Multimodal Quality of Service
Part I: Truck Level of Service

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16. Abstract

The Systems Planning Office of the Florida Department of Transportation has been one of the national leaders in funding research to develop level of service (LOS) planning analysis methodologies for alternative modes to the automobile. Past research funding by the Department has led to the development of LOS planning analysis methodologies for the modes of bicycles, pedestrians, and transit (bus).

The mode of heavy trucks has traditionally not received specific attention as far as level of service is considered. Trucks are typically converted to an “equivalent” number of passenger cars and the Highway Capacity Manual (HCM) LOS analysis procedures determine a single LOS measure for the traffic stream as a whole, without distinction of possible LOS differences between the different modes operating in that stream.

This report documents an exploratory investigation, and development, of a methodology for assessing the level of service of heavy trucks in the traffic stream separately from that of passenger vehicles, for basic freeway segments. This methodology is based on a ‘relative maneuverability’ concept, which is a function of the ratio of percentage of free-flow speed of trucks to percentage of free-flow speed of passenger cars. Speed prediction equations were developed for various classes of trucks, as well as for the passenger car, for use in calculating a ‘Relative Maneuverability Index’, which is subsequently used to determine truck level of service. Microscopic simulation was used for the speed prediction model development. This document also briefly discusses some other potential alternative approaches and measures for assessing truck level of service that have conceptual and technical merit.

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Executive Summary

Since the 1970s, the Transportation Research Board (TRB) and its member organizations have developed complex analytic tools to examine highway levels of service throughout the U.S. This analytic process is documented in the TRB's Highway Capacity Manual (HCM) through a series of editions. Until the 1990s, there was little work in the development of measures to assess the quality of service for transportation modes other than the automobile, including those for bicycles, pedestrians, transit and trucks.

The Florida Department of Transportation (FDOT) has recently developed level of service (LOS) methodologies at a planning level for the modes of bicycles, pedestrians, and transit. This project is focused on exploring the development of a level of service methodology specific to the mode of large trucks. Although the passenger car (PC) is by far the most dominant mode of transportation on the roadway system, heavy vehicles (e.g., commercial trucks) are also a very important mode because freight movement is vital to Florida's, as well as the Nation's, economy. Consequently, it is important to know whether or not trucks are actually obtaining the same level of service as passenger cars, especially since they typically have very different physical and performance characteristics. The emphasis on this study was exploratory. That is, to explore the concept of developing a separate LOS methodology for trucks—the theoretical and conceptual feasibility of developing such a methodology and consideration of practical and technical barriers.

This study developed a preliminary methodology for assessing truck level of service for basic freeway segments. This methodology is based on a 'relative maneuverability' concept, which is a function of the ratio of percentage of free-flow speed of trucks to percentage of free-flow speed of passenger cars. This document also briefly discusses some other potential alternative approaches and measures for assessing truck level of service that have conceptual and technical merit.

Conceptually, the 'relative maneuverability' approach is based on the premise that trucks have more difficulty utilizing available gaps in the traffic stream than passenger cars due to their larger size and lesser performance capabilities. Thus, as the traffic density increases, trucks will have relatively fewer gaps available to them for making passing maneuvers for the purpose of maintaining their desired speed. This will result in trucks, on average, not being

able to maintain as high of a percentage of their desired free-flow speed relative to passenger cars.

Central to the development of a truck level of service methodology based on this concept was the development of speed prediction models by vehicle class, for various roadway and traffic variables. In this study, a microscopic simulation based approach was taken. This allowed for reasonably accurate modeling of traffic streams and the ability to execute an extremely large number of experiments, which were necessary for developing a robust and statistically valid model. This simulation model was calibrated with field data from a section of Interstate-4 in the downtown Orlando, FL area.

The results of this study represent a good starting point for the consideration of methodologies for the separate assessment of truck level of service for a mixed vehicle class traffic stream on a specific roadway facility. The report concludes with specific recommendations on future research that should be conducted before implementation of such a methodology.

1 Introduction

1.1 Project Purpose

Since the 1970s, the Transportation Research Board (TRB) and its member organizations have developed complex analytic tools to examine highway levels of service throughout the U.S. This analytic process is documented in the TRB's Highway Capacity Manual (HCM) [1] through a series of editions. Until the 1990s, there was little work in the development of measures to assess the quality of service for transportation modes other than the automobile, including those for bicycles, pedestrians, transit and trucks.

The Florida Department of Transportation (FDOT) has recently developed level of service (LOS) methodologies at a planning level for the modes of bicycles, pedestrians, and transit. This project is focused on exploring the development of a level of service methodology specific to the mode of large trucks. Although the passenger car (PC) is by far the most dominant mode of transportation on the roadway system, heavy vehicles (e.g., commercial trucks) are also a very important mode because freight movement is vital to Florida's, as well as the Nation's, economy. Consequently, it is important to know whether or not trucks are actually obtaining the same level of service as passenger cars, especially since they typically have very different physical and performance characteristics. The emphasis on this study was exploratory. That is, to explore the concept of developing a separate LOS methodology for trucks—the theoretical and conceptual feasibility of developing such a methodology and consideration of practical and technical barriers.

Since, to date, this has been a relatively unexplored topic, it was not expected to develop a highly refined methodology for truck LOS (for any facility) in this study. Thus, one of the main goals of this initial study was to explore the conceptual issues that might make a case for a specific level of service assessment for trucks. An understanding of these issues could help guide future studies in the proper direction to ultimately provide a comprehensive analysis of truck LOS across all FIHS facilities.

1.2 Problem Statement

The current LOS methodologies prescribed by the HCM for various roadway facilities present single LOS criteria for all vehicles that use the facility. While passenger cars, buses, recreational vehicles, and heavy trucks all use these facilities, the LOS values determined by HCM procedures are intended to apply to the traffic stream as a whole.

With this method of determining level of service, trucks and passenger cars cannot be examined separately. It is important to determine if the LOS indicated for the traffic stream as a whole is actually representative of the LOS for trucks. A fundamental principle in determining level of service, as described in the HCM, is that the chosen measure of effectiveness should correlate with user perceptions of the quality of service being provided by the facility. Given the significantly different physical and performance characteristics of passenger vehicles and large trucks, it is quite possible that truck drivers do not perceive the quality of service in an equal manner to that of passenger vehicle drivers under the same roadway and traffic conditions.

1.3 Research Direction

One of the first tasks of this project was to consider the various directions that this research could take in terms of facilities considered and potential research approaches. Since this research project was intended to be exploratory, the FDOT was initially very flexible with regard to the direction this research project eventually took. Thus, a document was produced that outlined the investigation of a LOS methodology that would explicitly consider trucks for different types of roadway facilities. In particular, this document outlined approaches with regard to interrupted flow (e.g., signalized intersection) and uninterrupted flow (e.g., freeways) facilities. This document was originally submitted to the FDOT in November 2000, and was entitled “Conceptual Framework/Possible Research Directions”. This document is included in Appendix A.

After review of this document by FDOT staff, and subsequent discussion with UF research personnel, it was decided to investigate the truck LOS methodology with respect to freeway facilities for this research project.

1.4 Literature Review

Another preliminary task of this project was to search the literature for any relevant research. The intent of this search was to determine if any other researchers had investigated the issue of developing separate measures for level of service for different modes within the same traffic stream, particularly with respect to the mode of large trucks.

Overall, the concept of developing separate level of service evaluation methods for different modes in the same traffic stream (particularly for motorized modes) has been relatively unexplored. Although there are a number of studies that are peripherally related, in terms of trucks and traffic flow theory, nothing in the literature specifically addressed the issue of separate levels of service for different classes of vehicles within the same traffic stream. The literature search summary is included in Appendix B.

2 Current and Proposed Level of Service Methodologies

This chapter will review the current level of service methodology prescribed by the Highway Capacity Manual for basic freeway segments and then discuss the conceptual approach taken by the research team to develop a methodology that can discern trucks from passenger cars.

2.1 Current LOS Methodology for Freeways

The Highway Capacity Manual (HCM) defines a freeway as “a divided highway [that provides uninterrupted flow] with full control of access and two or more lanes for the exclusive use of traffic in each direction”. Factors that affect level of service (LOS) on basic freeway segments include number of lanes, lane width, lateral clearance, horizontal and vertical alignments, interchange density, free-flow speed, and percentage of heavy vehicles in the traffic stream.

Density is the prescribed service measure for multilane uninterrupted-flow facilities by the HCM. Density is a function of traffic volume and average vehicle speed [Density = volume (veh/hr) / speed (mi/hr)]. Density is preferred over speed because speed is relatively insensitive to increasing flow (until flow begins to approach capacity). But as vehicle volumes increase, vehicles become more constrained in their ability to make both lateral and longitudinal position adjustments. Thus, as the density of the traffic stream increases, motorists perceive a decreased ability to travel their desired speeds and to maneuver between lanes, and thus a lower LOS. Density encompasses this concept well, and thus possibly correlates well with driver perceptions of the quality of service.

The density ranges, measured in passenger cars-per-mile-per-lane (pc/mi/ln), that define the LOS thresholds in the HCM are shown in Table 1.

Table 1. Level of Service Thresholds

Level of Service	Density Range (pc/mi/ln)
A	0 – 11.0
B	> 11.0 – 18.0
C	> 18.0 – 26.0
D	> 26.0 – 35.0
E	> 35.0 – 45.0
F	> 45.0

Trucks are accommodated in the analysis methodology through a concept referred to as passenger car equivalents (PCEs). A PCE is the number of passenger cars displaced by a single heavy vehicle under specific roadway and traffic conditions. Thus, the PCE is used to convert a traffic stream that consists of some percentage of passenger cars and heavy vehicles into an “equivalent” number of passenger cars only in the traffic stream. So although this concept accounts for trucks in the traffic stream, the overall methodology does not treat trucks explicitly with regard to a level of service measure.

2.2 Conceptual Approach for New LOS Methodology

The obvious shortcoming of the HCM’s LOS methodology is that the determined LOS value applies to the traffic stream as a whole, passenger cars and trucks alike. This section describes the conceptual approach taken to developing a level of service methodology for freeway facilities in which trucks can be analyzed separately. In describing this conceptual approach, it is first necessary to state a few key assumptions that underlie it, as follows.

1. One of the primary desires for roadway users is to be able to maintain their speed of choice. This is particularly true for truck drivers that have delivery deadlines to meet. As the density of traffic increases, a driver’s ability to maintain their desired speed decreases.
2. When a driver approaches a vehicle in its lane that is traveling at a slower speed, the driver of the faster vehicle will usually try to change lanes in an effort to maintain his/her desired speed before resorting to reducing their speed (particularly in the case of a driver using cruise control).
3. Truck drivers are generally more aggressive in trying to maintain their desired speed due to the relatively longer period of time necessary to re-accelerate to their desired

speed and schedule pressures. Thus, the distribution of truck driver behavior is skewed/shifted more towards the aggressive driver end of the scale than that of passenger vehicle drivers.

The first two assumptions are generally consistent with those cited in other traffic flow theory related studies (see Donnel, et al. [2]; Hoogendoorn and Bovy [3]).

From a driver's perspective, density can be considered to be analogous to a vehicle's ability to maneuver (both laterally and longitudinally) in the traffic stream. The ability to maneuver within the traffic stream is characterized by a vehicle's ability to utilize gaps in the traffic stream. The more gaps a driver can utilize, the easier it will be for the driver to maintain his/her desired travel speed. When making a lane change, there will be a minimum time between the passage of two successive vehicles (i.e., critical time gap) in the adjacent lane required by a driver before attempting to utilize the gap (analogous to gap acceptance theory of two-way stop-controlled intersections). Driver characteristics, such as aggressiveness, and vehicle characteristics, such as size and performance, will influence the critical gap value.

Based on the premise that truck drivers are more aggressive, in general, than passenger car drivers, it is plausible that truck drivers will be more aggressive in trying to utilize available gaps in an effort to maintain their desired speed. The ability to utilize available gaps to maintain desired speed can be thought of in terms of passing opportunities. However, as congestion (i.e., density) increases, available gap frequencies and sizes will decrease. With the combined effect of lesser acceleration capabilities, and substantially longer vehicle lengths, there will be a smaller percentage of gaps available for trucks to use, for any given density. This translates to a lower level of maneuverability for trucks relative to passenger cars, which ultimately means that truck drivers will be less able to travel their desired speed, on average, than passenger car drivers. Thus, at a given density, the LOS perceived by truck drivers is likely to be less than that perceived by passenger car drivers. The obvious exception to this is at the ends of the traffic flow spectrum (i.e., free-flow and stop-and-go conditions). Under free-flow conditions, by definition, drivers are able to maintain their desired speed due to negligible vehicle-to-vehicle interactions. Thus, both truck and passenger car drivers should consider this condition to be LOS A. Under stop-and-go conditions (i.e., forced-flow), vehicle speeds and passing opportunities are minimal for both vehicle types, and this would be perceived as LOS F for all drivers.

2.3 Proposed LOS Performance Measure

For any given set of traffic and roadway conditions (except for ideal conditions[1] or forced-flow conditions), it is hypothesized that average truck speeds will be lower than average passenger vehicle speeds because of a lower level of maneuverability. Thus, percent of free-flow speed (on a segment-specific basis) for trucks relative to that of passenger cars, for a common density, is proposed as a potential performance measure to be used in determining LOS for trucks.

2.4 Proposed General LOS Methodology

Level of maneuverability is seen as a measure of a driver's ability to maintain their desired speed under a given set of traffic and roadway conditions. As discussed above, it is theorized that truck maneuverability in the traffic stream decreases at a faster rate than that for passenger vehicles as density increases. Thus, the perceived LOS for trucks will decline at a faster rate than that for passenger vehicles. There are certain traffic stream and roadway characteristics that are likely to have a more significant impact on truck maneuverability than passenger vehicle maneuverability. These factors will be discussed in the research methodology section. In general, it is proposed that truck LOS be a function of a 'Relative Maneuverability Index (RMI)', as indicated in equations 1 and 2 below.

$$\text{Truck LOS} = f(\text{Relative Maneuverability Index}) \qquad \text{[Eqn. 1]}$$

Where:

$$\text{RMI} = \frac{\%\text{Free Flow Speed}_{\text{trucks}}}{\%\text{Free Flow Speed}_{\text{cars}}} \qquad \text{[Eqn. 2]}$$

Under low density, ideal conditions, % of Free Flow Speed (%FFS) for both trucks and cars should be at or near 100%; thus LOS should be same (i.e., 'A'). Under high density (at or near jam), %FFS for both trucks and cars should be at or near 0%; thus, LOS should be same (i.e., 'F'). At densities in between, %FFS for trucks will probably be less than that for cars, thus giving a ratio less than 1.0.

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[1] Free-flow speeds, no horizontal or vertical curvature, basic freeway segment (i.e., no on/off ramps)

Dividing this ratio into the overall traffic stream density will give the density at which the same LOS value occurs for trucks.

The ‘percent free-flow speed’ measure would be a function of traffic and roadway characteristics, such as volume and grade. One of the objectives of this research was to identify and quantify appropriate traffic and roadway factors for this function and establish the mathematical form of this function.

3 Research Approach

The research approach consisted of the following steps:

1. Identify the traffic and roadway variables of interest to this study,
2. Decide on a method for studying those variables (e.g., field study, simulation),
3. Develop an experimental design,
4. Conduct the study according to the experimental design, and
5. Develop an example truck level of service methodology based on the experimental results.

3.1 Identify Traffic and Roadway Variables

There are several potential traffic and roadway variables that can impact vehicle maneuverability (both longitudinally and laterally) within the traffic stream. Additionally, some roadway factors will have a greater effect on the ability to maintain a desired speed (longitudinal mobility) for trucks than passenger cars. A brief discussion of these variables now follows.

3.1.1 Traffic Variables

- **Volume:** Traffic flow theory has demonstrated the relationship between volume and speed. Before breakdown conditions, increasing volume leads to increasing density, which again, is theorized to have a more detrimental effect on truck maneuverability than on automobile maneuverability, and thus, a lower LOS is provided to trucks for certain volume levels.
- **Percent heavy vehicles:** It was initially postulated that an increasing percentage of trucks within the traffic stream would decrease the LOS for trucks because of their impacts on available gaps for maneuverability. It was also postulated that this would only hold until a certain point when the percentage of trucks became so great that the dynamics of the truck platoons would begin to dominate the flow of the traffic stream. From a driving comfort standpoint, the perceived level of service for passenger vehicle drivers would probably decrease with the increase in truck percentage.

3.1.2 Roadway Variables

- **Horizontal curvature (radius, superelevation):** Relatively sharp curves will often lead to truck drivers slowing from their normally desired travel speed.
- **Vertical curvature (i.e., grades):** It is well documented that grades have a more significant impact on trucks than automobiles. For downhill grades, poorer braking and deceleration characteristics typically lead to trucks accelerating on downhill segments. For uphill grades, the power-to-weight ratio of trucks becomes a liability and for a length of extended grade, trucks will not be able to maintain their desired speed as much as on a level grade. Extended inclines are probably the most significant roadway variable with regard to a truck being able to maintain its desired speed.
- **Lane widths:** Narrow lane widths can cause reductions in speed due to trucks and passenger cars in adjacent lanes being in closer proximity.
- **Presence of on/off-ramp, and type (loop, diamond, directional, etc.):** In general, the presence of an on-ramp or off-ramp in the freeway section results in pockets of reduced speed in the merging/diverging area, particularly in the outside lane. As a result, many through vehicles try to move out of outside lane when approaching merge/diverge sections. As density increases, trucks will be at a disadvantage in this situation because of fewer acceptable gaps for lateral movement.

  It is also expected that varying ramp configurations will have differing impacts on truck speeds. For example, loop ramps, with their tight radii, result in relatively low truck speeds on the ramp, and subsequently lower merging speeds on the mainline because of lesser acceleration capabilities. Likewise, exiting trucks will generally have lower mainline speeds when approaching a loop ramp versus a directional ramp because trucks will begin to decelerate sooner in anticipation of the lower loop ramp design speed.
- **Truck lane restrictions:** Facilities with a lane or lanes that are prohibited from truck usage obviously constrain the lateral (and consequently longitudinal) mobility of trucks more than passenger cars. Having fewer travel lanes available for use by trucks than passenger cars would logically result in truck drivers perceiving a lower level of service than passenger car drivers.

