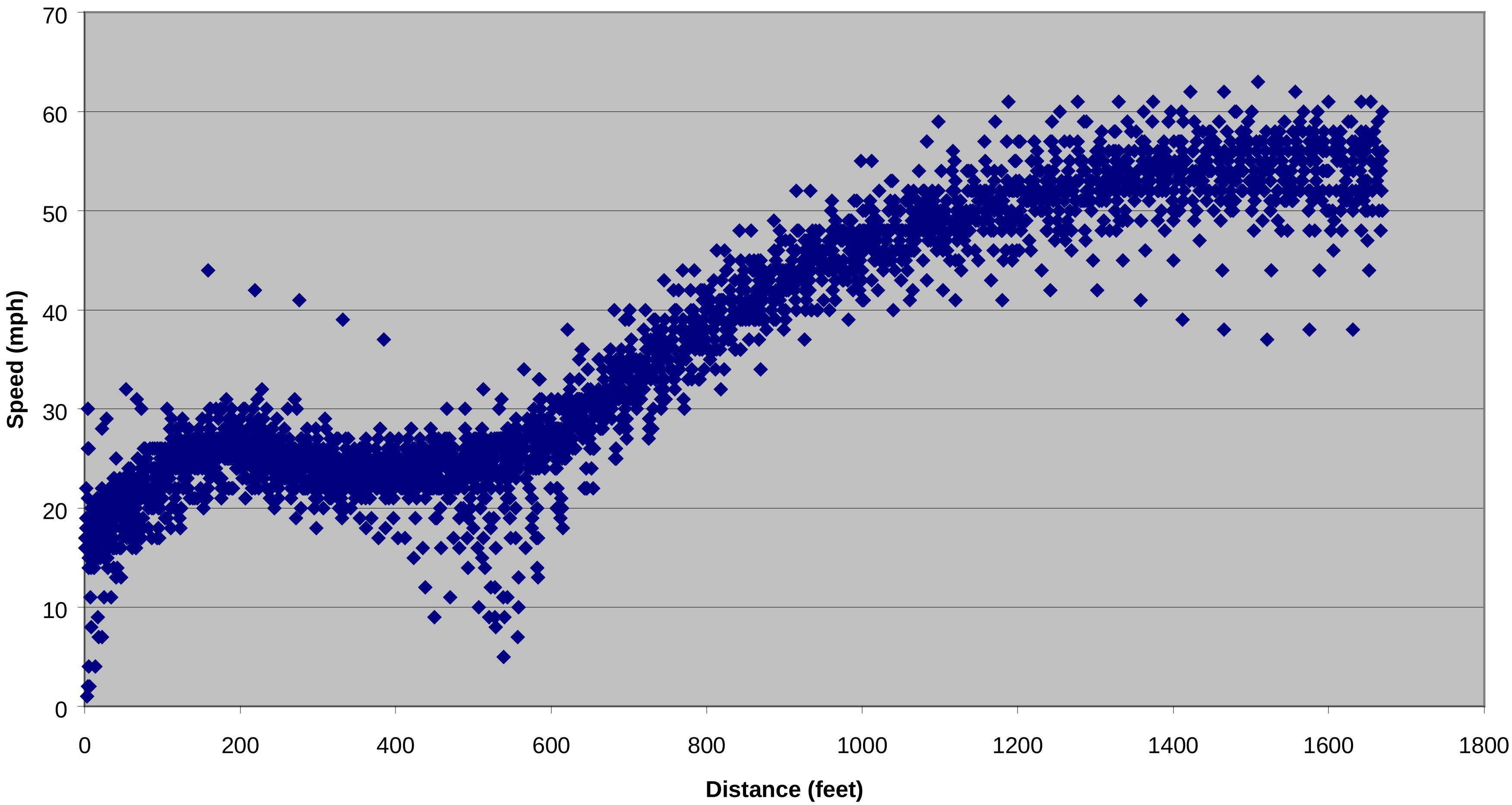


Figure 5
West Paces Ferry
Metered
Individuale Speed Observations by Distance

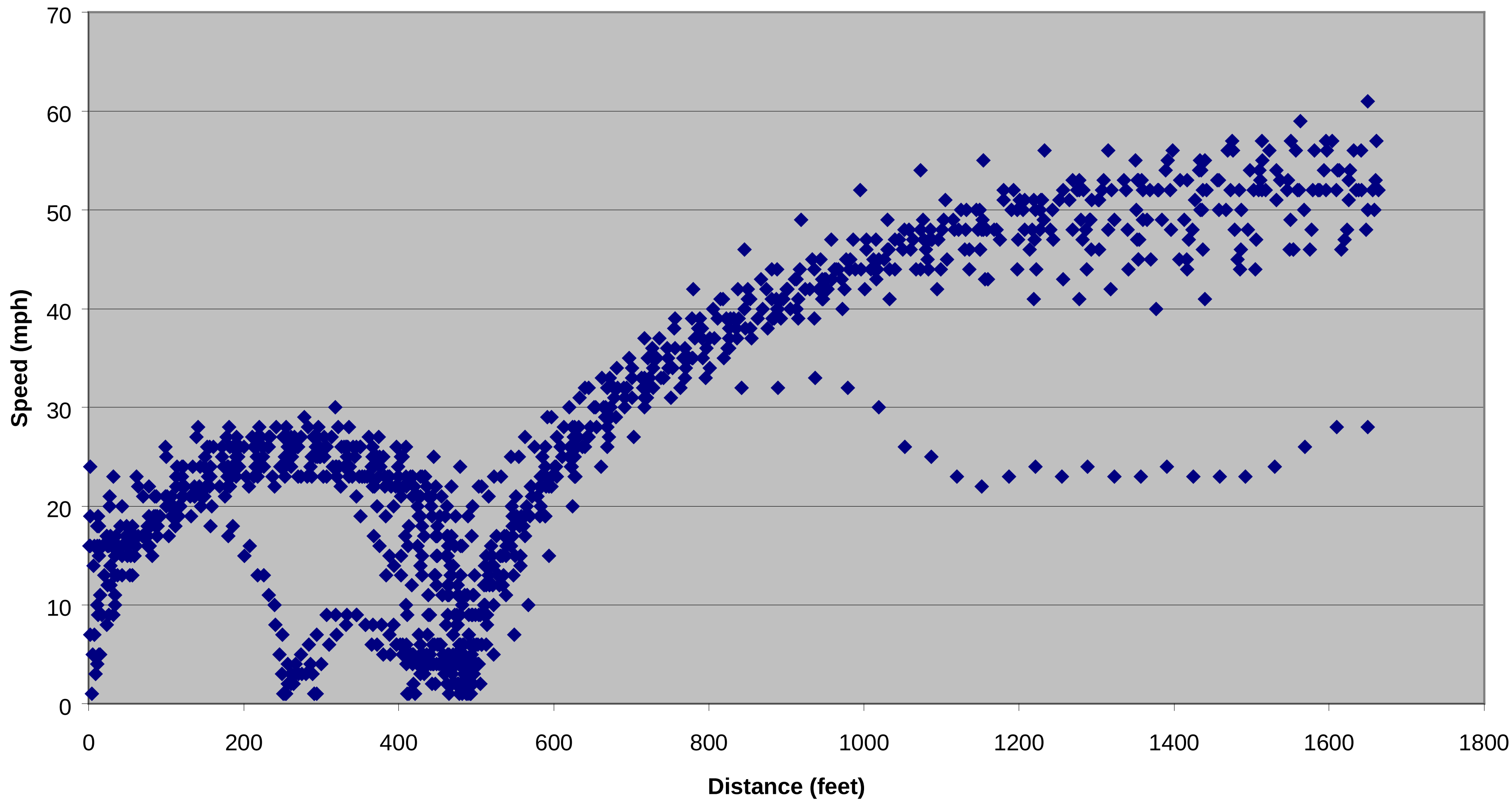


Figure 6
West Paces Ferry
Non-Metered
Individual Speed Observations by Distance

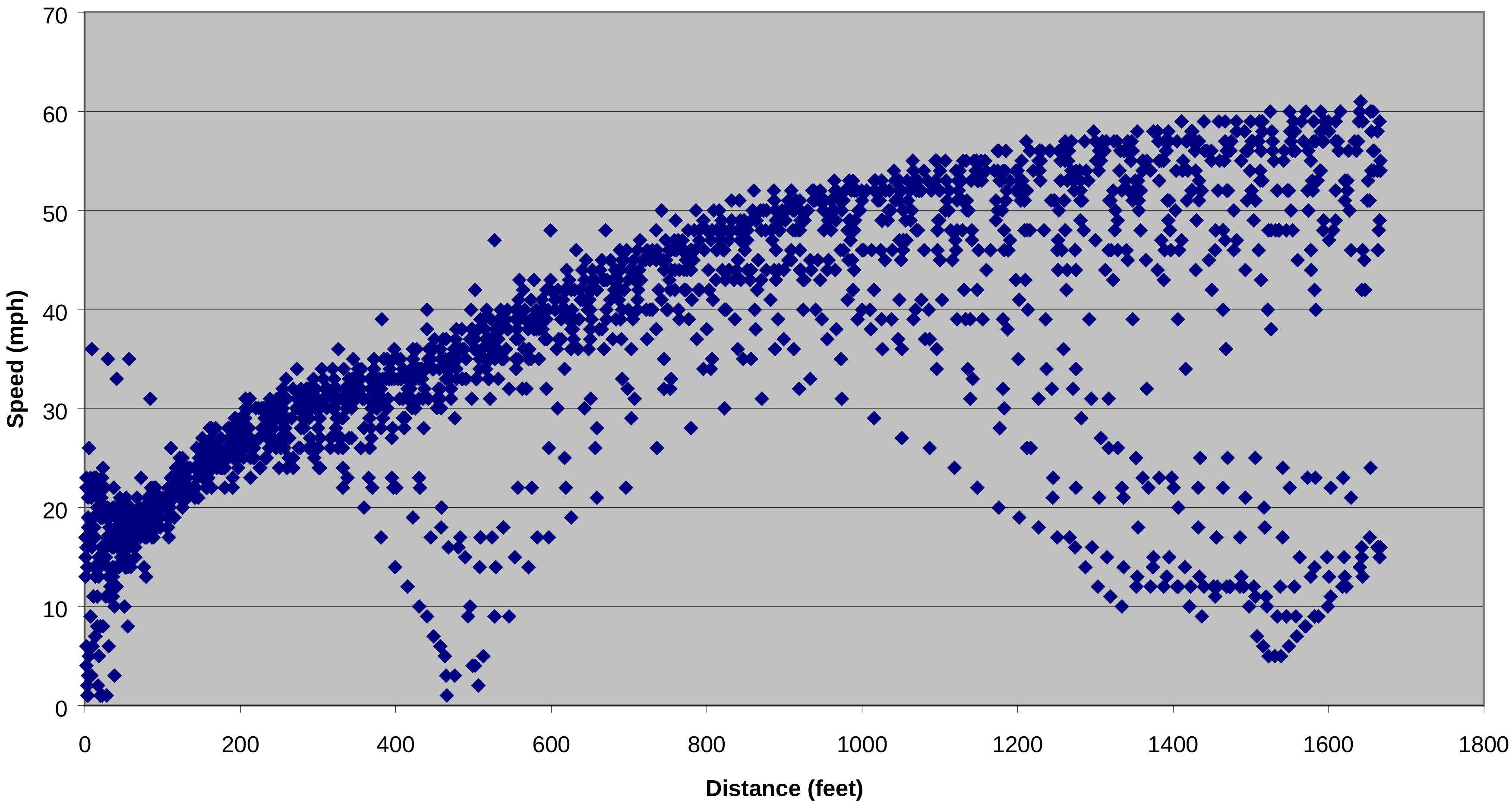


Figure 7
Northside Drive
Metered