3.2 Method of Study

Several possibilities were discussed for studying the effects these variables have on maneuverability. Two approaches that were totally field-data based and eventually removed from consideration are discussed briefly below:

- Pacing trucks with vehicles equipped with GPS (Global Positioning System) units. The concept was that by essentially "shadowing" trucks in the traffic stream, reasonably accurate field data could be obtained on their speed, acceleration, and lane change characteristics. This method, however, has several practical difficulties—"shadowing" a large truck on the roadway could be inherently dangerous; as density increases it may not always be possible to match a truck's lane changing behavior; getting a statistically valid sample size for any given segment could require a prohibitive amount of resources.
- Recording traffic flow over a segment of roadway using video cameras. From the video, travel speeds, headways, and lane changing behavior would try to be observed and measured. This type of approach would be very difficult and laborious. Measuring headways and speeds from video requires very good distance calibration pavement markings. However, lane changing behavior could be the most difficult item, as a video camera set up for viewing along a fairly extended length of roadway segment would be necessary, and a tremendous amount of video would be necessary to gain a statistically valid sampling of lane change maneuvers for any particular section. And of course many different segments would need to be recorded to account for varying roadway characteristics.

Given the practical limitations and difficulty with just about any completely field-based approach, it was decided to use a simulation-based approach. A simulation-based approach, in particular microscopic simulation, would allow very detailed traffic flow data from each and every vehicle in the traffic stream to be obtained, and avoid the difficulties and danger with a field-based approach.

In general, microscopic simulation models are much better suited for studying issues that require performance measurements specific to different vehicle types, due to the ability to model individual vehicles. Some progress has been made since the mid-90's toward the development of macroscopic traffic flow models that consider more than one vehicle class (see Hoogendoorn and Bovy [3,4]; Daganzo [5]). However, these models have not been extensively tested or validated, and of course are more limited in the traffic and roadway factors that can be considered due to their macroscopic nature. Furthermore, the mathematical foundation of these models tends to be very complex, requiring numerous assumptions just to be put into a computationally tractable form.

Of course, for a simulation approach to have any validity, the chosen model must be capable of reproducing actual field conditions with reasonable accuracy. For this study, the chosen model must also have a comprehensive set of input variables, particularly with respect to varying vehicle types. A simulation model that meets these requirements is FRESIM (FREeway SIMulation), a component of the CORSIM (CORridor SIMulation) program [6]. FRESIM is a microscopic simulation model, which allows a detailed investigation into the operational parameters of both trucks and passenger cars (e.g., speed, acceleration, headway). In particular, with FRESIM the following is possible:

- Can specify four different truck classifications within the traffic stream,
- Can extract several vehicle operating parameters on a second-by-second, and link-by-link basis (this is facilitated by the use of a custom program incorporating a CORSIM data file reading tool developed by Dr. John Leonard of Georgia Tech University),
- Can specify detailed geometric design factors (e.g., grade), and
- Can specify driver behavior characteristics (e.g., driver aggressiveness).

Vehicle characteristics, such as length and acceleration/deceleration capabilities and driver aggressiveness characteristics are all inputs to the FRESIM microscopic simulation program; thus, these factors will be taken into account in the detailed car-following and lane-changing models of the simulation.

3.3 Experimental Design

As previously mentioned, for a simulation model to have any validity, it must be capable of reasonably replicating field conditions. Other studies (e.g., Webster and Elefteriadou [7]) have shown that FRESIM has this capability. However, like any simulation model, it must be calibrated for each particular study. Thus, the first step in the simulation process was to establish a network for which conditions could be calibrated to measured field conditions.

3.3.1 Calibration of Simulation Model

Since freeway facilities were chosen as the focus of this initial study, a freeway facility needed to be selected for which reliable field data to test the simulation network could be obtained. There were some necessary conditions that the chosen field site must also meet, which included:

- It must experience the full range of traffic flow conditions (free-flow to stop-and-go) on a recurring basis,
- It must have at least a moderate percentage of truck traffic,
- It should have a variety of geometric design characteristics,
- It must also have surveillance detectors from which standard traffic flow parameters (volume, lane occupancy, and speed [if possible]) can be collected, and
- It must be possible to collect truck volume and classification data in some manner.

A facility that met these conditions was I-4 through the downtown Orlando area (see Figure 1). Specifically, the chosen section was from Church St. to Maitland Blvd. This section is approximately 6.5 miles in length, which is long enough to incorporate several segments with varying geometric characteristics, yet short enough to keep the amount of necessary data collection to a reasonable level.

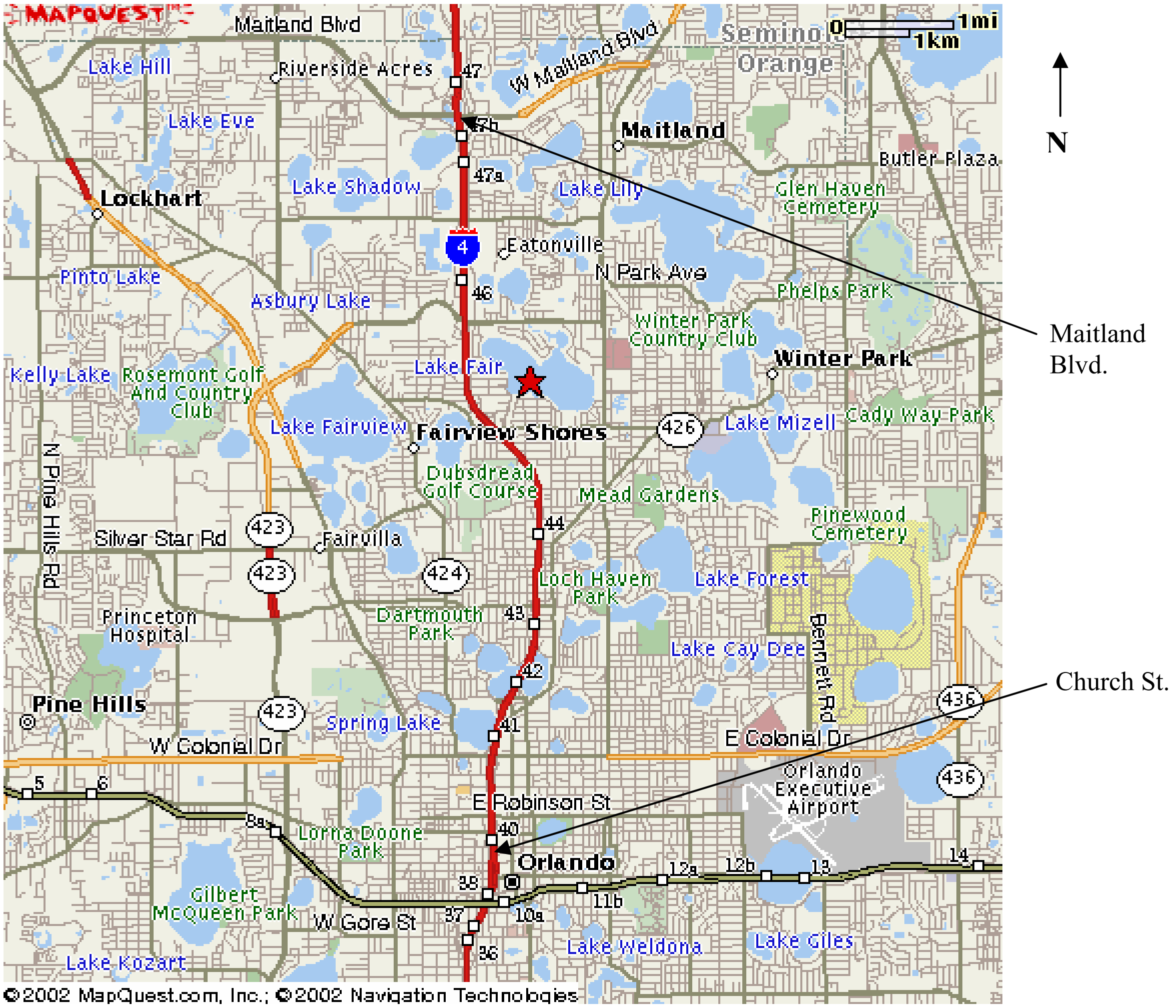

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Figure 1. I-4 in Orlando from Downtown to Maitland

This section is equipped with dual-inductance loop detector stations spaced approximately every half-mile. The dual-loops provide the capability to collect not only volume and lane occupancy data, but also speed data. Furthermore, these data are being archived on a website maintained by the Center for Advanced Transportation Systems Simulation (CATSS) [8] center at the University of Central Florida (UCF). This allowed convenient access to these data. This section is also equipped with several video surveillance cameras. The video can be used to extract truck volume and classification data. From the archived loop detector data, and the truck data obtained from video, the FRESIM model of I-4 can be specified with the same volume and truck input data as is actually occurring in the field. FRESIM also has the capability of modeling inductance loop detectors; thus, detectors can be specified just as they exist in the field and the FRESIM loop measured data can be compared with the field detector data (from the CATSS website). This was the primary model calibration method.

It was decided to calibrate the I-4 network model under the following traffic flow conditions:

- Low density, Free-flow speed
- Medium density, Medium speed
- High density, Low speed

Once the I-4 network was calibrated (within reasonable thresholds), a large variety of traffic flow and roadway conditions could be simulated, with confidence that they were fairly representative of actual field conditions.

3.3.2 Testing Variables

The variables that were initially considered for testing are indicated in Table 2. A brief discussion about each of these variables and their expected role in the testing also follows.

Table 2. Roadway and Traffic Variables

Roadway (Geometric) Variables	Traffic Variables	Combined Roadway and Traffic Variables
Lane width	Traffic volume	Merge/diverge friction from interchange on- and/or off-ramp presence
Horizontal curves	Percent heavy vehicles	
Vertical curves (grades)	Predominant truck length (truck type)	
Truck lane restrictions		

- **Lane width**: Preliminary testing and FRESIM documentation indicated that the FRESIM simulation model does not account for changes in lane width (the same applies for lateral clearances). Furthermore, this variable is rarely less than 12 ft in an urban freeway setting. Thus, this variable was removed from consideration.
- **Horizontal curves**: It was initially theorized that horizontal curvature would have a greater effect on truck speeds than automobile speeds. Again, preliminary testing

also indicated that horizontal curvature had a negligible effect on trucks and automobiles for the typical range of curvature (i.e., combination of radius and superelevation) found on freeway facilities. This variable was also removed from consideration.

- **Vertical curves**: FRESIM has the ability of accepting a wide range of grade and segment length inputs. This variable was included for testing.
- **Truck lane restrictions**: FRESIM allows any lane(s) to be specified as restricted from use by large trucks. Since truck lane restrictions are becoming more common on both rural and urban freeway settings, it was decided to include this variable in the initial study.
- **Traffic volume**: This variable is a direct input to FRESIM and was included in the study.
- **Percent heavy vehicles**: This variable is a direct input to FRESIM, for each truck type, and was included in the study.
- **Predominant truck length**: The intent of this variable was to account for speed variances due to predominance of a particular class of truck in the traffic stream. For example, a facility that gets heavy usage by FedEx type delivery trucks or WB-96 (triple trailer) combinations would likely exhibit different traffic flow characteristics than a facility with a balanced mix of truck types. Modeling of this variable, with its wide range of possibilities, would overly complicate this initial experiment, and thus was removed from consideration.
- **Interchanges**: It was decided that the investigation of the effect of merge/diverge traffic at interchanges was too complex to include in this initial study and warranted a more dedicated comprehensive follow-on study. Thus, the study was essentially restricted to basic freeway segments (i.e., free from the influences of merge and diverge traffic). However, if a truck LOS methodology is to ever be extended to the facility level analysis, it must account for interchange effects.

Thus, traffic volume, percent trucks, grade, and number of lanes restricted from truck use were left as the variables to include for testing. This provided two roadway- and two traffic-related variables.

3.3.3 Factorial Experimental Design

For efficiency in measuring the effects of each of these factors, as well as all of the possible interactions between these factors, a factorial design was chosen for the experiment. A factorial design with four factors, each measured at three levels, is denoted as 3^4. This mathematical notation also indicates the number of runs necessary to account for each unique combination of factor settings—in this case 81. By comparison, if six factors were included in this study, 729 different runs would be required.

Factorial experiments are commonly designed with just two settings (low and high) for each factor. This is appropriate if the researcher has no particular reason to believe that any underlying relationships are non-linear in nature. However, with only two factor levels, it is impossible to test for the possibility of a non-linear relationship. In this experiment, it was decided to include a third factor level (i.e., medium) to be able to test for the possibility of non-linear relationships for any of the factors. The low and medium levels are separated by the same interval as the medium and high levels to test for non-linearity. The variables (factors) and their chosen settings are summarized in Table 3.

Table 3. Experimental Design Factors

Factor	Settings		
	Low	**Medium**	**High**
Volume (vphpl) (vehicles-per-hour-per-lane)	600	1200	1800
Grade (%)	-3	0	3
Number of Lanes Restricted from Truck Use	0	1	2
Percent Trucks	3	9	15

Each of the 81 unique combinations of these four variables for the three different settings is shown in Appendix C.

Additionally, to account for the stochastic nature of the FRESIM model, six replications of each factor combination were run in FRESIM using different random number seeds. These six runs were used to arrive at average values for each factor combination on the experimental section. This resulted in a total of 486 (81*6) separate FRESIM simulation runs being necessary for this experiment.

4 Results

This chapter discusses the results of steps four through six of the research approach outlined in the previous chapter. Step four was to conduct the study according to the experimental design. As indicated in the previous chapter, this step included the development of an I-4 simulation network in the FRESIM simulation program, field data collection, simulation model validation, and performing simulation runs according to the factorial experiment.

4.1 Data Collection

Several sources were utilized to collect detailed information on roadway geometrics and traffic operations for the Interstate-4 network. These sources are described in the subsections that follow. It should be noted that only the eastbound direction of I-4 was used in this study.

4.1.1 Loop Detector Data

The CATSS loop detector data archive web site was used to obtain volume, speed, and lane occupancy data (for the same dates as discussed in the following subsection). The data obtained from this site that was used in this study is shown in Appendix D. This site, however, only contains mainline data—on- and off-ramp volume data had to be estimated from historical tube counts. The FDOT supplied these ramp counts, which were most recently done in January 2000. These volumes were adjusted to maintain consistent percentages with the mainline volumes used for this study. A ramp volume count was also performed for the on-ramp contained in the video picture of Ivanhoe Blvd. to further check for consistency with existing traffic conditions.

4.1.2 Surveillance Camera Video

The FDOT staff at the traffic management center in Orlando assisted us in obtaining recorded traffic video from four different closed circuit surveillance cameras installed along this corridor. A snapshot view from each of the cameras is shown in Figure 2 (a-d). Each of the cameras is pointing north/eastward. The video data were collected for the following dates:

- Wednesday, April 11, 2001
- Thursday, April 12, 2001

- Tuesday, April 17, 2001
- Tuesday, May 22, 2001
- Wednesday, June 6, 2001

It was originally planned to collect the video data from April 10 – 12 (Tuesday – Thursday). Typical weekday volumes were desired; thus Monday and Friday were not used for data collection days. Due to a recording problem on April 10th, another recording for a Tuesday was made the following week (April 17th). However, due to some untimely loop detector data server problems, additional recordings were made until the video data were recorded at a time when the loop detector data for that day and time where also being archived to the server. This was necessary to check for correlation between the video and loop measured volumes. Six hours of traffic were recorded during each session, from 1:30 PM to 7:30 PM. This time frame was intended to capture traffic conditions ranging from free-flow to forced-flow.

a) Camera (30) Church St.

b) Camera (39) Kennedy Blvd.

c) Camera (34) Par Ave.

d) Camera (32) Ivanhoe Blvd.

Figure 2. Surveillance camera snapshot views

After review of the videotapes and the corresponding speed and volume loop data, it was determined that the following time periods provided the representative traffic flow conditions:

- 1:55 – 2:55 PM, low-density data
- 3:15 – 4:15 PM, medium-density data
- 4:30 – 5:30 PM, high-density data

From this video, for these times, lane specific total vehicle volume counts were made and compared to the loop detector data. The specific loop detector station numbers that were utilized, for correspondence with video camera views, are as follows:

- Church St. – #38, 1165+00
- Ivanhoe Blvd. – #42, 1246+00
- Par Ave. – #45, 1325+00
- Kennedy Blvd. – #51, 1471+00

A sample of this information is contained in Appendix E. Additionally, lane-specific truck volume counts and truck classifications were made. Trucks were classified into four categories: single-unit trucks, medium utility trucks, tractor-trailers, and double-bottom trailers, representative of the major categories of heavy trucks. Buses were counted in a separate category. A sample of this information is also contained in Appendix E. For model calibration purposes (discussed in Section 4.2.2), FRESIM input volumes were based on an average of at least two days (from those listed in Section 4.1.2) of the corresponding flow conditions (i.e., low, medium, or high density).

4.1.3 Site Visits

Several drives of the freeway section provided additional field data, which are shown in Appendix F. The section was recorded on video from a moving vehicle, as well as with a global positioning system (GPS) during the high-density period. The GPS information provided actual speed, time, and location information. The locations of all exit warning signs, loop detectors, surveillance cameras, auxiliary lanes, and ramp gores were also recorded. These data aided in the coding of the simulation network input file.

4.2 FRESIM Simulation

This section describes the modeling process employed with the FRESIM simulation program.

4.2.1 I-4 Network Coding

The Florida DOT provided Microstation CAD files that contained the following geometric information:

- Cross section details,
- Vertical grade,
- Horizontal curve length, central angle, degree of curvature, and
- Surveillance camera station locations.

This information, in addition to the information gained from the site visits was used to develop a link-node network diagram that could then be easily translated into a FRESIM input file. FRESIM expects a link-node structure for input file coding. The I-4 network was divided into links that were relatively homogenous with regard to roadway and/or traffic characteristics. For example, a section of roadway that transitions from four lanes to three lanes would be a natural point for a new node, to start a new link (segment). Another example would be a posted speed change along the corridor. Thus, each separate link in our FRESIM input file had at least one roadway and/or traffic characteristic different from the previous link. The location of the inductance loop detectors was estimated from stationing information on the CATSS web site and site visit observations. Figure 3 shows an excerpt from the complete network link-node diagram.