Individual Acceleration Observations by Distance

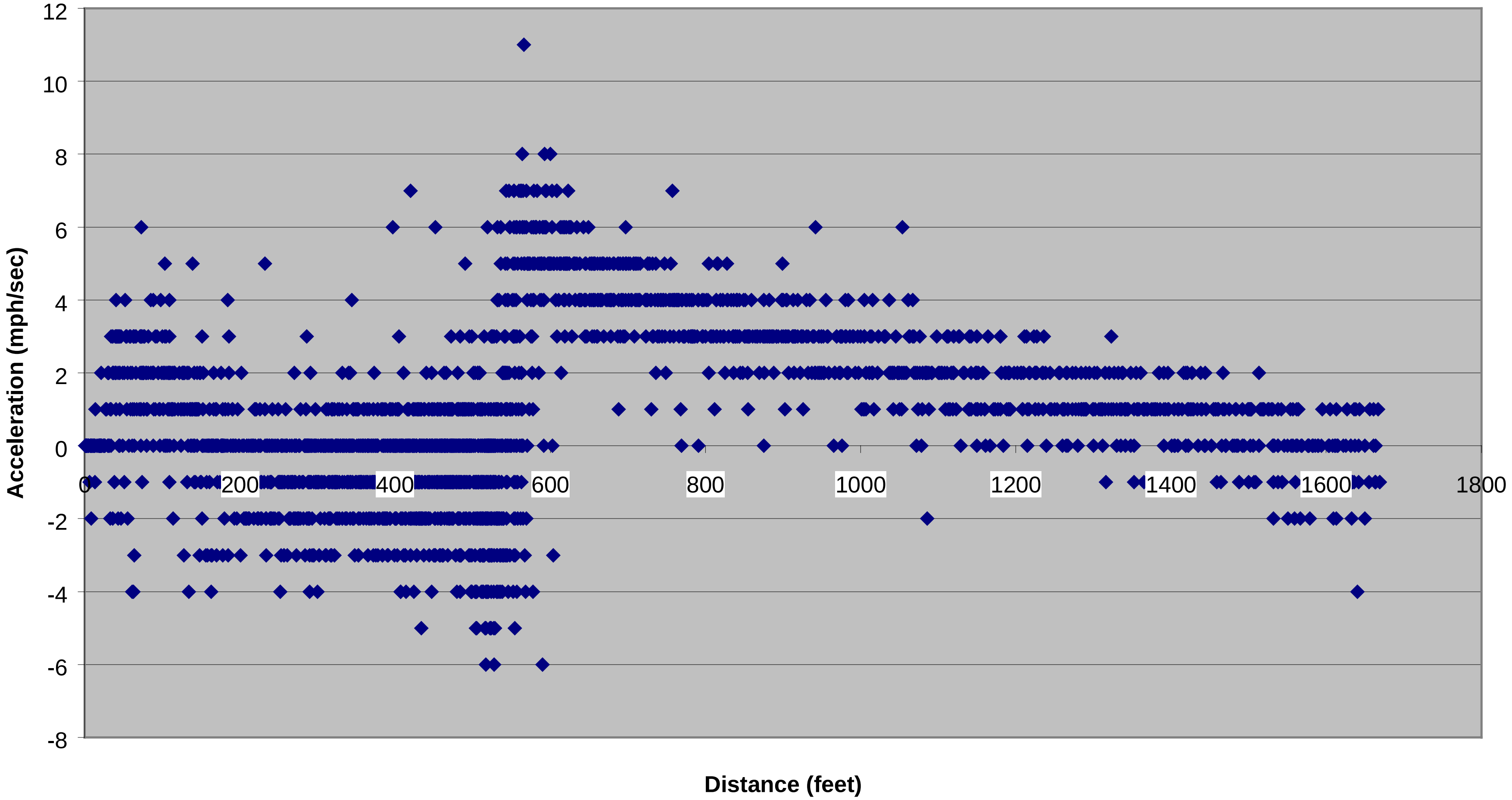


Figure 8
Northside Drive
Non-Metered
Individuale Acceleration Observations by Distance

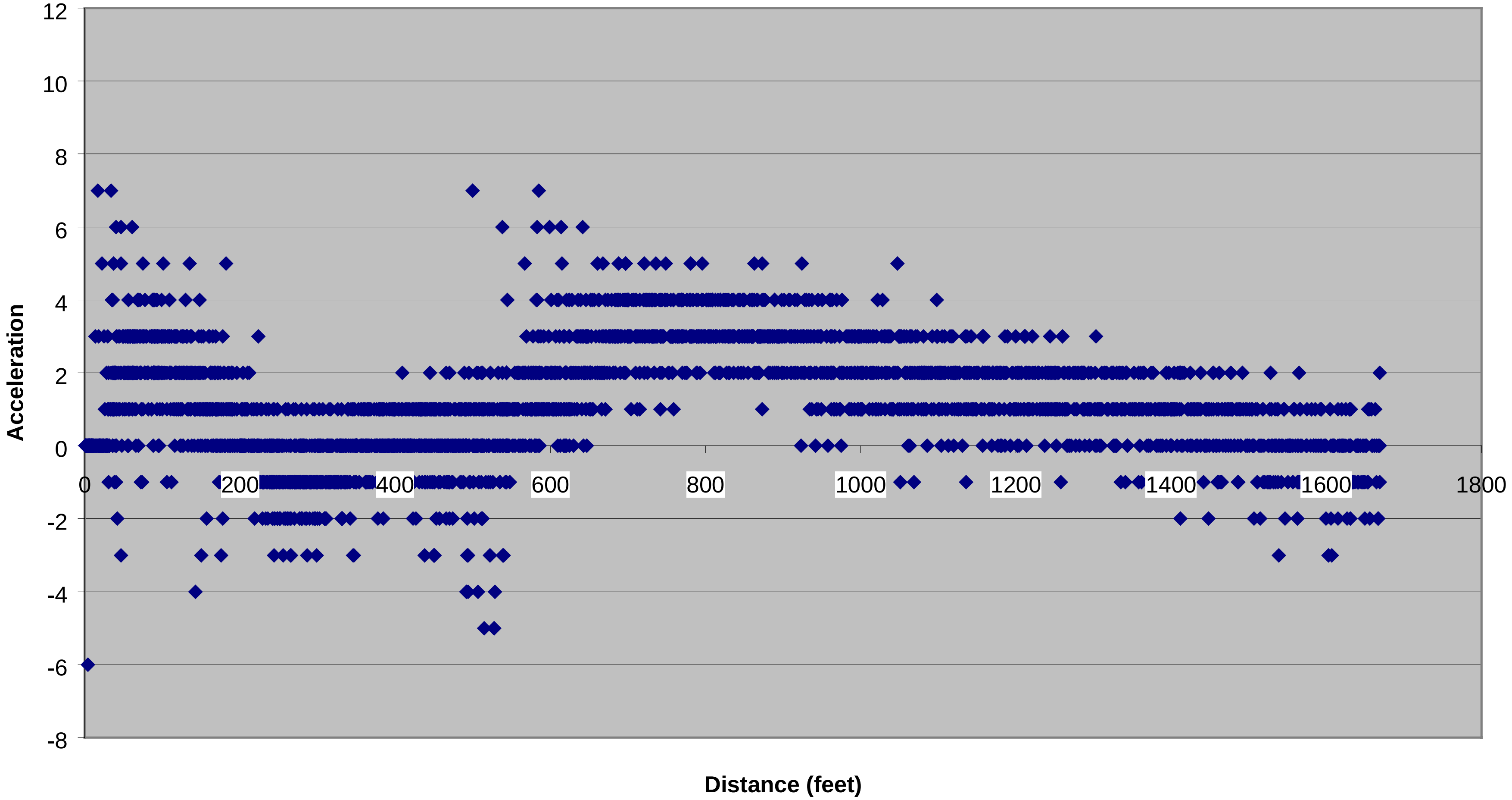


Figure 9
West Paces Ferry
Metered
Individual Acceleration Observations by Distance