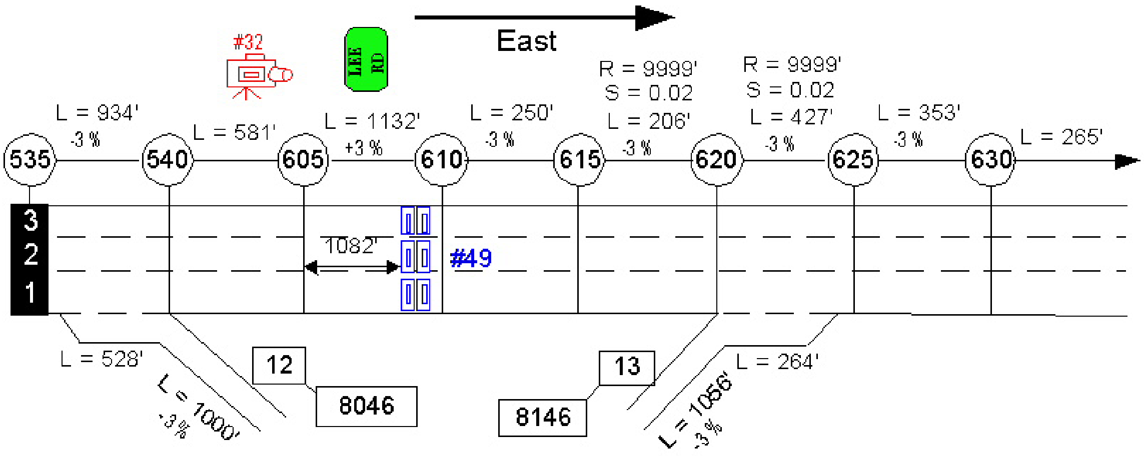


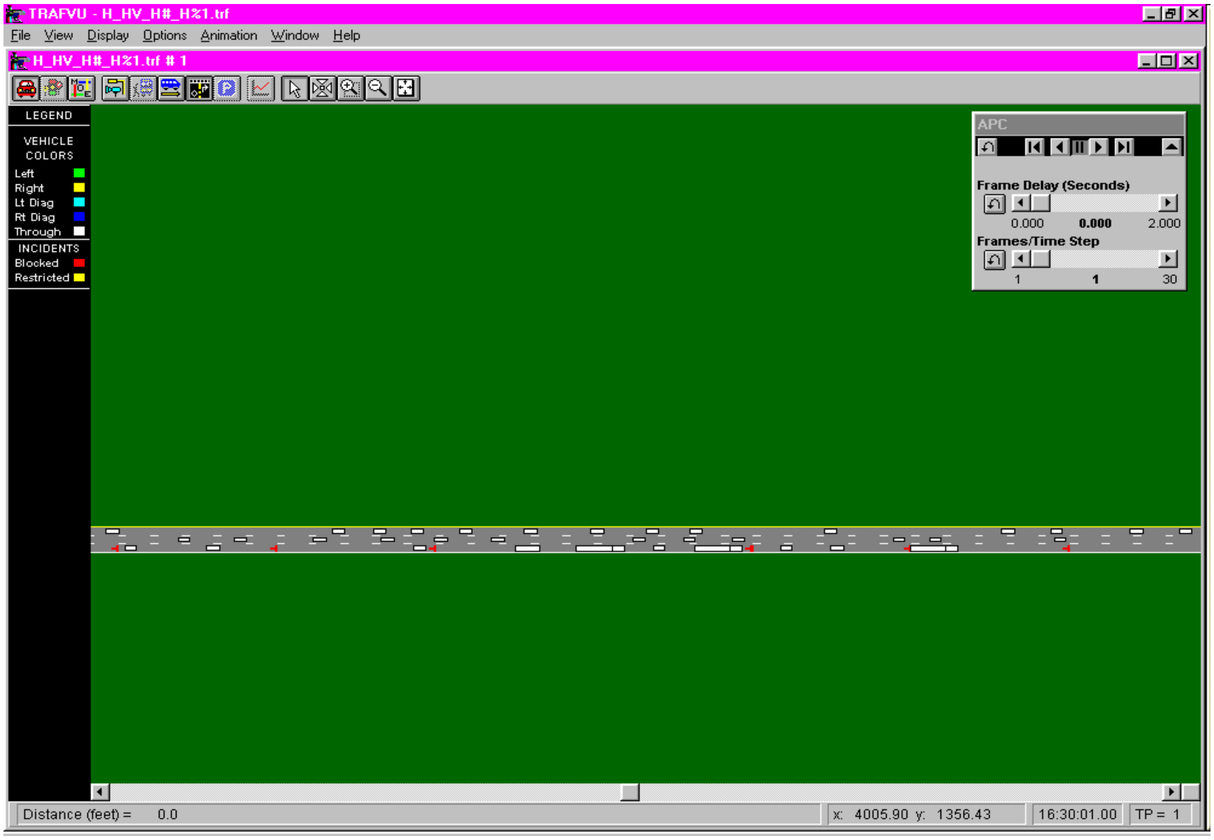
Figure 3. Partial Network Link-Node Diagram

The node numbers are enclosed in circles, with the links connecting the nodes. The nodes are numbered, starting at 100, in multiples of five in accordance with the mile markers on I-4. The node numbering continues with the next hundred at each mile marker. The lanes are numbered such that Lane 1 is the outermost lane. The length of each link is given, in addition to the grade, horizontal curve radius, and superelevation. Both on- and off-ramps are shown with their respective acceleration and deceleration lane lengths and ramp lengths. Loop detectors (e.g., #49) and surveillance cameras (e.g., #32) are also graphically depicted in the diagram. The locations of major cross-streets are also shown. The entire network link-node diagram can be seen in Appendix G. A sample FRESIM input file for the I-4 corridor is shown in Appendix H.

4.2.2 Model Calibration

The low- and medium-density model calibrations were relatively straightforward. The field-measured entry and exit volumes, as well as the truck percentages were used. Since these periods had little to moderate congestion, FRESIM modeled them with reasonable accuracy (volume and speed within 10% of loop data, using an average of 10 runs). The main calibration parameters for these conditions were the free-flow speed and car-following sensitivity factor. Free-flow speeds were adjusted in FRESIM to match loop detector measured speeds under low-flow, low-density conditions. The car-following sensitivity factors were also adjusted to allow vehicles to travel at smaller headways. This was more representative of the generally more aggressive driving behavior observed for these urban traffic conditions and allowed the FRESIM modeled capacities to match more closely with those observed from loop detector volume data. These particular settings were used in all subsequent simulations.

The high-density simulation was much more difficult to calibrate. During this period, the traffic on I-4 experiences stop-and-go conditions. Because the traffic is moving so slowly, the hourly volume is much less than during free flow conditions. When the field-measured volume (as opposed to the true demand volume) was input into FRESIM, the program simulated very light traffic flow conditions, with all the vehicles traveling at free-flow speeds. In order to get FRESIM to model a congested facility, the network had to be “flooded” with the maximum allowed number, 9999 vehicles per hour, entering the facility. This created a backup at the beginning of the network (observed from field data at the Church St. location), thus the vehicles entered at smaller headways and lower speeds, closer to the true conditions vehicles experience on I-4 at this time of day. The TRAFVU (TRAF Visualization Utility) animation component program was used to visually confirm that the roadway section was being modeled correctly. A still view of an animation file is shown in Figure 4. The lane marked with ‘T’s’ is the lane to which truck travel is restricted.



Frame Delay (Seconds) 0.000 (range 0.000 – 2.000)

Frames/Time Step 1 (range 1 – 30)

Distance (feet) = 0.0

x: 4005.90 y: 1356.43

16:30:01.00

TP = 1

Figure 4. TRAFVU Animation Snapshot

4.2.3 Experimental Network

After the FRESIM simulations had been calibrated for the three different traffic flow conditions, an experimental section with the same car-following parameter settings as the I-4 corridor was developed. The experimental section consisted of five consecutive basic freeway segments (i.e., no ramps or weaving areas), each 1500-ft in length. While the volume, percentage of heavy vehicles, and truck lane restrictions were consistent across all five segments, only the middle segment was used to vary the grade (the other segments were level). All segments were also free of any horizontal curvature. Vehicle performance statistics were collected from the middle segment. The leading and trailing segments allow steady-state conditions to be achieved in the middle segment. The link-node diagram for the experimental section is shown in Appendix I.

The decision to use a 1500-ft length for the data extraction middle segment was unfortunately driven more by practical constraints than by a scientific basis. The time-step data (TSD) file processor (which is described in more detail in the following section) extracts the performance statistics for every vehicle every second while it is present on the link of interest. For high-density conditions, this means every vehicle on the link will have statistics recorded for it for many seconds over the course of 1500 ft. Ultimately, this translates to a data file that contains over 50,000 rows (each row representing the performance statistics for a vehicle at a specific time step). These data files were imported into Microsoft Excel for processing with macro-code (i.e., Visual Basic for Applications) for automating the data reduction and compilation process. Excel has an upper limit of 65,000 rows for any individual worksheet. For the high-density condition, this value of 65,000 was nearly exceeded for many of the test scenarios.

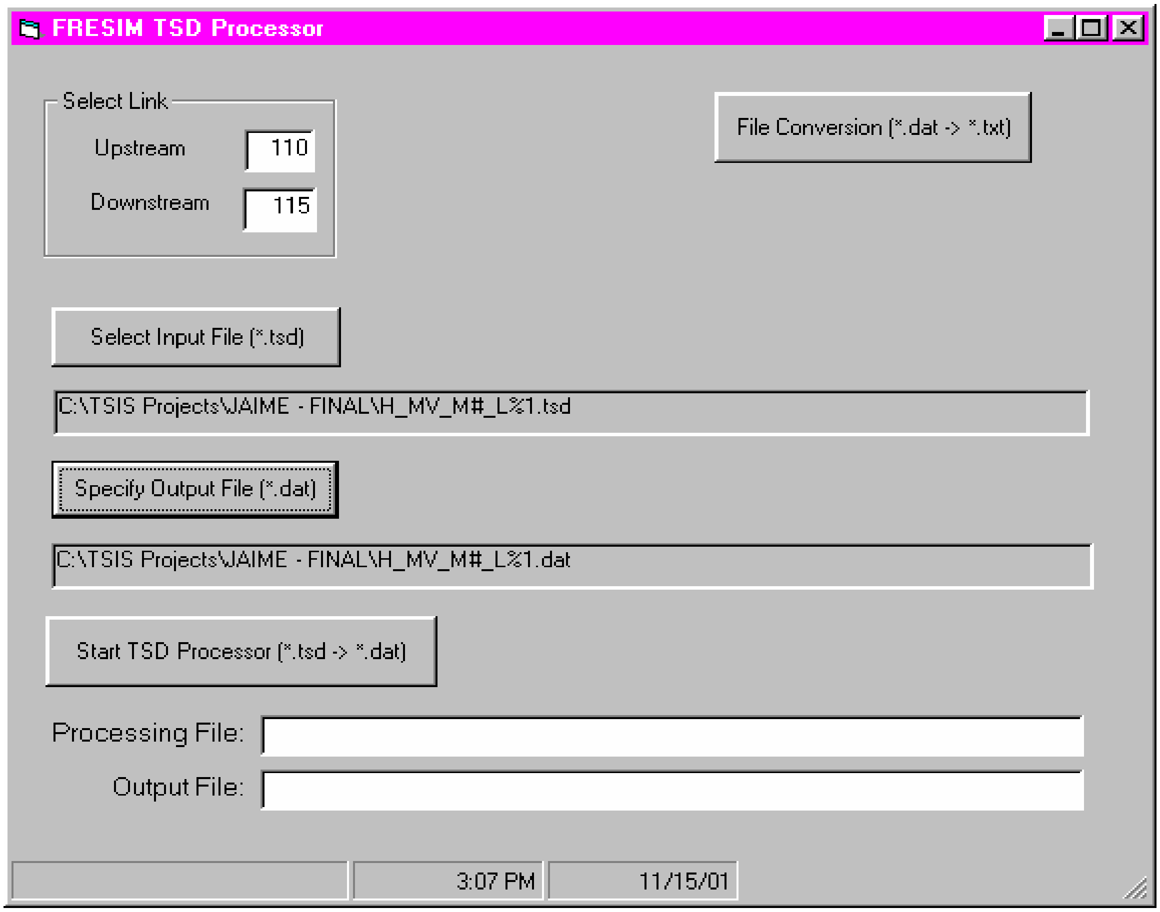
However, it was felt that 1500 ft would be enough length for the grade to exhibit its influence on the traffic stream. Truck speeds of course can be heavily influenced by the length and magnitude of uphill grades; however, it was not the intent of this study to allow trucks to eventually reach crawl speeds. This is unrealistic for typical urban freeway geometries, as well as for rural freeways in the State of Florida.

Another consideration, although not as constraining, was that of the TSD file processing time. The 486 FRESIM simulation runs themselves did not take an inordinate amount of computer processing time. However, the TSD file processing time for each individual TSD file was significantly longer than the time required for FRESIM to produce the TSD file. There was also additional processing time required for the Microsoft Excel macro-code to process each converted TSD file. Thus, any small efficiency made in the experimental network would be translated into a significant time savings for the post-processing effort.

4.3 Model Development

4.3.1 Simulation and Data Processing

As previously discussed, the proposed service measure for assessing truck versus passenger car LOS is percent of free-flow speed (as a surrogate for relative maneuverability). To calculate this measure, the speed of each vehicle in the traffic stream must be individually recorded. FRESIM, however, only reports aggregate measures of performance. Second by second statistics for each vehicle are accumulated in a separate file (.TSD) that is used by the TRAFVU animation program. This file is in a binary format that is normally inaccessible to the average FRESIM user. Dr. John Leonard of Georgia Tech University has developed a software tool (in the form of a dynamic link library) to enable advanced users of the program to access the contents of this TSD file [9]. This tool must be used in conjunction with a custom software program to extract the desired individual vehicle performance statistics from this file. Dr. Washburn wrote the custom program that utilized the dynamic link library to extract the detailed performance statistics. This program extracts the binary information and then converts it into a comma-delimited text file format. The user interface to this TSD file-processing program is shown in Figure 5.



Select Link
Upstream 110
Downstream 115

C:\TSIS Projects\JAIME - FINAL\H_MV_M#_L%1.tsd

C:\TSIS Projects\JAIME - FINAL\H_MV_M#_L%1.dat

Processing File:
Output File:

3:07 PM 11/15/01

Figure 5. TSD File Processing Program User Interface

Each of the data sets representing the 81 different factor combinations were run with FRESIM. Each simulation was run for a period of 15 minutes, after FRESIM initialized the network to an equilibrium condition. The Visual Basic Script (VBS) functionality of CORSIM/FRESIM was used to perform six consecutive runs of each input file (one of the 81 unique factor combinations) with a different random number seed each time.

A file-naming scheme was devised which allowed the TSD Processor to automatically process the six FRESIM replications for a factor combination after the first file was selected. These text files were subsequently opened in Excel. A macro was developed to sort the performance statistics by vehicle type and by vehicle ID, and then compute the average speeds for all vehicle types. The six FRESIM replications for each combination of factors were averaged to arrive at a single measure of average speed for each vehicle type over the variable link in the experimental section. These average values were then treated as a single replication within the factorial analysis. Sample excerpts of the Excel spreadsheets are shown in Appendix J.

4.3.2 Statistical Analysis

Typically, in a factorial analysis, multiple replications of each combination of factor settings provide a measure of experimental error within each unique factor combination. This within-factor combination variance can then be tested against the between-factor combination variance in a standard analysis-of-variance (ANOVA) to determine any significant effects. However, the six replications of each combination of factors were averaged into a single value. This was done to offset the stochastic nature of individual FRESIM runs that might potentially mask significant effects, since the variance resulting from the stochastic nature of FRESIM would be greater than that typically obtained from a carefully controlled replication. Thus, due to the six FRESIM runs for each factor combination being averaged into a single value, there were no replications left for ANOVA purposes.

For this situation where standard ANOVA techniques are not applicable, an alternative analysis method that makes use of probability plots can be utilized. A half-normal probability plot was used to make an evaluation on the potential significance of various factors for each vehicle type. The half- (and full) normal probability plot provides insight as to whether the factor effects approximate samples from an underlying normal distribution or whether the effects are significant. If all of the factor effect estimates lie on an approximately straight line in this plot, then it can be concluded that the variance in speed for this particular vehicle type is essentially a random variable following a normal distribution and not due to any particular factor effects. If a factor effect estimate deviates substantially from this straight line, it can be concluded that this factor is probably significant in explaining variance in vehicle speeds.

The plot[2] for single-trailer trucks is shown in Figure 6. It indicates that three factors are likely significant: grade (both linear and quadratic), volume-per-lane (divided by 100), and the number of lanes with truck restrictions. The volume was divided by 100 so it would be on the same order of magnitude as the other three factor values.

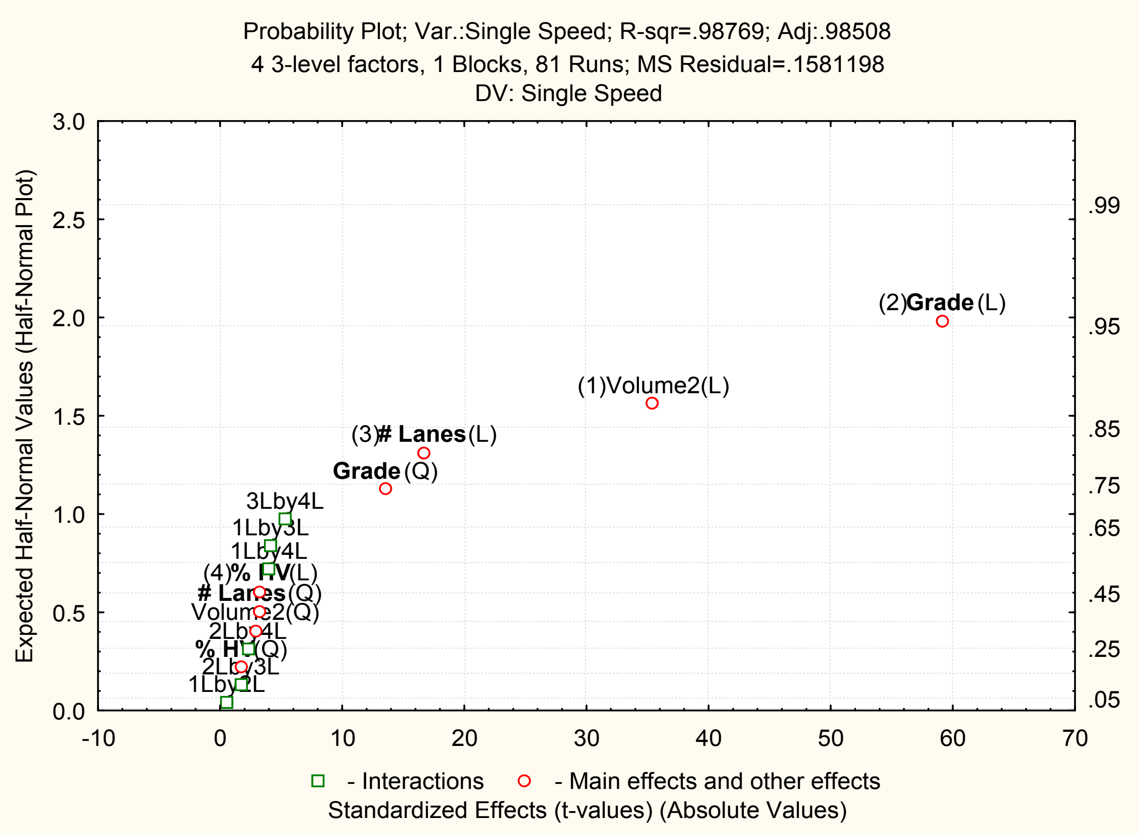


Figure 6. Probability Plot for Single-Trailer Trucks

Results were also checked for the case of using all six replications for each factor combination, yielding 486 data points (81 factor combinations * 6 replications). The half-normal probability plot for these data yielded the same results for factor significance as for the unreplicated case (i.e., using just the average of the six replications). However, with the six replications, one can also examine the t-statistics for factor significance since a measure of within-factor combinations is available. The t-statistic is considered significant when its absolute value is greater than 1.96 (two-tailed t-stat for 95% confidence level). These results are shown in Table 4.