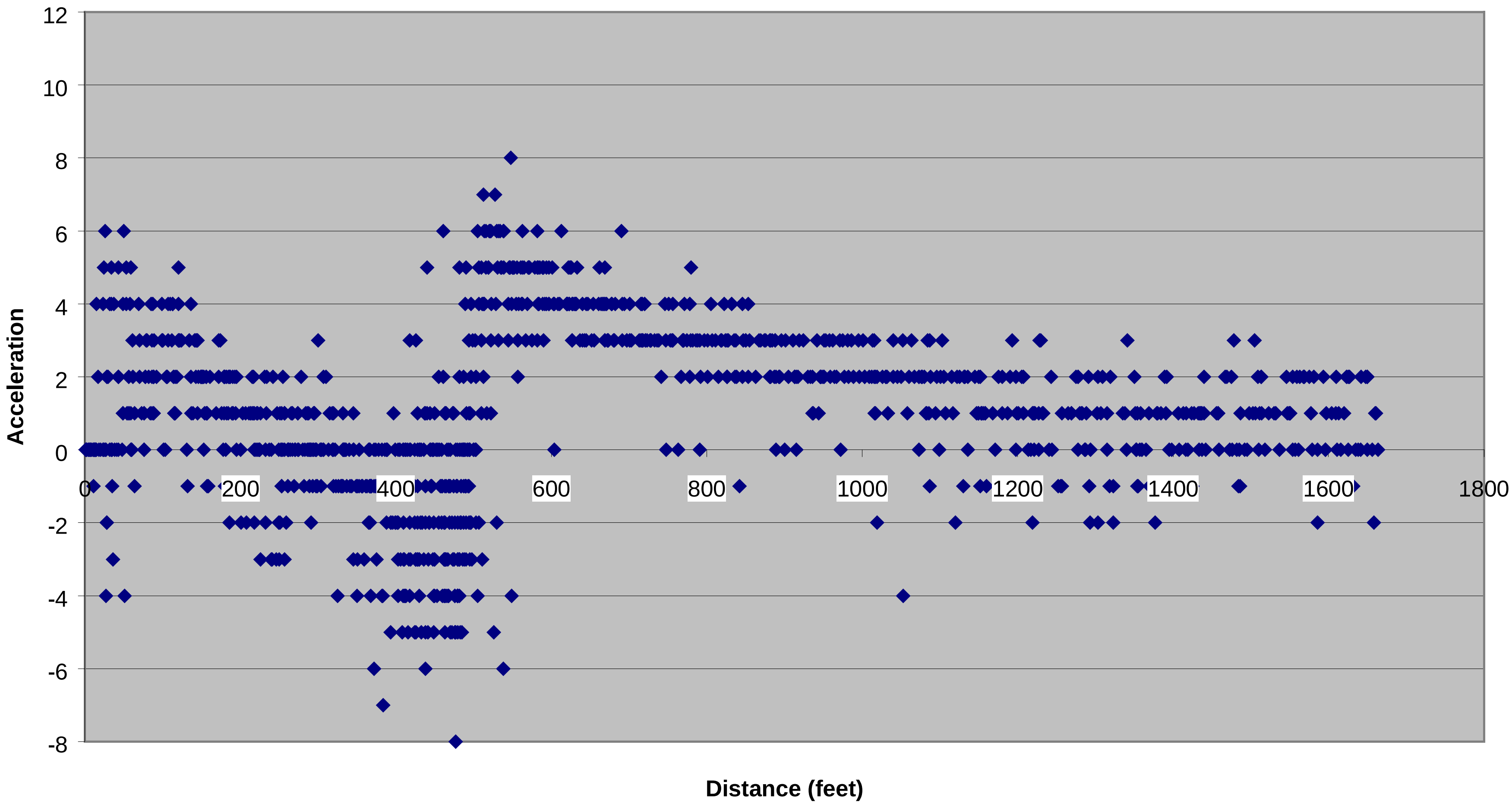


Figure 10
West Paces Ferry
Non-Metered
Individual Acceleration Observations

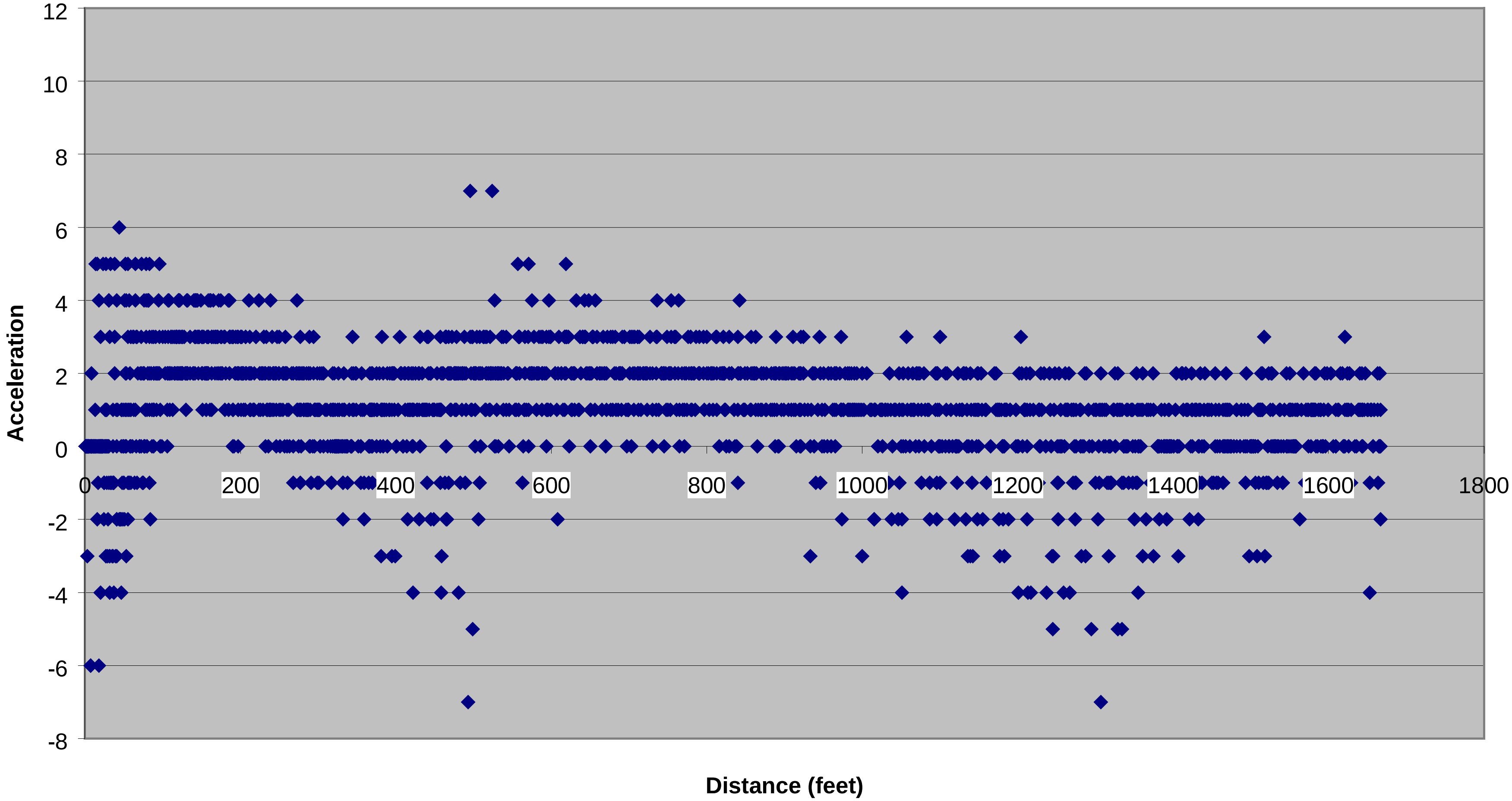


Figure 11
Northside Drive