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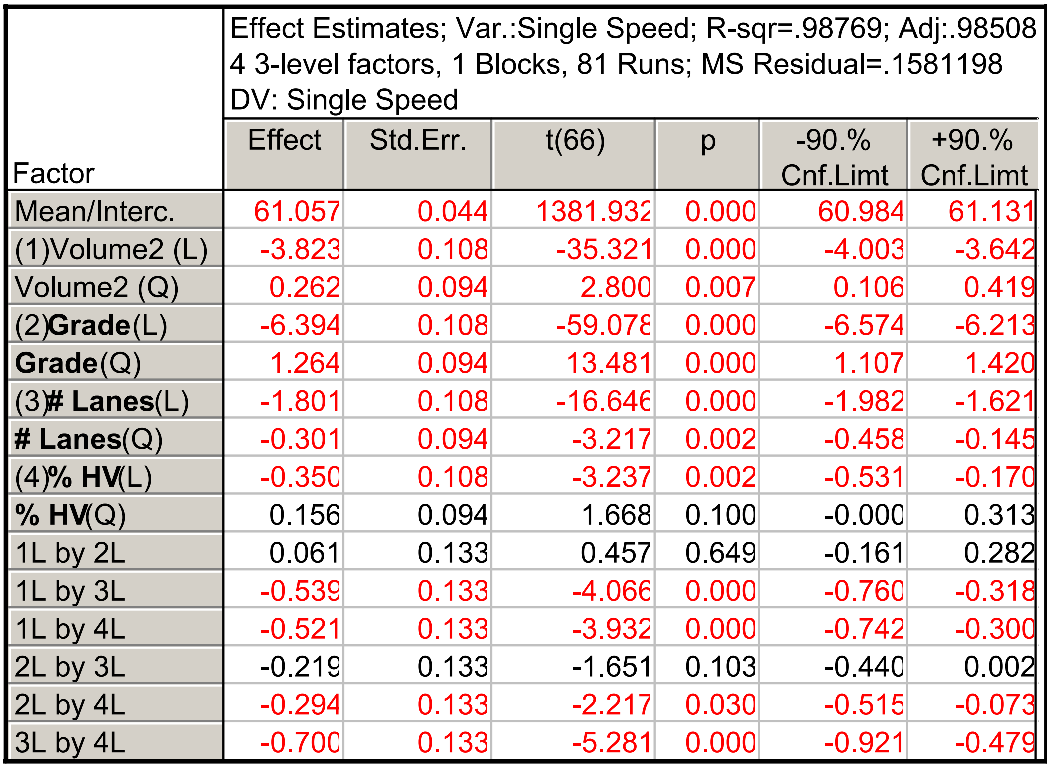
[2] Statistical plots and tables were generated with the 'Statistica' software package [10]

Table 4. Effect Estimates for Single-Trailer Trucks

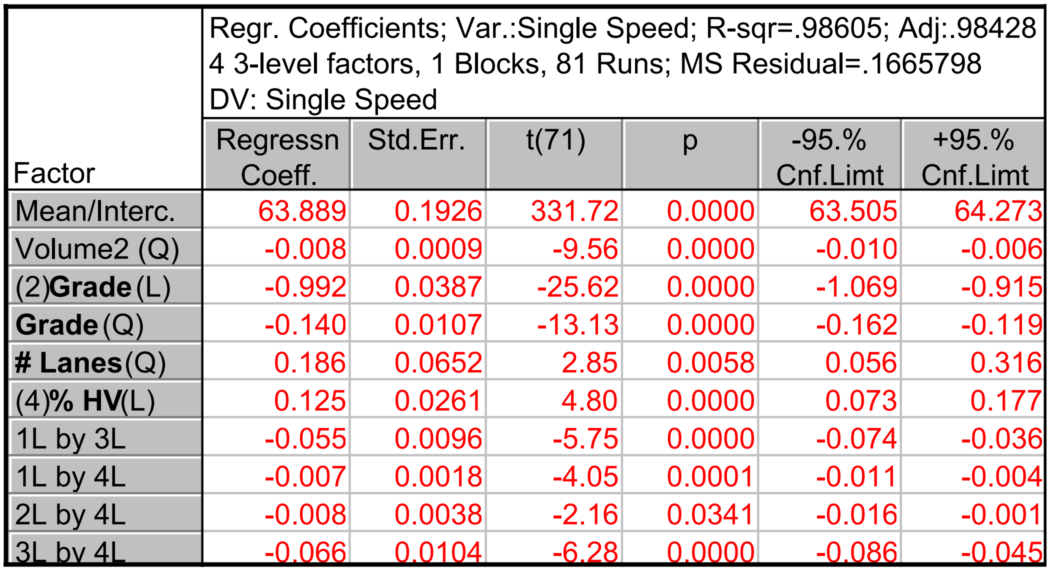


	Effect Estimates; Var.:Single Speed; R-sqr=.98769; Adj:.98508 4 3-level factors, 1 Blocks, 81 Runs; MS Residual=.1581198 DV: Single Speed					
Factor	Effect	Std.Err.	t(66)	p	-90.% Cnf.Limt	+90.% Cnf.Limt
Mean/Interc.	61.057	0.044	1381.932	0.000	60.984	61.131
(1)Volume2 (L)	-3.823	0.108	-35.321	0.000	-4.003	-3.642
Volume2 (Q)	0.262	0.094	2.800	0.007	0.106	0.419
(2)**Grade**(L)	-6.394	0.108	-59.078	0.000	-6.574	-6.213
Grade(Q)	1.264	0.094	13.481	0.000	1.107	1.420
(3)**# Lanes**(L)	-1.801	0.108	-16.646	0.000	-1.982	-1.621
# Lanes(Q)	-0.301	0.094	-3.217	0.002	-0.458	-0.145
(4)**% HV**(L)	-0.350	0.108	-3.237	0.002	-0.531	-0.170
% HV(Q)	0.156	0.094	1.668	0.100	-0.000	0.313
1L by 2L	0.061	0.133	0.457	0.649	-0.161	0.282
1L by 3L	-0.539	0.133	-4.066	0.000	-0.760	-0.318
1L by 4L	-0.521	0.133	-3.932	0.000	-0.742	-0.300
2L by 3L	-0.219	0.133	-1.651	0.103	-0.440	0.002
2L by 4L	-0.294	0.133	-2.217	0.030	-0.515	-0.073
3L by 4L	-0.700	0.133	-5.281	0.000	-0.921	-0.479

The factor rows highlighted in red indicate significance at the 95% confidence level. As can also be seen in this table, the t-statistics (third column of values) for the same factors identified in the half-normal probability plots (volume-per-lane, grade, and number of lanes restricted from truck use) are very large compared to the other factors (and two-factor interactions). Examination of the t-statistics for all factors confirms the very significant factors identified in the half-normal probability plot. Linear factors are denoted by (L) and quadratic factors by (Q). The two-factor interactions are represented by numbers, with 1, 2, 3, and 4 denoting volume per lane, grade, truck-lane restrictions, and percent trucks, respectively.

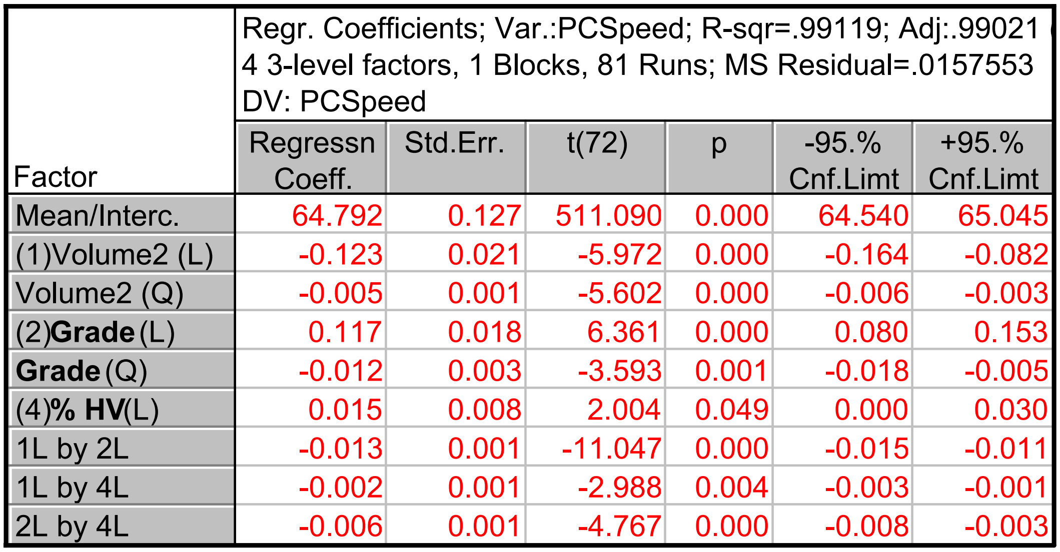
Regression equations were developed from the factorial analysis to predict average speed for each of the different classifications of truck, as well as for passenger cars. Each vehicle type has different factors and interactions that make up the significant regression coefficients. For simplifying purposes, the quadratic interaction effects were excluded from the speed prediction models. The results are shown in the following tables. Table 5 shows the regression coefficients for single-trailer trucks, Table 6 for passenger cars, Table 7 for single-unit trucks, and Table 8 for medium and utility trucks.

Table 5. Regression Coefficients for Single-Trailer Trucks



	Regr. Coefficients; Var.:Single Speed; R-sqr=.98605; Adj:.98428 4 3-level factors, 1 Blocks, 81 Runs; MS Residual=.1665798 DV: Single Speed					
Factor	Regressn Coeff.	Std.Err.	t(71)	p	-95.% Cnf.Limt	+95.% Cnf.Limt
Mean/Interc.	63.889	0.1926	331.72	0.0000	63.505	64.273
Volume2 (Q)	-0.008	0.0009	-9.56	0.0000	-0.010	-0.006
(2)**Grade** (L)	-0.992	0.0387	-25.62	0.0000	-1.069	-0.915
Grade (Q)	-0.140	0.0107	-13.13	0.0000	-0.162	-0.119
# Lanes (Q)	0.186	0.0652	2.85	0.0058	0.056	0.316
(4)**% HV**(L)	0.125	0.0261	4.80	0.0000	0.073	0.177
1L by 3L	-0.055	0.0096	-5.75	0.0000	-0.074	-0.036
1L by 4L	-0.007	0.0018	-4.05	0.0001	-0.011	-0.004
2L by 4L	-0.008	0.0038	-2.16	0.0341	-0.016	-0.001
3L by 4L	-0.066	0.0104	-6.28	0.0000	-0.086	-0.045

Table 6. Regression Coefficients for Passenger Cars



	Regr. Coefficients; Var.:PCSpeed; R-sqr=.99119; Adj:.99021 4 3-level factors, 1 Blocks, 81 Runs; MS Residual=.0157553 DV: PCSpeed					
Factor	Regressn Coeff.	Std.Err.	t(72)	p	-95.% Cnf.Limt	+95.% Cnf.Limt
Mean/Interc.	64.792	0.127	511.090	0.000	64.540	65.045
(1)Volume2 (L)	-0.123	0.021	-5.972	0.000	-0.164	-0.082
Volume2 (Q)	-0.005	0.001	-5.602	0.000	-0.006	-0.003
(2)**Grade** (L)	0.117	0.018	6.361	0.000	0.080	0.153
Grade (Q)	-0.012	0.003	-3.593	0.001	-0.018	-0.005
(4)**% HV**(L)	0.015	0.008	2.004	0.049	0.000	0.030
1L by 2L	-0.013	0.001	-11.047	0.000	-0.015	-0.011
1L by 4L	-0.002	0.001	-2.988	0.004	-0.003	-0.001
2L by 4L	-0.006	0.001	-4.767	0.000	-0.008	-0.003

Table 7. Regression Coefficients for Single-Unit Trucks

	Regr. Coefficients; Var.:SUT Speed; R-sqr=.94198; Adj:.93642 (tru 4 3-level factors, 1 Blocks, 81 Runs; MS Residual=.4224292 DV: SUT Speed					
Factor	Regressn Coeff.	Std.Err.	t(73)	p	-95.% Cnf.Limt	+95.% Cnf.Limt
Mean/Interc.	69.879	0.240	291.754	0.000	69.402	70.357
(1)Volume2 (L)	-0.446	0.015	-30.234	0.000	-0.475	-0.416
(2)**Grade** (L)	-0.150	0.062	-2.437	0.017	-0.273	-0.027
Grade (Q)	-0.054	0.017	-3.144	0.002	-0.087	-0.020
(3)**# Lanes** (L)	-2.044	0.335	-6.101	0.000	-2.712	-1.376
# Lanes (Q)	0.824	0.153	5.382	0.000	0.519	1.130
2L by 4L	-0.019	0.006	-3.080	0.003	-0.031	-0.007
3L by 4L	-0.049	0.011	-4.267	0.000	-0.071	-0.026

Table 8. Regression Coefficients for Medium/Utility Trucks

	Regr. Coefficients; Var.:Med Speed; R-sqr=.96515; Adj:.96283 4 3-level factors, 1 Blocks, 81 Runs; MS Residual=.2930994 DV: Med Speed					
Factor	Regressn Coeff.	Std.Err.	t(75)	p	-95.% Cnf.Limt	+95.% Cnf.Limt
Mean/Interc.	68.085	0.200	341.265	0.000	67.688	68.483
(1)Volume2 (L)	-0.367	0.012	-29.857	0.000	-0.391	-0.342
(2)**Grade** (L)	-0.773	0.025	-31.465	0.000	-0.822	-0.724
Grade (Q)	-0.119	0.014	-8.376	0.000	-0.147	-0.091
(3)**# Lanes** (L)	-1.544	0.266	-5.812	0.000	-2.073	-1.015
# Lanes (Q)	0.374	0.128	2.930	0.004	0.120	0.628

Using the regression coefficients from these models, speed prediction equations were determined. For the example of the single-trailer trucks (Table 5), the equation is:

$$\begin{aligned}\text{Predicted Speed} = {} & 63.88933 + (-0.00818 * (V/100)^2) + (-0.99215*G) + (-0.14039*G^2) \\ & + (0.18568*R^2) + (0.12522*T) + (-0.05522*V/100*R) \\ & + (-0.0074*V/100*T) + (-0.00816*G*T) + (-0.06557*R*T) \qquad \text{[Eqn. 3]}\end{aligned}$$

where:

V = volume in vehicles-per-hour-per-lane,
G = grade in percent,
R = the number of lanes restricted from truck use, and
T = the percentage of trucks in the traffic stream.

For example, if the volume is 1000 vphpl, the grade is 2%, one lane is restricted from truck use, and there are five percent trucks, the predicted single-trailer truck speed is 60.01 mph.

Examination of diagnostic plots of the residuals did not reveal any concerns with the underlying data or model. The plot of the residuals versus the predicted values, seen in Figure 7, shows no particular pattern, which confirms that the errors are random rather than systematic.

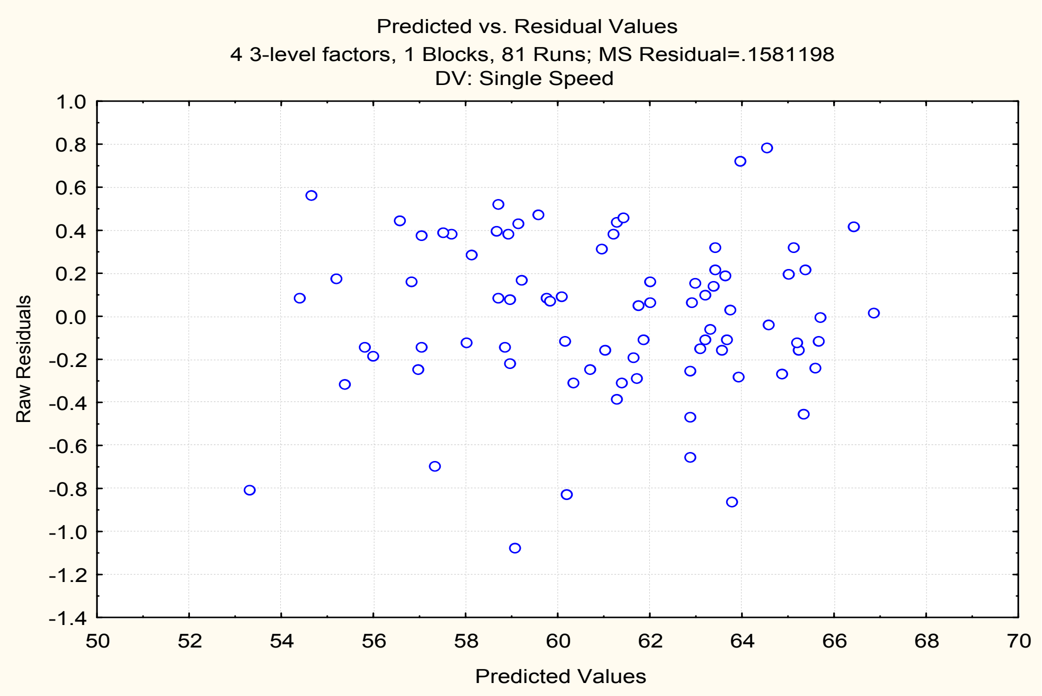


Figure 7. Predicted vs. Residual Values for Single-Trailer Trucks

A normal probability plot of the residuals, shown in Figure 8, indicates that the residuals generally follow a normal distribution, as they should. The residual plots for the other models (i.e., Passenger Cars, Single-Unit Trucks, and Medium/Utility Trucks) were similar.

Figure 8. Normal Probability Plot of Residuals for Single-Trailer Trucks

4.4 Speed Model Validation

The I-4 simulation network was used to test the speed prediction equations developed from the experimental section runs. Since the prediction equations were developed from an experimental section free from ramp merge/diverge effects, test segments were chosen from the I-4 network that were as far from upstream and downstream ramps as possible. Due to the very urban nature of this stretch of I-4, only three segments were identified for testing that were of reasonable distance from upstream and downstream ramps. These segments were as follows (which can be seen in Appendix G).

- 405-410 (1340 feet from upstream on-ramp, 725 feet from downstream off-ramp, 319 feet in length),
- 635-640 (620 feet from upstream on-ramp, 1800 feet from downstream off-ramp, 1868 feet in length), and
- 700-705 (2720 feet from upstream on-ramp, 660 feet from downstream off-ramp, 898 feet in length).

Table 9 shows simulated and predicted speeds for single-trailer trucks with varying grades and lane restrictions on I-4, for medium density conditions and a fixed percentage of trucks. Figure 9 depicts this graphically. The lower line is the y = x line, or the desired relationship between the predicted and simulated speeds. The upper line is the best-fit regression line. As the figure shows, the prediction equation generally over-predicts the I-4 simulated speeds by about 2 mph for these segments. Despite the test segments being the most removed from adjacent ramps, it is likely that the interchanges are still influencing the speeds within these segments. It is theorized that the increased traffic friction at the ramp junctions is causing the lower I-4 speeds relative to the predicted speeds.

Table 9. I-4 Simulated and Predicted Single-Trailer Truck Speeds

Link	Volume (vphpl)	Grade (%)	Restricted Lanes	Percent Trucks	Simulated (mph)	Predicted (mph)	Difference (mph)
405-410	1245	-3	0	9	62.54	64.85	2.31
405-410	1237	-3	1	9	61.57	63.79	2.22
405-410	1229	-3	2	9	61.03	63.10	2.07
635-640	1300	0	0	9	62.89	62.77	-0.12
635-640	1286	0	1	9	59.88	61.69	1.81
635-640	1288	0	2	9	59.64	60.94	1.30
700-705	1291	3	0	9	57.59	58.33	0.74
700-705	1276	3	1	9	54.60	57.27	2.67
700-705	1271	3	2	9	54.47	56.55	2.08

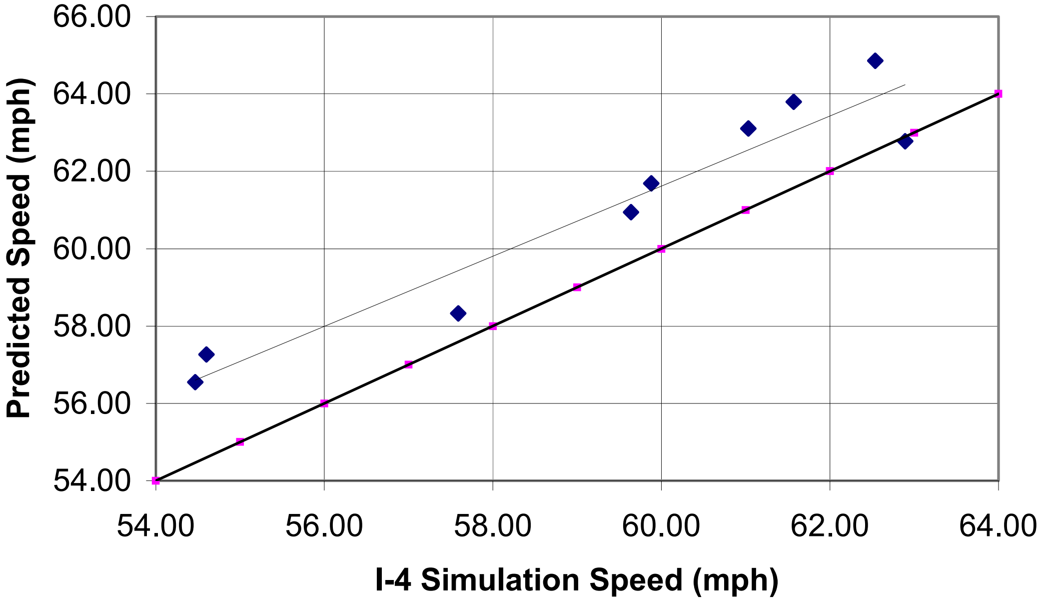


Figure 9. I-4 Predicted vs. Simulated Speeds

The factor that resulted in the most inconsistent effects between the experimental section and the I-4 network was that of the number of lanes restricted from truck use. Lane restrictions applied to all four of the truck types in FRESIM, while buses and PCs were free to use any lane, according to the FRESIM documentation. However, some inconsistent behavior was observed (through the TRAFVU animation) with the modeling of the truck-lane restrictions in some situations. For example, on the I-4 network trucks used only the outermost lane (of three lanes) when only the inside lane was restricted from truck use. In the experimental section, trucks sometimes changed lanes when restricted to just the outermost lane. It may be possible that FRESIM allows violators of truck lane restrictions, but this “feature” is not documented.

Another unexplained result was the fact that single-unit trucks usually had higher average speeds than PCs in both the I-4 simulation model and the experimental section.

4.5 Potential LOS Methodologies

This section provides a discussion about how the speed prediction models developed in this study could be applied to a level of service estimation methodology specific to trucks. There is also further discussion on other potential LOS methodologies that could be pursued with this particular research approach.

An example will be illustrated with the following basic segment characteristics:

- 1500 vphpl
- 3% grade
- 1 lane restricted from trucks
- 5% heavy vehicles

Applying the speed prediction equation for single trailer trucks (Equation 3), yields the following average speed on this segment under these conditions:

$$
\begin{aligned}
\text{Truck Speed} = {} & 63.889 + (-0.00818 * (1500/100)^2) + (-0.99215*3) + (-0.14039*3^2) \\
& + (0.18568*1^2) + (0.12522*5) + (-0.05522*1500/100*1) \\
& + (-0.0074*1500/100*5) + (-0.00816*3*5) + (-0.06557*1*5) = 56.8 \text{ mph}
\end{aligned}
$$

Likewise, applying the speed prediction equation for passenger cars (variables and coefficients from Table 6), yields the following average speed on this segment under these conditions:

$$
\begin{aligned}
\text{PC Speed} = {} & 64.792 + (-0.123 * (1500/100) + (-0.005 * (1500/100)^2) + (0.117*3) \\
& + (-0.112*3^2) + (0.015*5) + (-0.013*1500/100*3) \\
& + (-0.002*1500/100*5) + (-0.006*3*5) = 62.4 \text{ mph}
\end{aligned}
$$

Setting all parameter values equal to zero yields the desired (i.e., ideal conditions) average free-flow speeds for both vehicle types, as follows:

Single trailer truck predicted FFS = 63.9 mph
Passenger car predicted FFS = 64.8 (checks with FRESIM coded FFS of 65,
for I-4 conditions)

Using these speeds to calculate the percent free-flow speed values yields,

% FFS truck = 56.8/63.9 = 0.889

% FFS car = 62.4/64.8 = 0.963

which gives a Relative Maneuverability Index value (from Equation 2) as follows:

RMI = 0.889/0.963 = 0.923

Over the range of traffic flow conditions (i.e., free-flow to forced-flow), the maneuverability index would likely resemble the sample function shown in Figure 10. This parabolic function would yield an index value of 1.0 under "zero" density and ideal conditions because all vehicles would be able to travel their desired speed. At the other end of the spectrum, the index would also be (approximately) 1.0 because all vehicles are under stop-and-go conditions (i.e., traveling the same forced-flow speed) and have extremely limited maneuverability. The jam density value (i.e., 100) and maximum and minimum Index values (i.e., 1.0 and about 0.6) are hypothetical in this graph, as these would vary based upon the specific roadway and traffic conditions. Also, the right half of this curve (increasing part) would correspond to the congested regime of traffic flow, similar to a flow-density curve.

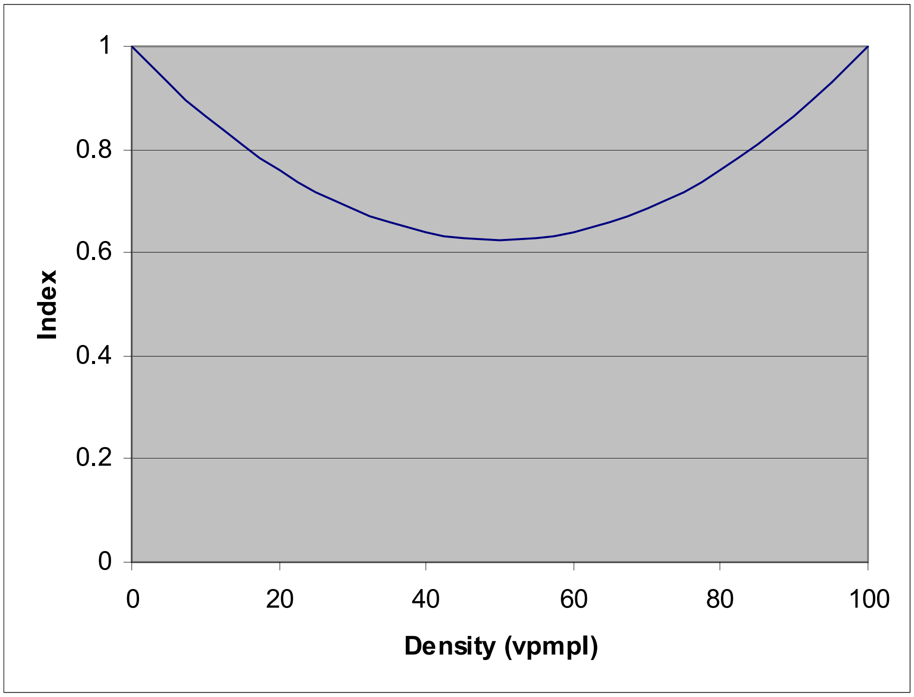


Figure 10. Example Relative Maneuverability Index Function for Truck LOS

The following steps illustrate a possible approach to determining truck level of service using the Relative Maneuverability Index (continuing with the previous example data). An overall traffic stream density is first calculated according to the following equation.

$$\text{Density (veh/mi/lane)} = \frac{\text{volume (veh/hr/lane)}}{\text{speed (mi/hr)}} \qquad \text{[Eqn. 4]}$$

$$\text{Density} = \frac{1500}{(1500 * 0.95 * 62.4) + (1500 * 0.05 * 56.8) \big/ 1500} = \frac{1500}{62.12} = 24.15 \text{ veh/mi/lane}$$

This example calculation uses a volume weighted speed average in the denominator. The density value for trucks can then be calculated with the following equation:

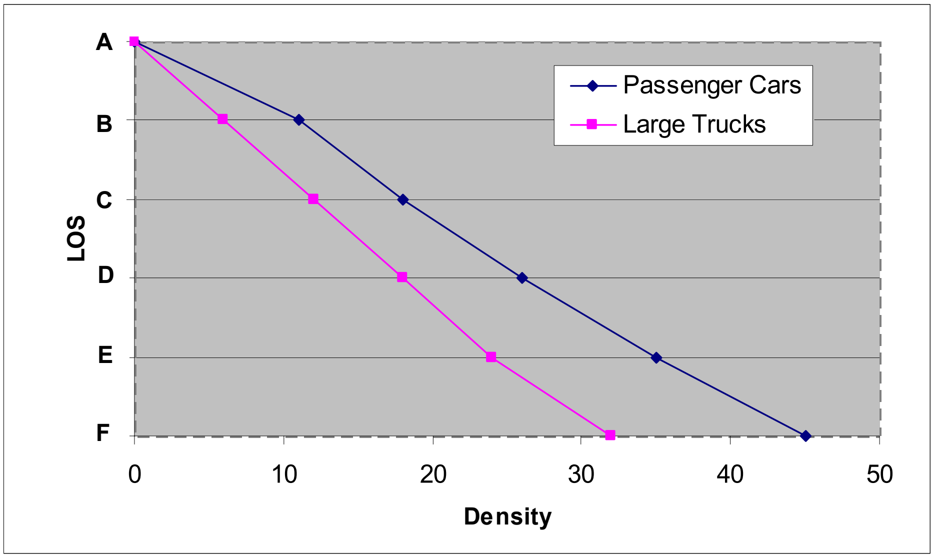
$$\text{Density}_{\text{trucks}} = \frac{\text{Density}_{\text{stream}}}{\text{Relative Maneuverability Index}} \qquad \text{[Eqn. 5]}$$

$$\text{Density}_{\text{trucks}} = \frac{24.15}{0.923} = 26.16 \qquad \text{[Eqn. 6]}$$

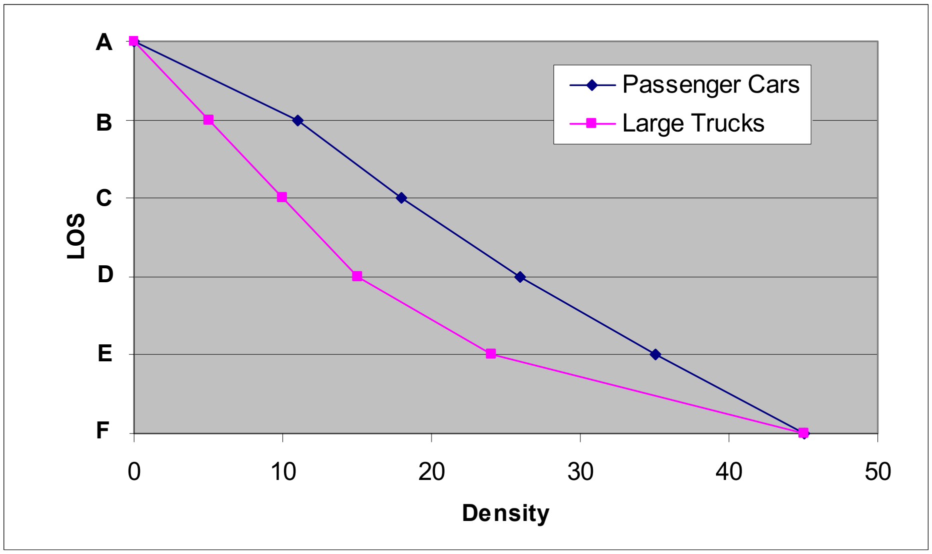
Referring to Table 1, the density value of 24.15 falls in the range of LOS C, which would be the assigned LOS for passenger cars, and the density value of 26.16 falls in the range of LOS D, which would be the assigned LOS for trucks.

It needs to be emphasized that there is really only one overall density for the traffic stream (in this case in terms of vehicles, not passenger cars), and that this density calculation for trucks is essentially a density adjustment to reflect the reduced level of maneuverability for trucks relative to passenger cars.

Furthermore, a separate LOS-Density curve could be developed for trucks. The figures below are a couple of possible examples of the LOS-Density relationships between trucks and passenger cars that could be developed. Note the passenger car “curve” is the same as the one in the HCM.



(a) Approximately Linear Relationship



(b) Non-Linear Relationship

Figure 11. Example Truck Density-LOS Curves Relative to Passenger Vehicles

In the first example, the truck density-LOS curve is approximately linear, similar to that for the passenger vehicles, but with a steeper slope to represent the more rapidly deteriorating level of service for trucks relative to passenger vehicles. In the second example, the truck density-LOS curve is non-linear to allow the curve to tie-in at both end points of the passenger car curve. The basic idea is that the level of service threshold values will be lower for trucks than for passenger cars; and for any given traffic stream density, truck driver perceived level of service will generally be less than that of passenger car driver perceived level of service.

For any proposed density-LOS curve relationship, it is felt that both the truck and passenger car curves should start at the same point for “zero” density conditions, because under very low volume, free-flow speed conditions, there is very little or no vehicle-to-vehicle interaction, and neither trucks nor passenger cars encounter any impedance to traveling their desired speed. Of course, there are conditions in which a high level of service might not be achievable for trucks, even under low density conditions (e.g., a segment with a significant uphill grade).

4.5.1 Implementation Possibilities for Developed Methodology

The methodology explored in this study for determining truck LOS, based on relative maneuverability (as evidenced by relative speeds), could be incorporated into the FREEPLAN software program, with a limited number of modifications.

Volume and percent heavy vehicles are inputs to the current version of the program. Inputs for truck lane restrictions and specific grade would need to be incorporated. However, the speed prediction models could possibly be modified to fit the existing structure of FREEPLAN’s terrain input (i.e., level or rolling). This would probably entail some additional experiments with a large variety of grade combinations to model the rolling terrain situation. Since grade is a very significant factor for large truck speeds, it is important to capture its effects as realistically as possible. While horizontal curvature can have an influence on vehicle speeds, and possibly more so on truck speeds than passenger cars, it is unlikely that horizontal curve data would be collected for planning level analyses. This variable, however, could potentially be factored into a more complex model for typical rolling terrain, such that it would be transparent to the end-user in terms of inputs. The speed prediction models would also need to be modified to account for varying base free-flow speeds.

As previously mentioned, in order to extend the methodology from a segment level to a facility level, interchange ramp effects must be included. If future research is conducted to develop a methodology for including the effects of interchange friction on truck and passenger car speeds, this could likely be incorporated without great difficulty into FREEPLAN since it already includes comprehensive inputs for interchanges. Additionally, toll plazas and weigh stations might need to be considered eventually. These types of facilities could utilize a delay measure, analogous to the treatment of signals in an arterial analysis.

The final output would be separate truck and passenger car average speeds and LOS estimates for the given density, for each segment, and for the facility overall.

4.5.2 Other Possible Approaches/Measures for Truck LOS Methodology

While the approach taken in this study is believed to have strong merit as a methodology for separately assessing truck level of service, there are some other methods/measures that warrant consideration, and may possibly be more applicable in certain situations. This section will briefly discuss some of these other possibilities.