Metered

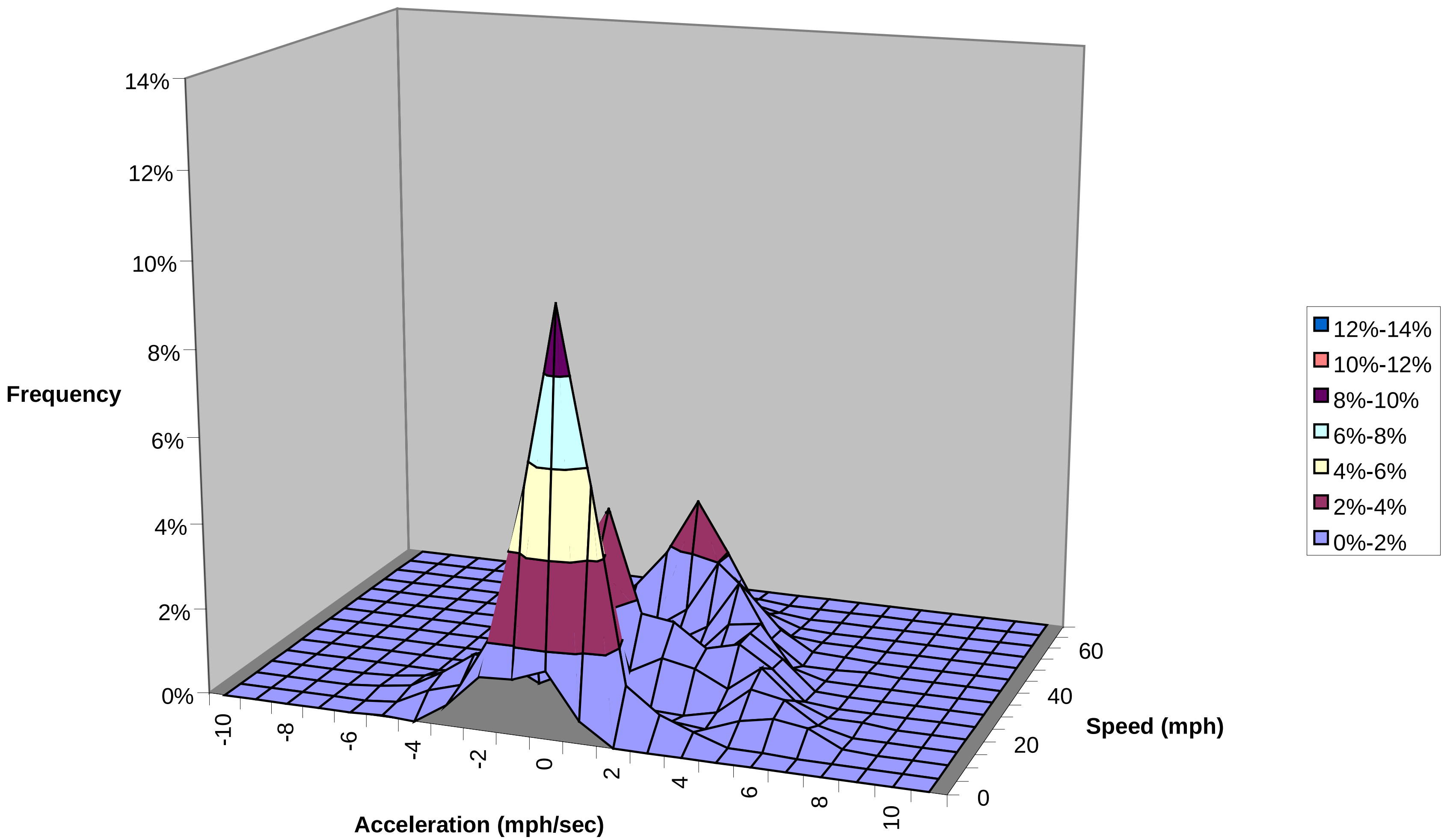
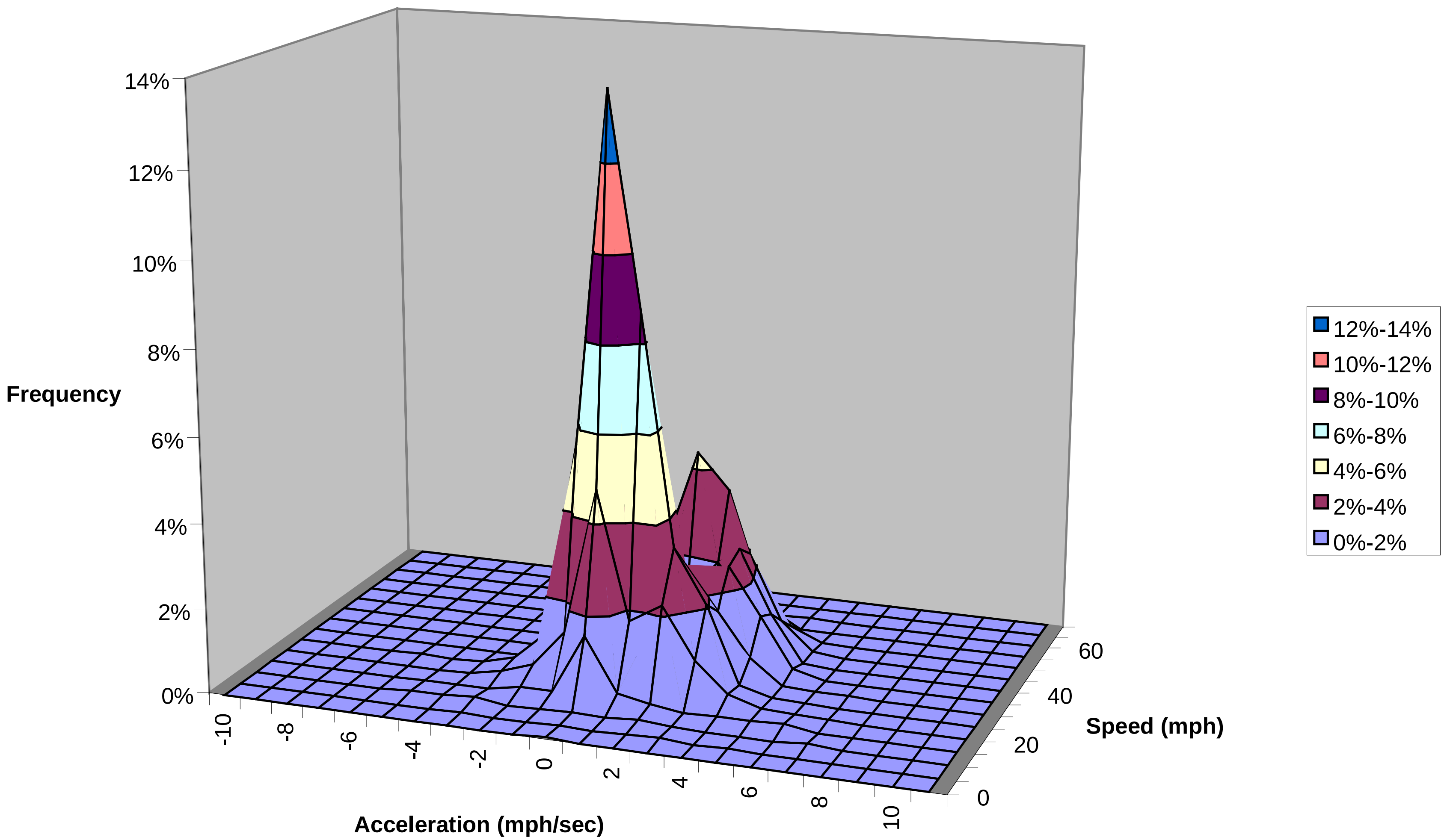