- Acceleration noise: Defined as the root mean square deviation of the acceleration of a vehicle in the traffic stream, this is a measure of speed fluctuation. As volumes begin to increase, truck acceleration noise would likely be greater than that for passenger cars due to their lower relative maneuverability. This would also probably be the case for non-ideal geometric conditions (e.g., uphill grades). This measure is discussed in more detail in a report under another contract [11]; but was applied to the traffic stream as a whole (i.e., vehicle class was not distinguished) in that study. A very similar measure, velocity variance, is another possibility. This measure, however, may not show as much variance as the acceleration noise measure. Both of these measures could be explored with the same methodology as used in developing the speed prediction models. They were not explored in this particular study since the focus was on urban freeways and these particular measures have previously been considered in a rural freeway context.

- 'Passing opportunities': This measure has conceptual appeal across both multilane freeways/highways and two-lane highways. Just as with the maneuverability discussion, it is likely that passing opportunities become disproportionately smaller for trucks than cars as overall traffic volume increases. The percent free-flow speed measure investigated in this study is still a reasonable surrogate for passing opportunities. However, other measures could also be used. For example, a ratio of the number of times a lane change maneuver was desired to the number of times that lane change maneuver was possible under the given traffic and roadway conditions. This measure has some difficulties, however; not all lane changes are made for the purpose of passing (e.g., getting in position for an exit) and it is difficult to know when a driver wants to make a lane change. This was given a preliminary look in the FRESIM simulation program, as FRESIM includes some information about lane change behavior in the TSD file. The FRESIM TSD file includes detailed information on lane change maneuvers executed, and even includes a field for lane change maneuvers desired. Unfortunately, though, the functionality for this latter field had yet to be implemented by the CORSIM developers.

- Percent-time-spent-following (PTSF): This is a measure of the percentage of time a vehicle is constrained to follow a vehicle with a lower desired speed. This measure may have some appeal, primarily since it is currently used as a service measure for two-lane highways. Trucks likely, on average would have a higher PTSF value for specific volume conditions, due to more limited passing opportunities (i.e., less capability of utilizing available gaps). A methodology using this measure could also be investigated with the microscopic simulation approach used in this study; however, a TSD post-processor would have to be designed with fairly sophisticated car-following behavior logic.

- Heavy vehicle factor (f_{HV}): Given the level of effort that has already been invested in the development of passenger car equivalent (PCE) values for trucks (as well as buses and RVs), an approach to utilize this concept could be developed. For example, the calculated heavy vehicle factor (f_{HV}), assuming in this case that it only includes trucks, could be a surrogate indicator for the relative operational level of trucks to passenger cars. For example, a low f_{HV} value means that truck operations are not very good, while a f_{HV} value close to one means that truck operations are similar to that of passenger cars (although a high f_{HV} value could also be due to a low percentage of trucks). The f_{HV} calculation does account for the percentage of trucks in the traffic stream, grade, and the length of the grade (the latter two through the PCE tables). The drawback of course is that it is limited to these inputs, so a variable such as truck lane restrictions would have to be accommodated in another fashion. Also not directly considered with this approach is the traffic volume (in HCM2000), which was found to have differing effects on trucks and passenger cars in the speed prediction models developed as part of this study. A study by Webster and Elefteriadou [7], however, did investigate PCE values for trucks under differing flow conditions and found some volume related differences.

The Systems Planning Office of the Florida DOT is currently exploring the use of performance measures other than density to assess level of service for rural freeways. The FDOT feels that motorists may have different expectations on rural freeways, and density may not be the most appropriate indicator of LOS for these facilities, particularly since density is often relatively low on rural freeways in the State of Florida (barring an incident or construction zone), even during peak periods. If passenger car motorists have different expectations between rural and urban freeways, it is quite possible that truck drivers do as well. With this in mind, it is desirable to use a method/measure for assessing truck level of service that can be applied on freeways in both areas.

5 Conclusions and Recommendations

The purpose of this study was to explore the concept of developing a method by which level of service could be assessed for trucks separately from passenger cars within the same traffic stream, both qualitatively and quantitatively. Overall, the literature was fairly void of this particular topic, but several papers addressed the issue of passenger car equivalents (PCEs) for trucks in the traffic stream. The concept of the PCE is that trucks have significantly different size and performance characteristics than passenger cars such that they must be specially accounted for in the traffic stream. Therefore, explicit in the PCE concept is that trucks are different enough from passenger cars that they warrant special attention. For that reason, it is logical to think that truck drivers' perception of level of service may also be different than that of passenger car drivers.

This study explored the development of a method to assess level of service for trucks based on a maneuverability measure, which was a function of relative percentages of free-flow speed between trucks and passenger cars. This approach has theoretical appeal and is based on reasonable conceptual assumptions. A few other potential measures were discussed briefly that also have theoretical and conceptual appeal.

While the speed prediction models that were developed as part of this study have sound technical merit and logical theoretical underpinnings, they were the result of a preliminary investigation that was purposefully limited in scope. One of the main objectives of this study was to provide some possible options and directions on the assessment of truck level of service for the Systems Planning Office to consider. This study has demonstrated one potential methodology and briefly discussed some other possibilities. Before any of these approaches can be fully implemented, additional research is strongly recommended. The next section will outline specific areas that should be addressed to make the methodology developed in this report more robust and accurate.

5.1 Recommendations for Further Research

The following areas should be explored and/or addressed before implementing a version of the Relative Maneuverability Index truck LOS methodology explored in this study.

- In this speed prediction model, speed reductions are made to a base free-flow speed; but, for a facility analysis that combines several contiguous segments, the model should be revised to use a variable for the segment entering average speed of the vehicle class. Along these same lines, the models developed in this study were based on data that came from a network with a base free-flow speed of 65 mph. Other base free-flow speeds need to be accounted for, which could be accomplished with the previously mentioned variable.

- It would be desirable to perform field verification of base free-flow speeds of trucks relative to passenger cars, to serve as validation for the values that result from the simulation model. The speeds obtained from the I-4 loop detector are not vehicle classification specific. A study by Dixon [12] looked at adherence to speed limits on *rural* freeways by passenger vehicles and trucks. As a result of this study, a substantial amount of speed data were collected under free-flow conditions by vehicle class. This might be a good starting point, but it would also be desirable to collect more local data from the State of Florida. Selecting multiple sites with varying geometric and traffic conditions will also provide some field validation of simulation developed speed models.

- The I-4 network consisted of three through lanes, and this value was kept constant with the experimental section as well. Consequently, the range of tested truck lane restrictions consisted of either zero, one, or two. Future studies should consider using a ratio of the number of lanes available to trucks to the total number of through lanes. This will make the model more robust to differing numbers of through lanes. So for this study, the values would have been 1.0 (3/3), 0.667 (2/3), or 0.333 (1/3). However, it should also be explored whether having one lane restricted out of three (1/3) is really equivalent to having two lanes restricted out of six (2/6 = 1/3?), and so on for the other combinations. This will, of course, increase the complexity of the experimental design as both the number of through lanes and truck lane restrictions would vary.

- Future experiments should expand variable ranges to account for both rural and urban freeways. The focus in this study was on urban freeways, but conceptually, there is no particular reason why this approach cannot also apply to rural freeways.

Volumes may not as a big of a factor for rural freeways (usually much lower), nor interchanges (much larger spacing), but roadway geometry can be more variable (e.g., steeper grades), and truck percentages can be more significant.

- To accommodate a facility-level analysis, consideration of interchange effects must be explicitly investigated (as discussed earlier in the report). Additionally, more comprehensive investigation of the impacts of consecutive grade segments and the inclusion of an extended segment general terrain analysis, such as rolling, should be performed.

- General investigation of some possible anomalies with FRESIM simulation results:
  - As previously discussed, there were some observed behavior inconsistencies of trucks with regard to truck lane restrictions
  - The free-flow speeds of Single Unit and Medium truck classifications seem unrealistically high

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7 Appendix Material

Appendix A. Conceptual Framework/Possible Research Directions

The current level of service (LOS) methodologies prescribed by the Highway Capacity Manual (HCM) for various roadway facilities present single LOS criteria for all motorized vehicles that use the facility. While passenger cars, buses, recreational vehicles, single unit trucks and combination trucks all use these facilities, the LOS values determined by the HCM procedures are intended to apply to the traffic stream as a whole.

Although the passenger car (PC) is by far the most dominant mode of transportation on the roadway system, heavy vehicles[3] are a very important mode because freight movement is vital to Florida's and the Nation's economy. Consequently, it is important to know whether or not trucks are being provided the same level of service as passenger vehicles.

The presence of heavy vehicles in the vehicle stream is currently accounted for in HCM methodologies by applying the concept of passenger car equivalents and adjusting the total traffic volume from a veh/hr measure to a passenger car/hour equivalent[4].

The transportation facilities that trucks operate on (as well as other motorized vehicles) can be classified into two general categories: 1) uninterrupted flow, and 2) interrupted flow. Uninterrupted flow facilities include freeways, multilane highways, and two-lane highways. Interrupted flow facilities include signalized and unsignalized intersections.

A fundamental principle in determining level of service, as described in the HCM, is that the chosen measure of effectiveness should correlate with user perceptions of the quality of service being provided by the facility. The primary traffic parameter used to determine LOS for multilane uninterrupted flow facilities is density[5]. The measure used for interrupted flow facilities is average travel speed (delay for controlled intersections).

For freeway/multilane highway facilities, density is a reasonable measure because as it increases, motorists certainly perceive the level of service they are being provided as declining. Likewise, for interrupted flow facilities, delay and average travel speed are reasonable measures because as it increases, drivers perceive a more congested facility, and a lower level of service.

A brief discussion on each of these measures for their respective facilities follows.

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[3] In this context, heavy vehicle refers to trucks with three or more axles.

[4] In the case of significant grades on freeways and multilane highways, a separate procedure has been developed to account for the non-proportional impact severe grades have on heavy trucks relative to passenger cars.

[5] Two-lane highways use service flow rates due to their unique operational characteristics.

Uninterrupted flow facilities and density

A reasonable question is whether drivers of trucks perceive and react to increasing density in the same manner as drivers of passenger cars. Quite possibly not, and if not, the level of service thresholds should probably be different for trucks and passenger cars.

Density is typically arrived at by dividing flow by speed. For HCM purposes, the speed used is an average passenger car speed. Under certain conditions, truck speeds may be significantly different than those of passenger cars. One such condition is steep grades, in which truck speeds are generally independent of vehicle density. Another condition in which trucks speeds may be significantly different than PC speeds is under low and moderate flows. Under free-flow operation, individual vehicle speeds are independent and trucks and PCs may have significantly different average speeds. However, under low volume conditions, one can argue that the level of service is still ‘A’ for all users of the facility, regardless of vehicle type and speed, since all vehicles are traveling at their desired speed. Under high flow conditions, speeds become dependent and significant differences in vehicle speeds are not present. It is under moderate flow conditions in which truck speeds and operations may be significantly different, and be subject to a different level of service than PCs.

Traffic stream maneuverability is a function of density. Increasing density may be more constraining on truck maneuverability than PC maneuverability. Due to their substantial length, lane-changing (lateral movement) opportunities are more restricted because of their inability to accept smaller gaps that PCs are able accept. Furthermore, their more limited acceleration and deceleration capabilities result in less lateral and longitudinal maneuverability.

Under low-density conditions, truck and PC level of service would both be ‘A’. As the density increases, it is conceivable that the density-LOS curves for trucks and PCs would diverge, with the LOS for trucks degrading at a faster rate than that for PCs.

Factors that may have a greater impact on truck performance than passenger car performance include the following:

- Geometric Factors
  - Lane width: due to trucks being much wider
  - Proximity of roadside objects: due to trucks being much wider
  - Horizontal curvature
  - Vertical curvature (i.e., grades)

- Traffic Stream Factors
  - Percentage of trucks in traffic stream
  - Average load level of trucks (difficult to measure)
  - Truck platooning characteristics (are trucks more likely to platoon with other trucks in proximity?)

- Special features/facilities
  - Truck lane restrictions: constrain lateral movement and passing ability
  - Truck-only lanes
  - Weigh stations
  - Toll plazas

We also could examine the issue of acceleration noise possibly having greater impact on trucks than PC's. If we choose this approach, we could also integrate the research on rural freeway/highway level of service here.

<u>General Research Approach</u>

- Field data collection of truck speeds, headways, platooning characteristics, relative to passenger vehicles
  - Of course also get volumes and truck classifications
  - Field data collection would be limited to a half-dozen sites, or less
  - Preferred sites would contain a high percentage of heavy vehicles in the traffic stream
- Use CORSIM/FRESIM to simulate a wide range of conditions for all important variables
  - Use field data to calibrate CORSIM/ FRESIM parameters
    - 4 different truck types
    - headway characteristics
    - driver types

- To pursue the acceleration noise approach, this would probably have to be done exclusively with simulation at this point, because outfitting trucks with GPS units or DMI units is clearly beyond the scope of this project.
- It might be an interesting exercise to collect data in the vicinity of a weigh-in-motion station to get the load percentages. However, I don't think this would prove terribly useful in the long run for a couple of reasons. These percentages are likely to vary considerably from one location to another, and unless tables are developed to encompass a wide variety of locations and conditions, this would be a difficult input to use in any analysis procedure because of its measurement difficulty.

<u>Expected Procedure(s)</u>

It is expected that there would be different factors and guidelines in the analysis of LOS for trucks only. For passenger vehicle LOS, the current HCM methodology would apply. Thus, there would still be a LOS measure for the traffic stream as a whole (PCs, trucks, buses, RVs) just like current HCM, but also a separate measure just for trucks.

Service volume tables could also be developed for a planning level approach. This would utilize a more limited data input set, with truck percentages, types, and special roadway features probably being the main inputs.

Interrupted flow facilities and average travel speed/delay

Average travel speed (of which delay is a component) is used as the LOS measures for interrupted flow facilities. Making the case for heavy trucks experiencing more delay at signalized and stop-controlled intersections may be difficult, but there are certainly some factors that are worth investigating.

Signalized intersections present significant operating demands on heavy vehicles, primarily in the following ways.

- Geometric Factors
  - Lane width
  - Turning radii (for left turns at intersections and median openings for arterials)

- Operational Factors / Truck Performance Factors
  - Start-up time for trucks at signals can be significant due to poor acceleration capabilities (especially when fully loaded)
  - More time required to accelerate to speed (impacts vehicles behind truck as well, as ability to change lanes from queue starting at green can be very difficult under congested conditions)
  - Because of long stopping distances, trucks may be more likely to run red lights
  - Delay withstanding, is stopping perceived by truck drivers more negatively than passenger car drivers given the reduced performance characteristics of trucks? If so, stops may be an important secondary measure to consider in the evaluation of LOS for trucks on interrupted flow facilities.
  - Mid-block speeds for arterial segments

<u>General Research Approach</u>

- Collect data from intersections on the Florida Intrastate Highway System (FIHS).
  - Again, data collection would be limited to a half-dozen sites or less
  - A mix of intersections with single, double, and triple lane approaches would be desired
  - Also, these intersections should contain a significant percentage of heavy vehicles in the traffic stream.
- Use of programs like AutoTURN and/or AutoTrack to simulate the turning movements of trucks at intersections/driveways. This will allow a more detailed analysis of the effects of turning radii on vehicle speed and intersection capacity.
- With video data and data from the above programs, parameters such as turning speed, start-up time, deceleration time/distance, can be calibrated within CORSIM/NETSIM and simulation can be used. With the use of the TRC's Red Light Running Analysis Package (RLRAP), we could also examine if there is any greater likelihood on the part of trucks to run red lights (or almost red lights) than PC's.

Expected Procedure(s)

It is expected that there would be more detailed guidelines on turning radii and how to assess its impact on truck LOS at intersections. Also, if it is determined that stops are more penalizing to trucks than PC's, this would be recommended as a secondary LOS measure for trucks, along with the appropriate threshold criteria.

Appendix B. Literature Search Summary

University of Florida, Transportation Research Center. *Development of Preliminary LOS Criteria and Thresholds for Rural Freeways.* Working Paper 806-2, Final Draft. January 2002.

> The Highway Capacity Manual uses traffic density as a criterion for measuring level of service on both urban and rural freeways. This method is appropriate for urban freeways where there is high traffic demand, but traffic volumes are usually low on rural freeways. The Federal Highway Administration and Department of Transportation set design standards for highway facilities with LOS D or C as the criterion. Applying those levels of service to rural freeways would result in congested conditions. Florida has adopted LOS B as the criterion for the planning of rural freeways. Acceleration noise, defined as the root mean square deviation of the acceleration of a vehicle in the traffic stream (i.e. speed fluctuation), is used as a measure of effectiveness. This measure, used as a surrogate for perceived driver level of comfort, is potentially a better service measure for level of service on these low-volume, rural freeways. A set of LOS thresholds was developed based on the acceleration noise level for rural freeways as a function of traffic volume. The results show that drivers' discomfort increases rapidly as volume starts to increase, but the rate of increase diminishes when the volume becomes high.

DeArazoza, R.D. and McLeod, D.S., *Methodology to Assess Level of Service on US-1 in the Florida Keys*, Transportation Research Record 1398, Transportation Research Board (1993).

> US-1 in the Florida Keys is primarily an uninterrupted-flow two-lane roadway from Key West to the Florida mainland. No major roads intersect this portion of US-1, and no other principal arterial exists in the Keys. US-1 has geography, land use, and trip-making characteristics unlike any other road, therefore a method to determine the level of service (LOS) of this unique road is needed. The Florida Department of Transportation (FDOT) has LOS standards for all state roads, with LOS C as the standard in the Keys. Average travel speed was assumed to be more important to motorists on US-1 than the ability to pass, so speed was used as the measurement of LOS. The 108 mile-long road was divided into 24 segments, based on uniform roadway cross-section and traffic flow. LOS-speed thresholds were developed for each of the segments, and travel time and delay were measured using the floating-car technique. All but 4 of the segments passed the FDOT's LOS C standard, and the average LOS of the road is C.

Hyman, W.A., et al, "Multimodal Corridor and Capacity Analysis Manual." *NCHRP Report 399,* Transportation Research Board (1997).

> This manual discusses methods to deal with capacity analysis, performance determination, and needs and options for multimodal transportation corridors. Four existing multimodal corridors, typical of many in the United States, were studied.

Current and future capacity problems and expansion constraints were analyzed, and strategies for enhancing or preserving long-term capacity were identified. Capacity in terms of passenger or freight throughput, rather than vehicle throughput, is considered. A set of user performance measures that could be used to determine level of service was derived. They consist of service frequency, travel time, travel comfort, travel time reliability, probability of loss and/or damage, and cost. Facility performance measures used include v/c ratio for vehicles, persons, and goods, speed on the facility, variability of speed, travel time, delay, and accidents on facility. Nonuser performance measures (possibly neighbors of a transportation facility) include congestion costs, noise, fuel use, emissions, and maintenance costs. The conclusion of the study was that capacity analysis requires methods tailored to specific modes of transportation and types of facilities, rather than a unified multimodal approach.

Good, D., Neudorf, R., Robinson, J.B.L., Sparks, and Sparks, G, *The Effect of Vehicle Length on Traffic on Canadian Two-lane, Two-way Roads.* Technical Report, Transportation Association of Canada (1991).

The objectives of this report were to determine if intersection design, signal timing, passing sight distances, and pavement markings are adequate for vehicle lengths longer than those currently permitted. It looks specifically at extending the maximum vehicle length from 23 to 25 meters. The research showed that the increased length would have little impact on intersection operations. At operating speeds over 80 km/h the existing passing zone pavement markings may not provide adequate sight distance for passing 23 meter trucks, so increasing the length to 25 meters would make the pavement markings more inadequate. Since standards for passing sight distance and passing zone markings have been traditionally based on passenger cars, it was recommended that they be reevaluated based on trucks.

Koehne, Jodi, Mannering, Fred, and Hallenbeck, Mark. *Analysis of Trucker and Motorist Opinions Toward Truck-Lane Restrictions*. Transportation Research Record 1560.

Truck restrictions, which are becoming increasingly popular throughout the United States, are justified on the grounds of improving traffic operations and safety, decreasing pavement wear, and other related factors. Although an abundance of research has been aimed at quantifying the benefits and costs of truck restrictions, little has been aimed done to measure truckers' and motorists' opinions of such restrictions statistically. Truckers' and motorists' opinions of the truck-lane restrictions in force in the Puget Sound region of Washington State are assessed statistically here. The assessment was made by administering separate opinion surveys to truckers and motorists and estimating logit models that give the probability of an individual's being in favor of or opposed to truck-lane restrictions. In addition, a logit model giving the probability that an individual is even aware of the truck-lane restrictions in the Puget Sound region is estimated. The result of these model estimations give a profile of individuals that are most likely to favor or oppose truck-

> lane restrictions. These profiles provide valuable information for policy analysts and administrators concerned with implementation since they define the opinions of population groups that can make or break truck restriction policies on U.S. highways.

Regan, Amelia C. and Golob, Thomas F. *Trucking industry perceptions of congestion problems and potential solutions in maritime intermodal operations in California*. Transportation Research, Part A. Issue 34, pp. 587-605 (2000).

> Maritime freight transportation plays a significant role in the economy of the United States. The large volumes of freight that are offloaded from ships are generally moved out of port via truck. Efficient maritime transportation is heavily dependent on the smooth operation of land transportation. Swift modal transfers are key to successful intermodal operations. In this paper we examine the efficiency of maritime intermodal transfer facilities in California, from the point of view of the trucking companies that use these facilities. We also examine the perceived effects of traffic network congestion on intermodal carriers' operations. Conclusions are based on a recent survey of nearly 1200 private and for-hire carriers operating in California. A Computer Aided Telephone Interview was conducted, with the logistics or operations managers in charge of operations for trucking companies as the subjects. Over 450 of the companies surveyed had operations involving maritime ports in California. These provided a rich sample of responses and significant insights into the current state of the industry. The major problems the trucking industry has with the ports are congestion, waiting, delays, crowding, and backups at the ports. Information technologies may soon be able to reduce delays inside and outside ports.

Khan, A.M., Rastogl, M., Wong, J.Y., *Heavy Vehicle Performance on Grade and Climbing Lane Criteria.* Ontario Ministry of Transportation, Downsview, Ontario, Canada (1990).

> The objectives of this study were to determine the estimated heavy vehicle performance on grade in speed-distance curves, to develop metric speed-distance curves, and to review warrants for climbing lanes based on speed-distance performance and cost-effectiveness. Weight and power data were gathered for a representative set of heavy vehicles, and two simulation models were developed to obtain speed-distance curves. The first model simulates vehicle motion. The second model is less detailed and is based on empirical functions from the American Society of Automotive Engineers. The two models were consistent with the measured data. Climbing lane recommendations were made, based on speed loss on grade, decreased level of service, and cost-effectiveness.

Krammes, R.A. and Crowley, K.W., "Passenger Car Equivalents for Trucks on Level Freeway Segments." *Transportation Research Record 1091*, Transportation Research Board, Washington, D.C. (1986).

This paper determines a method for estimating PCE for basic level freeway segments. It suggests that the parameters for determining PCE should be the same as those used to determine level of service on that roadway type or section. The main factors that contribute to the effects of trucks on roadways are: trucks are larger than passenger cars, their operating capabilities are inferior to those of passenger cars, and trucks have both physical and psychological impacts on the vehicles and drivers nearby. The spatial headway approach to measuring passenger car equivalents was found to be appropriate for level freeway segments, and a PCE formula was derived based on headway measurements.

Benekohal, Rahim F. and Zhao, Weixiong, *Delay-Based Passenger Car Equivalents for Trucks at Signalized Intersections.* Transportation Research, Part A: Policy and Practice, v 34, n 6, 2000. p. 437-457.

This paper discusses a method for computing passenger car equivalents (PCE) for signalized intersections based on delay rather than time headway. The headway-based method is commonly used, but does not account for travel time, vehicular delay, queue length, heavy vehicle type, traffic volume, or percentage of heavy vehicles. The delay-based PCE (D_PCE) uses delay as the main criteria, but also considers vehicle type, traffic volume, and percentage of heavy vehicles in finding the PCE. D_PCE is the ratio of the delay caused by a heavy vehicle to the delay of a car in an all-passenger car traffic stream. The mathematical models that were developed to estimate D_PCE showed that D_PCE increased as traffic volume and the percentage of heavy vehicles increased.

Morrall, J.F. and Werner, A., "Measuring Level of Service of Two-Lane Highways by Overtakings." *Transportation Research Record 1287,* Transportation Research Board (1990).

This paper looks at the level of service concept based on the supply of passing opportunities and the demand for passing. The current level of service criteria are percentage time delayed, capacity, and speed. Ability to overtake vehicles is suggested as an additional criterion for LOS. This is measured by the overtaking ratio, which can be computed as the ratio of achieved number of overtakings on a two-lane highway to the desired number of overtakings on a two-lane highway.

Reilly, W., Harwood, D., Schoen, J., et al., *Capacity and Level of Service Procedures for Multilane Rural and Suburban Highways.* Final Report, NCHRP Project 3-33, JHK & Associates, Tucson, Arizona (1988).

This report's purpose is to confirm and develop operational, design, and planning procedures to be used in determining capacity and level of service of multilane highways. It focuses on highways with four or more lanes, but also considers other configurations, such as 3 lane highways, 2-way operation (2-1 split), and continuous

left turn lane. The procedures used in this report have been incorporated into Chapter 7, “Multilane Highways”, of the Highway Capacity Manual.

Schoen, J., *Speed-Flow Relationships for Basic Freeway Segments.* Final Report, NCHRP Project 3-45, JHK & Associates, Tucson, Arizona (1995).

The purpose of this report is to update Chapter 3 for the 1994 Highway Capacity Manual by revising the material on speed-flow relationships. Basic freeway flow characteristics and impact of heavy vehicles, along with restricted lane and shoulder widths are studied. The main change in HCM 1994 is the freeway capacity is raised to 2200 vphpl.

Landis, B.W., Vattikuti, V.R., Brannick, M.T., “Real-time Human Perceptions: Toward a Bicycle Level of Service.” *Transportation Research Record 1578,* Transportation Research Board (1997).

The focus of this study is to develop a bicycle level of service (BLOS) model to apply to U.S. metropolitan areas. The common performance measure used to rate bicycle level of service is the bicyclists’ perception of magnitude of the hazards of traveling within the shared roadway. Capacity is generally not used in measuring BLOS, because it is not relevant for this mode of transportation. BLOS is based solely on human perceptions. A group of 150 bicyclists representing a cross section of age, gender, experience level, and geographic origin completed a course representative of traffic and roadway conditions in urbanized areas of the United States. They were instructed to grade each segment within the course with a letter grade from A to F. It was found that bicycle lane striping and pavement conditions had the largest effects on bicycle level of service.

U.S. Department of Transportation, Federal Highway Administration, Offices of Research & Development, Structures and Applied Mechanics Division, *Significant Factors in Truck Ride Quality.* Washington, D.C. (1981).

The main in-cab conditions that affect truck drivers are vibration, noise, and temperature. The factors that affect truck ride quality are pavement condition, wheel asymmetries, design and loading variations, and speed.

Pepler, R.D., Naughton, T.J., *Relationship Between Truck Ride Quality and Drivers’ Health: Methodology Development.* U.S. Department of Transportation, National Highway Traffic Safety Administration (1980).

This paper discussed the health effects on truck drivers exposed to prolonged whole body vibration.

Databases searched: TRIS, DB/Text *WebPublisher* (www.dcdata.com), the TRB Publication Index, the DOT webpage, and WebLuis (University of Florida on-line library database).

Keywords used: trucks and level of service, heavy vehicle, passenger car equivalence, simulation programs, truck movement models, and designated truck routes

Appendix C. Factorial Experimental Design Factor Combinations

Factor Setting Levels: L = Low, M = Medium, H = High

Run	Volume	Grade	# Lanes	% Trucks
1	L	L	L	L
2	L	L	L	M
3	L	L	L	H
4	L	L	M	L
5	L	L	M	M
6	L	L	M	H
7	L	L	H	L
8	L	L	H	M
9	L	L	H	H
10	L	M	L	L
11	L	M	L	M
12	L	M	L	H
13	L	M	M	L
14	L	M	M	M
15	L	M	M	H
16	L	M	H	L
17	L	M	H	M
18	L	M	H	H
19	L	H	L	L
20	L	H	L	M
21	L	H	L	H
22	L	H	M	L
23	L	H	M	M
24	L	H	M	H
25	L	H	H	L
26	L	H	H	M
27	L	H	H	H
28	M	L	L	L
29	M	L	L	M
30	M	L	L	H
31	M	L	M	L
32	M	L	M	M
33	M	L	M	H
34	M	L	H	L
35	M	L	H	M
36	M	L	H	H
37	M	M	L	L
38	M	M	L	M
39	M	M	L	H
40	M	M	M	L
41	M	M	M	M
42	M	M	M	H
43	M	M	H	L
44	M	M	H	M
45	M	M	H	H
46	M	H	L	L
47	M	H	L	M
48	M	H	L	H

49	M	H	M	L
50	M	H	M	M
51	M	H	M	H
52	M	H	H	L
53	M	H	H	M
54	M	H	H	H
55	H	L	L	L
56	H	L	L	M
57	H	L	L	H
58	H	L	M	L
59	H	L	M	M
60	H	L	M	H
61	H	L	H	L
62	H	L	H	M
63	H	L	H	H
64	H	M	L	L
65	H	M	L	M
66	H	M	L	H
67	H	M	M	L
68	H	M	M	M
69	H	M	M	H
70	H	M	H	L
71	H	M	H	M
72	H	M	H	H
73	H	H	L	L
74	H	H	L	M
75	H	H	L	H
76	H	H	M	L
77	H	H	M	M
78	H	H	M	H
79	H	H	H	L
80	H	H	H	M
81	H	H	H	H

Appendix D. Inductance Loop Detector Data

LOOP DATA: LOW DENSITY - April 12, 2001

Ivanhoe Blvd.

		Volume					Speed				Lane Occupancy			
		1 hour				5 min.								
Time Interval		Lane 1	Lane 2	Lane 3	Sum		Lane 1	Lane 2	Lane 3	Avg.	Lane 1	Lane 2	Lane 3	Avg.
13:55	14:00	1920	1680	1815	5415	451	49	67	54	🟩 56.9	15	10	13	12.6
14:00	14:05	1940	1644	1812	5396	450	40	53	43	🟩 45.6	16	17	18	17
14:05	14:10	2040	1860	1902	5802	484	40	57	45	🟩 47.5	18	15	18	17
14:10	14:15	1954	1644	1906	5504	459	51	67	55	🟩 58.2	12	10	13	11.6
14:15	14:20	2160	1572	1946	5678	473	49	65	53	🟩 56	15	10	14	13
14:20	14:25	2016	1656	1776	5448	454	51	66	54	🟩 57.4	14	11	12	12.3
14:25	14:30	2200	1632	1834	5666	472	48	65	54	🟩 56.2	15	11	13	13
14:30	14:35	1860	1596	1860	5316	443	47	67	53	🟩 55.7	15	10	14	13

Par Ave.

13:55	14:00	1680	1965	1920	5565	464	41	48	52	🟩 47.3	16	19	19	18
14:00	14:05	1560	1956	2112	5628	469	43	49	52	🟩 48.4	13	17	18	16
14:05	14:10	1868	1853	2250	5971	498	39	44	46	🟧 43.6	18	18	21	19
14:10	14:15	1893	2066	2080	6039	503	42	48	50	🟩 46.9	17	20	21	19.3
14:15	14:20	1826	2093	2000	5919	493	42	49	51	🟩 47.8	15	18	19	17.3
14:20	14:25	1788	1992	1920	5700	475	41	49	51	🟩 47.4	15	18	20	17.6
14:25	14:30	1776	2026	2100	5902	492	44	50	53	🟩 49.3	14	17	18	16.3
14:30	14:35	1653	1668	1620	4941	412	31	33	33	🟧 32.9	20	26	29	25
14:35	14:40	1800	1740	1946	5486	457	28	30	34	🟧 31.1	23	25	25	24.3

LOOP DATA: LOW DENSITY - April 12, 2001

Kennedy Blvd.		Volume					Speed				Lane Occupancy			
		1 hour				5 min.								
Time Interval		Lane 1	Lane 2	Lane 3	Sum		Lane 1	Lane 2	Lane 3	Avg.	Lane 1	Lane 2	Lane 3	Avg.
13:55	14:00	1920	2057	1980	5957	496	0	58	47	53	7	6	7	6.6
14:00	14:05	1620	1725	1954	5299	442	0	62	51	57.3	6	6	7	6.3
14:05	14:10	1868	1933	1860	5661	472	0	61	49	55.2	6	6	6	6
14:10	14:15	2091	2053	2040	6184	515	0	60	48	54.3	7	7	7	7
14:15	14:20	2190	1992	2100	6282	524	0	59	48	54.2	8	6	7	7
14:20	14:25	1880	1755	2005	5640	470	0	63	51	57.3	7	6	7	6.6
14:25	14:30	1980	1780	1480	5240	437	0	60	51	56	7	7	7	7
14:30	14:35	1834	1782	1875	5491	458	0	64	53	58.9	6	6	6	6
14:35	14:40	1875	1720	1875	5470	456	0	61	51	56.6	6	6	6	6
14:40	14:45	2160	1905	2016	6081	507	0	56	45	51	8	6	7	7
14:45	14:50	1830	1800	2040	5670	473	0	63	52	57.9	6	6	7	6.3
14:50	14:55	2080	1890	1920	5890	491	0	61	50	56	6	6	7	6.3

LOOP DATA: LOW DENSITY - April 17, 2001

Ivanhoe Blvd.		**Volume**					**Speed**				**Lane Occupancy**			
		1 hour				5 min.								
Time Interval		**Lane 1**	**Lane 2**	**Lane 3**	**Sum**		**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**	**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**
13:55	14:00	1830	1380	1752	4962	414	53	70	58	60.5	10	8	11	9.6
14:00	14:05	1840	1500	1785	5125	427	53	71	58	61.1	12	9	11	10.6
14:05	14:10	1746	1380	1786	4912	409	53	71	57	60.7	10	9	12	10.3
14:10	14:15	1920	1488	1872	5280	440	52	62	57	57.6	13	9	13	11.6
14:15	14:20	1868	1572	1740	5180	432	52	67	58	59.1	12	10	11	11
14:20	14:25	1680	1524	1728	4932	411	52	72	57	60.7	11	9	11	10.3
14:25	14:30	1902	1500	1890	5292	441	52	69	57	59.8	12	9	13	11.3
14:30	14:35	1937	1584	1840	5361	447	53	70	58	60.7	11	10	12	11
14:35	14:40	1740	1416	1584	4740	395	55	73	58	62.4	9	8	10	9
14:40	14:45	2088	1512	1946	5546	462	51	66	56	58	13	9	13	11.6
14:45	14:50	2060	1573	1813	5446	454	52	68	56	59.2	12	11	13	12
14:50	14:55	1944	1560	1946	5450	454	53	70	57	60.2	12	9	13	11.3
Par Ave.														
13:55	14:00	1506	1740	1782	5028	419	44	51	55	50.4	13	15	15	14.3
14:00	14:05	1573	1695	1902	5170	431	44	50	54	50	14	15	16	15
14:05	14:10	1584	1932	1817	5333	444	45	51	57	51.2	13	16	15	14.6
14:10	14:15	1572	1800	1971	5343	445	44	51	54	50.1	12	18	16	15.3
14:15	14:20	1608	1893	1880	5381	448	46	52	55	51.4	12	16	16	14.6
14:20	14:25	1653	1893	1830	5376	448	43	51	55	49.9	15	16	14	15
14:25	14:30	1680	1908	1820	5408	451	43	50	55	50.1	14	16	16	15.3
14:30	14:35	1755	1875	2010	5640	470	41	47	51	46.9	17	18	18	17.6
14:35	14:40	1584	1860	1980	5424	452	45	52	56	51.4	12	14	15	13.6
14:40	14:45	1586	1815	2040	5441	453	44	50	54	49.7	13	17	17	15.6
14:45	14:50	1986	1890	2100	5976	498	43	50	53	49	16	17	18	17
14:50	14:55	1653	1773	1830	5256	438	43	49	51	48.1	14	16	19	16.3

LOOP DATA: LOW DENSITY - April 17, 2001

Kennedy Blvd.		**Volume**					**Speed**				**Lane Occupancy**			
		1 hour				5 min.								
Time Interval		**Lane 1**	**Lane 2**	**Lane 3**	**Sum**		**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**	**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**
13:55	14:00	1644	1812	1776	5232	436	0	64	54	🟩 59.6	5	6	5	5.3
14:00	14:05	1665	1902	1755	5322	444	0	63	52	🟩 58.1	6	6	6	6
14:05	14:10	1650	1626	1848	5124	427	0	62	54	🟩 58.6	6	5	6	5.6
14:10	14:15	1866	1920	1851	5637	470	0	61	51	🟩 56.4	6	6	6	6
14:15	14:20	1748	1880	1973	5601	467	0	62	51	🟩 57.2	6	6	6	6
14:20	14:25	1786	1824	2005	5615	468	0	62	49	🟩 56.1	5	5	7	5.6
14:25	14:30	1545	1760	1980	5285	440	0	64	53	🟩 59	5	7	7	6.3
14:30	14:35	1980	1853	1902	5735	478	0	62	51	🟩 57.2	6	6	6	6
14:35	14:40	1620	1960	2025	5605	467	0	62	52	🟩 57.3	6	6	7	6.3
14:40	14:45	1760	1752	1905	5417	451	0	63	55	🟩 59.4	5	5	6	5.3
14:45	14:50	1840	1710	1872	5422	452	0	63	51	🟩 57.4	7	7	7	7
14:50	14:55	1890	1512	1890	5292	441	0	61	49	🟩 55.7	6	6	7	6.3

LOOP DATA: MEDIUM DENSITY - April 12, 2001

Ivanhoe Blvd.