Figure 12
Northside Drive
Non-Metered



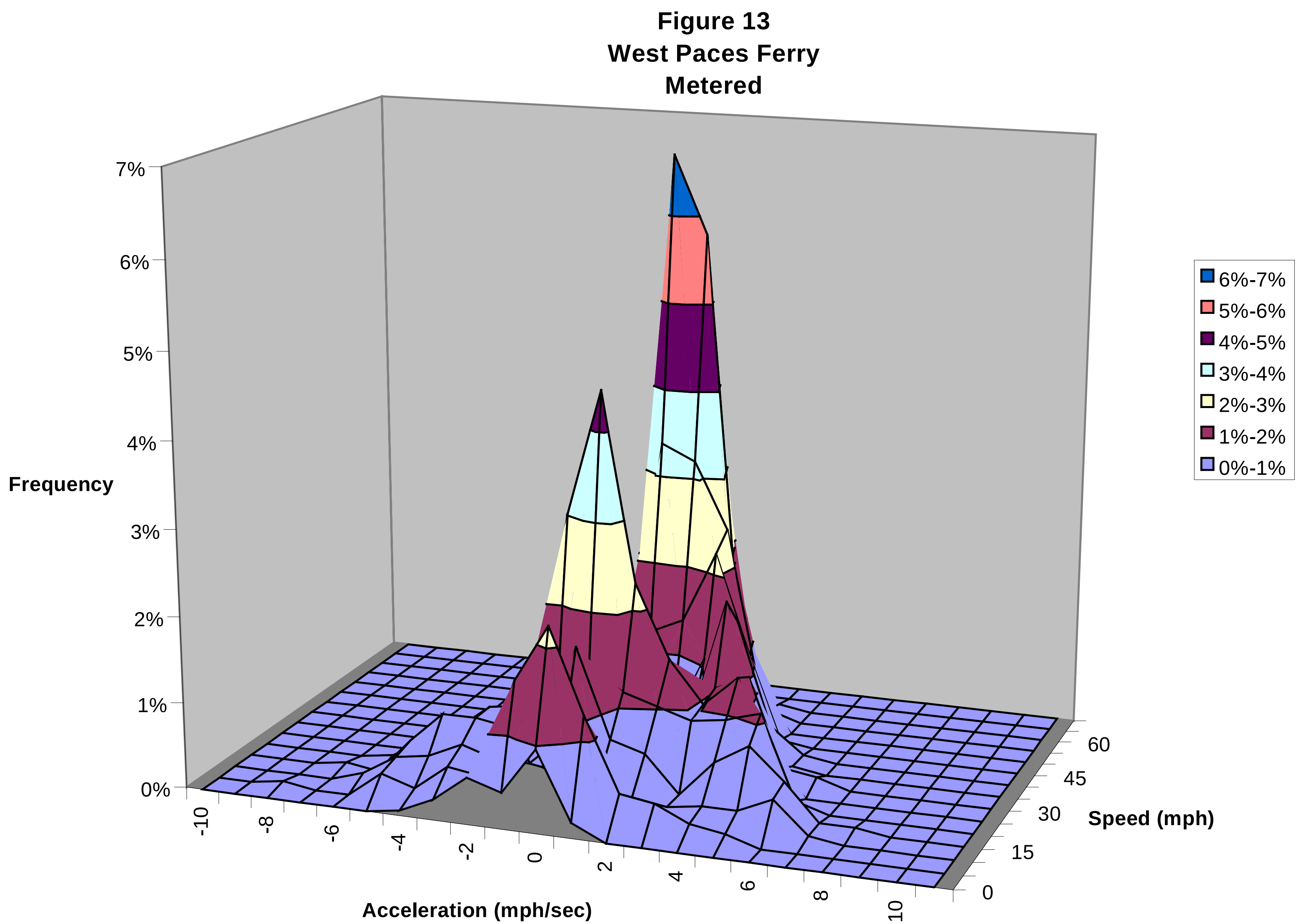


Figure 13
West Paces Ferry
Metered
Frequency
7%
6%
5%
4%
3%
2%
1%
0%
-10
-8
-6
-4
-2
0
2
4
6
8
10
Acceleration (mph/sec)
0
15
30
45
60
Speed (mph)
6%-7%
5%-6%
4%-5%
3%-4%
2%-3%
1%-2%
0%-1%

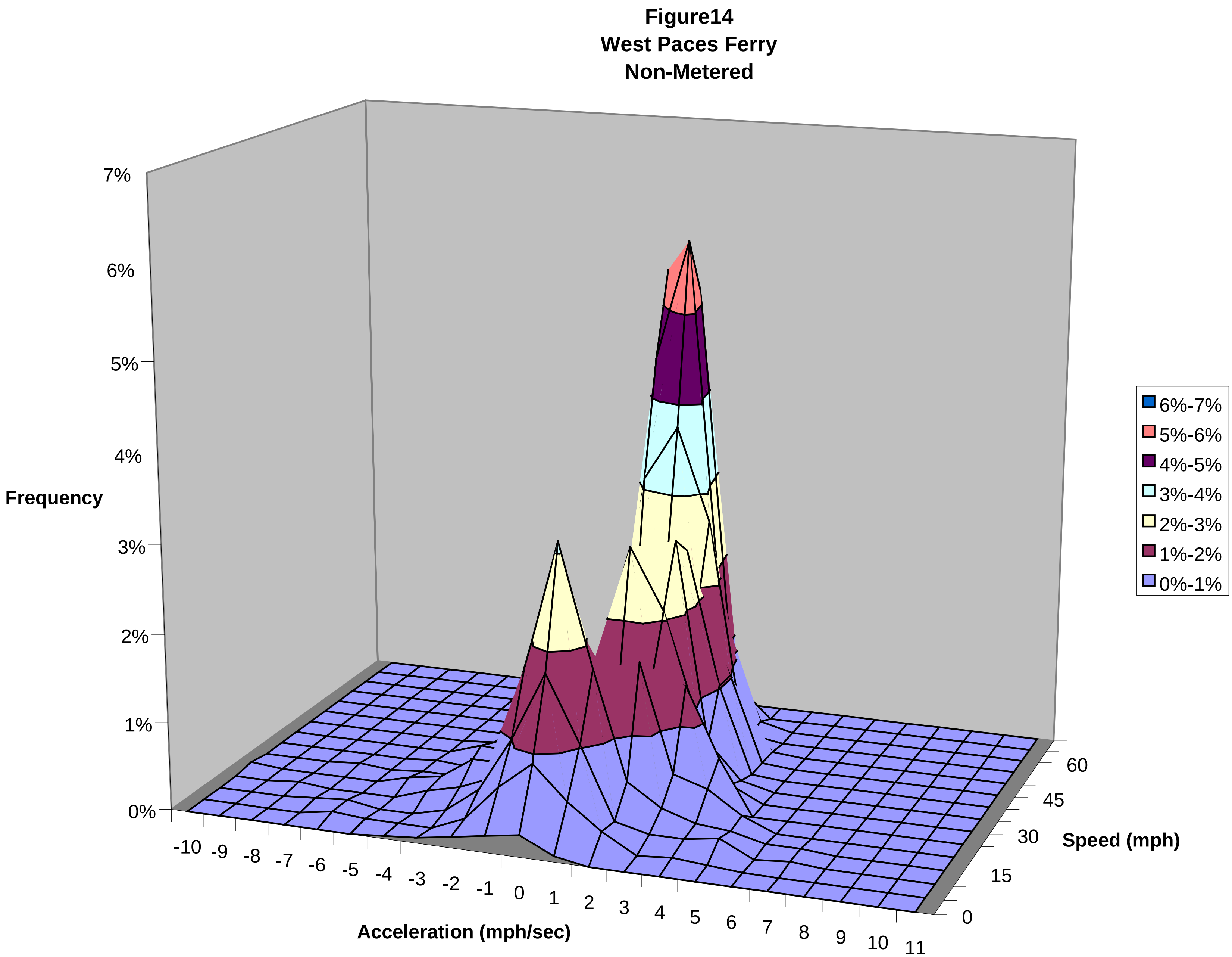


Figure14
West Paces Ferry
Non-Metered
Frequency
7%
6%
5%
4%
3%
2%
1%
0%
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11
Acceleration (mph/sec)
0
15
30
45
60
Speed (mph)
6%-7%
5%-6%
4%-5%
3%-4%
2%-3%
1%-2%
0%-1%