		Volume					Speed				Lane Occupancy			
		1 hour				5 min.								
Time Interval		**Lane 1**	**Lane 2**	**Lane 3**	**Sum**		**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**	**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**
15:15	15:20	1788	1416	1692	4896	408	21	25	23	🟥 23.8	25	27	29	27
15:20	15:25	1836	1464	1572	4872	406	23	25	23	🟥 23.8	24	29	26	26.3
15:25	15:30	2074	1693	1760	5527	461	34	51	38	🟧 41.2	19	16	17	17.3
15:30	15:35	1656	1380	1500	4536	378	20	25	21	🟥 22.1	26	29	29	28
15:35	15:40	1728	1512	1632	4872	406	26	38	27	🟧 30.9	22	20	27	23
15:40	15:45	1776	1488	1512	4776	398	26	35	27	🟧 30	24	22	23	23
15:45	15:50	1800	1560	1596	4956	413	30	44	34	🟧 36.2	19	17	20	18.6
15:50	15:55	1960	1404	1728	5092	424	46	64	51	🟩 53.9	12	9	12	11
15:55	16:00	2120	1584	1890	5594	466	45	63	49	🟩 52.9	14	11	14	13
16:00	16:05	1820	1668	1896	5384	449	35	54	40	🟧 43.2	19	13	18	16.6
16:05	16:10	1920	1728	1813	5461	455	37	54	41	🟧 44.3	15	13	17	15
16:10	16:15	1344	1164	1212	3720	310	14	20	17	🟥 17.5	32	33	32	32.3

Par Ave.

15:15	15:20	1776	1836	2055	5667	27	32	32	🟧 31	26	25	27	26
15:20	15:25	1980	1920	2074	5974	28	32	33	🟧 31.3	24	26	26	25.3
15:25	15:30	1824	1620	1826	5270	19	24	24	🟥 22.7	34	29	32	31.6
15:30	15:35	1896	1860	2040	5796	30	32	35	🟧 32.7	22	23	23	22.6
15:35	15:40	1776	1695	1980	5451	28	28	30	🟥 29	23	30	28	27
15:40	15:45	1932	1776	2013	5721	30	31	33	🟧 31.8	22	26	25	24.3
15:45	15:50	1980	1986	2136	6102	33	37	37	🟧 36.3	20	23	25	22.6
15:50	15:55	1826	1890	2136	5852	43	47	49	🟩 46.8	14	17	19	16.6
15:55	16:00	1786	1920	1896	5602	39	43	39	🟧 40.8	16	18	25	19.6
16:00	16:05	1788	1906	2190	5884	33	36	36	🟧 35.5	19	24	24	22.3
16:05	16:10	1740	1680	1692	5112	25	24	23	🟥 24.6	25	34	34	31
16:10	16:15	1800	1788	1733	5321	27	25	22	🟥 25	23	31	37	30.3

LOOP DATA: MEDIUM DENSITY - April 12, 2001

Kennedy Blvd.		**Volume**					**Speed**				**Lane Occupancy**			
		1 hour				5 min.								
Time Interval		**Lane 1**	**Lane 2**	**Lane 3**	**Sum**		**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**	**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**
15:15	15:20	1900	1780	1960	5640	470	0	59	47	🟩 53.7	7	6	7	6.6
15:20	15:25	2022	2108	2088	6218	518.2	0	59	48	🟩 54.2	7	7	7	7
15:25	15:30	1860	1920	2020	5800	483.3	0	62	50	🟩 56.5	6	7	7	6.6
15:30	15:35	1954	1840	2064	5858	488.2	0	60	49	🟩 55	6	6	7	6.3
15:35	15:40	1800	1933	1872	5605	467.1	0	59	48	🟩 53.9	8	6	7	7
15:40	15:45	1880	1848	2020	5748	479	0	58	48	🟩 53.5	7	7	7	7
15:45	15:50	2232	1834	2055	6121	510.1	0	56	45	🟩 51.1	7	6	7	6.6
15:50	15:55	2020	1988	2053	6061	505.1	0	54	43	🟩 48.8	7	7	6	6.6
15:55	16:00	2232	1980	1980	6192	516	0	54	45	🟩 50.1	8	6	7	7
16:00	16:05	2016	1868	2055	5939	494.9	0	58	0	🟩 58.1	7	6	7	6.6
16:05	16:10	2088	1968	2142	6198	516.5	0	58	0	🟩 58.3	8	6	7	7
16:10	16:15	2080	2040	2074	6194	516.2	0	59	0	🟩 59.2	7	7	7	7

LOOP DATA: MEDIUM DENSITY - April 17, 2001

Ivanhoe Blvd.		**Volume**					**Speed**				**Lane Occupancy**			
		1 hour				5 min.								
Time Interval		**Lane 1**	**Lane 2**	**Lane 3**	**Sum**		**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**	**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**
15:15	15:20	1920	1476	1788	5184	432	51	70	56	🟩 59.4	12	9	12	11
15:20	15:25	2040	1400	1860	5300	441.7	50	66	55	🟩 57.4	14	9	13	12
15:25	15:30	1800	1560	1800	5160	430	50	65	56	🟩 57.5	13	11	12	12
15:30	15:35	1872	1752	1716	5340	445	36	47	40	🟧 41	20	19	18	19
15:35	15:40	2088	1728	1746	5562	463.5	34	55	41	🟧 43.5	21	14	19	18
15:40	15:45	1851	1704	1693	5248	437.3	30	43	33	🟧 35.7	23	19	24	22
15:45	15:50	1840	1400	1666	4906	408.8	30	38	31	🟧 33.4	21	20	23	21.3
15:50	15:55	1851	1590	1680	5121	426.8	32	46	36	🟧 38.2	19	16	20	18.3
15:55	16:00	1817	1695	1620	5132	427.7	32	51	36	🟧 40.1	20	14	19	17.6
16:00	16:05	1920	1644	1786	5350	445.8	33	48	34	🟧 38.9	18	16	22	18.6
16:05	16:10	1851	1613	1773	5237	436.4	28	39	31	🟧 33.1	22	21	23	22
16:10	16:15	2125	1706	1884	5715	476.3	32	42	37	🟧 37.5	20	20	19	19.6
Par Ave.														
15:15	15:20	1728	2053	2040	5821	485.1	44	50	52	🟩 49.1	14	18	19	17
15:20	15:25	1848	1986	2040	5874	489.5	41	46	50	🟩 45.9	15	19	21	18.3
15:25	15:30	1740	1950	0	3690	307.5	41	46	49	🟩 45.5	16	19	21	18.6
15:30	15:35	1776	1872	1760	5408	450.7	43	49	51	🟩 47.7	14	17	18	16.3
15:35	15:40	1946	1937	2280	6163	513.6	41	47	49	🟩 46	17	19	21	19
15:40	15:45	1752	1946	2040	5738	478.2	42	47	51	🟩 46.7	14	17	17	16
15:45	15:50	1668	1800	2160	5628	469	41	45	47	🟧 44.9	14	20	20	18
15:50	15:55	1956	1973	2040	5969	497.4	40	46	49	🟩 45.1	17	18	19	18
15:55	16:00	1872	1812	2180	5864	488.7	42	47	50	🟩 46.6	15	16	18	16.3
16:00	16:05	1706	2010	1860	5576	464.7	44	49	51	🟩 48.4	14	18	16	16
16:05	16:10	1956	2100	2220	6276	523	39	44	45	🟧 42.7	18	20	21	19.6
16:10	16:15	1812	2000	2100	5912	492.7	39	42	45	🟧 42.5	15	21	22	19.3

LOOP DATA: MEDIUM DENSITY - April 17, 2001

Kennedy Blvd.		Volume					Speed				Lane Occupancy			
		1 hour				5 min.								
Time Interval		Lane 1	Lane 2	Lane 3	Sum		Lane 1	Lane 2	Lane 3	Avg.	Lane 1	Lane 2	Lane 3	Avg.
15:15	15:20	2130	1940	2160	6230	519.2	0	58	47	🟩 53.1	8	7	8	7.6
15:20	15:25	1840	1875	2088	5803	483.6	0	57	47	🟩 52.5	6	6	7	6.3
15:25	15:30	2160	1988	2080	6228	519	0	56	47	🟩 51.7	8	7	7	7.3
15:30	15:35	1920	1800	2100	5820	485	0	57	47	🟩 52.1	8	7	7	7.3
15:35	15:40	2000	1840	1640	5480	456.7	0	58	48	🟩 53.2	7	6	7	6.6
15:40	15:45	1740	1944	1896	5580	465	0	60	50	🟩 55.6	8	7	7	7.3
15:45	15:50	1820	2013	1992	5825	485.4	0	61	50	🟩 56	7	6	7	6.6
15:50	15:55	2010	1848	1800	5658	471.5	0	60	51	🟩 55.8	7	7	7	7
15:55	16:00	1860	1890	2100	5850	487.5	0	60	50	🟩 55.7	7	6	7	6.6
16:00	16:05	2064	1760	2120	5944	495.3	0	62	51	🟩 56.5	7	7	7	7
16:05	16:10	1890	2022	2100	6012	501	0	60	51	🟩 55.7	6	7	8	7
16:10	16:15	1920	1988	2160	6068	505.7	0	55	46	🟩 50.9	7	7	8	7.3

LOOP DATA: HIGH DENSITY - April 11, 2001

Par Ave.

		Volume					Speed				Lane Occupancy			
		1 hour				5 min.								
Time Interval		**Lane 1**	**Lane 2**	**Lane 3**	**Sum**		**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**	**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**
16:30	16:35	1656	1706	1720	5082	424	33	35	35	🟧 34.7	19	24	28	23.6
16:35	16:40	1872	1680	1815	5367	447	28	30	28	🟥 29.3	24	27	33	28
16:40	16:45	1740	1954	1880	5574	465	26	29	30	🟥 28.7	26	29	28	27.6
16:45	16:50	1830	1920	2040	5790	483	29	30	33	🟧 31.1	22	25	26	24.3
16:50	16:55	1860	1980	1920	5760	480	34	35	38	🟧 35.8	18	23	21	20.6
16:55	17:00	1853	1954	2140	5947	496	32	35	36	🟧 34.8	19	24	24	22.3
17:00	17:05	1933	1973	2100	6006	501	35	39	39	🟧 37.8	20	22	21	21
17:05	17:10	1905	2040	2200	6145	512	39	44	53	🟩 45.7	18	20	20	19.3
17:10	17:15	1830	1770	1650	5250	438	31	35	36	🟧 34.4	25	27	30	27.3
17:15	17:20	1380	1344	1428	4152	346	18	16	18	🟥 17.8	33	48	45	42
17:20	17:25	1140	1020	1140	3300	275	11	8	10	🟥 10	41	52	54	49
17:25	17:30	906	920	1000	2826	236	9	6	7	🟥 7.7	52	63	56	57

Kennedy Blvd.

16:30	16:35	1988	2013	2070	6071	505.9	0	54	48	🟩 51.3	7	7	16	10
16:35	16:40	2020	1902	2040	5962	496.8	0	52	47	🟩 50.2	7	6	15	9.3
16:40	16:45	2160	1968	2100	6228	519	0	51	45	🟩 48.7	8	7	17	10.6
16:45	16:50	2160	2280	2136	6576	548	0	53	47	🟩 50.6	8	8	16	10.6
16:50	16:55	2280	0	0	2280	190	0	55	50	🟩 52.7	8	8	16	10.6
16:55	17:00	2200	1920	2130	6250	520.8	0	54	47	🟩 50.9	8	7	16	10.3
17:00	17:05	2136	2100	2190	6426	535.5	0	52	48	🟩 50.4	7	7	17	10.3
17:05	17:10	2200	2025	1980	6205	517.1	0	53	48	🟩 51	8	7	17	10.6
17:10	17:15	1786	1872	1710	5368	447.3	0	60	54	🟩 57	6	5	12	7.6
17:15	17:20	1333	1573	1428	4334	361.2	0	62	57	🟩 60	4	5	8	5.6
17:20	17:25	1044	1392	1368	3804	317	0	63	58	🟩 60.9	3	4	8	5
17:25	17:30	1920	1937	2140	5997	499.8	0	56	51	🟩 54.3	7	6	15	9.3

LOOP DATA: HIGH DENSITY - April 17, 2001

Ivanhoe Blvd.		Volume					Speed				Lane Occupancy			
		1 hour				5 min.								
Time Interval		Lane 1	Lane 2	Lane 3	Sum		Lane 1	Lane 2	Lane 3	Avg.	Lane 1	Lane 2	Lane 3	Avg.
16:30	16:35	2100	1611	1885	5596	466.3	32	47	35	🟧 38.5	20	15	21	18.6
16:35	16:40	1954	1422	1628	5004	417	30	46	32	🟧 36.5	19	15	23	19
16:40	16:45	1542	1371	1611	4524	377	19	32	21	🟥 24.1	25	21	30	25.3
16:45	16:50	1851	1440	1800	5091	424.3	29	38	28	🟧 32.1	18	19	26	21
16:50	16:55	1740	1455	1530	4725	393.8	25	30	25	🟥 26.9	20	27	22	23
16:55	17:00	2000	1620	1680	5300	441.7	22	33	24	🟥 26.8	25	22	25	24
17:00	17:05	1560	1560	1420	4540	378.3	25	38	28	🟧 30.5	28	20	22	23.3
17:05	17:10	1650	1213	1346	4209	350.8	17	25	16	🟥 20.1	30	25	33	29.3
17:10	17:15	1746	1240	1653	4639	386.6	20	20	18	🟥 19.8	25	28	33	28.6
17:15	17:20	1885	1388	1628	4901	408.4	24	25	22	🟥 24.2	22	25	27	24.6
17:20	17:25	1380	1035	1275	3690	307.5	15	18	18	🟥 17.3	30	36	30	32
17:25	17:30	1560	1346	1586	4492	374.3	18	31	21	🟥 23.9	28	24	29	27
Par Ave.														
16:30	16:35	1932	1902	2220	6054	504.5	37	40	41	🟧 40	18	21	25	21.3
16:35	16:40	1800	1668	1826	5294	441.2	27	29	29	🟥 28.6	23	29	30	27.3
16:40	16:45	1853	1845	2190	5888	490.7	33	36	38	🟧 36.1	20	23	24	22.3
16:45	16:50	1728	1728	1800	5256	438	28	27	27	🟥 28	21	29	30	26.6
16:50	16:55	1733	1866	1800	5399	449.9	32	33	34	🟧 33.1	19	26	26	23.6
16:55	17:00	1908	1836	1965	5709	475.8	30	33	32	🟧 31.8	23	24	29	25.3
17:00	17:05	1812	1752	2025	5589	465.8	32	34	37	🟧 35	18	21	21	20
17:05	17:10	1908	1908	2053	5869	489.1	28	31	34	🟧 31.3	23	25	24	24
17:10	17:15	2016	2016	2040	6072	506	31	32	34	🟧 32.5	22	26	26	24.6
17:15	17:20	1800	1752	1872	5424	452	24	24	26	🟥 25.2	27	34	33	31.3
17:20	17:25	1944	1836	1992	5772	481	26	27	28	🟥 27.4	25	27	30	27.3
17:25	17:30	1812	1656	1824	5292	441	26	26	29	🟥 27.4	23	28	26	25.6

LOOP DATA: HIGH DENSITY - April 17, 2001

Kennedy Blvd.		**Volume**					**Speed**				**Lane Occupancy**			
		1 hour				5 min.								
Time Interval		**Lane 1**	**Lane 2**	**Lane 3**	**Sum**		**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**	**Lane 1**	**Lane 2**	**Lane 3**	**Avg.**
16:30	16:35	2175	2016	1900	6091	507.6	0	45	32	🟧 38.9	7	6	7	6.6
16:35	16:40	2160	1731	2074	5965	497.1	0	53	44	🟩 48.9	7	6	7	6.6
16:40	16:45	2100	1851	2160	6111	509.3	0	53	43	🟩 48.5	8	7	8	7.6
16:45	16:50	2125	2133	2010	6268	522.3	0	56	45	🟩 50.6	7	7	7	7
16:50	16:55	2020	1920	2080	6020	501.7	0	58	46	🟩 52.1	7	6	7	6.6
16:55	17:00	2200	2005	1992	6197	516.4	0	54	45	🟩 50	7	6	7	6.6
17:00	17:05	2140	1733	2108	5981	498.4	0	56	45	🟩 50.7	7	5	7	6.3
17:05	17:10	2160	2022	2160	6342	528.5	0	56	46	🟩 51.1	7	6	8	7
17:10	17:15	2190	1860	2256	6306	525.5	0	57	45	🟩 51.4	8	7	8	7.6
17:15	17:20	1920	2057	2000	5977	498.1	0	55	49	🟩 52.6	8	7	7	7.3
17:20	17:25	1980	1860	2100	5940	495	0	56	45	🟩 50.7	7	7	8	7.3
17:25	17:30	2160	1900	2070	6130	510.8	0	55	45	🟩 50.4	7	7	8	7.3

Appendix E. I-4 Surveillance Video Data

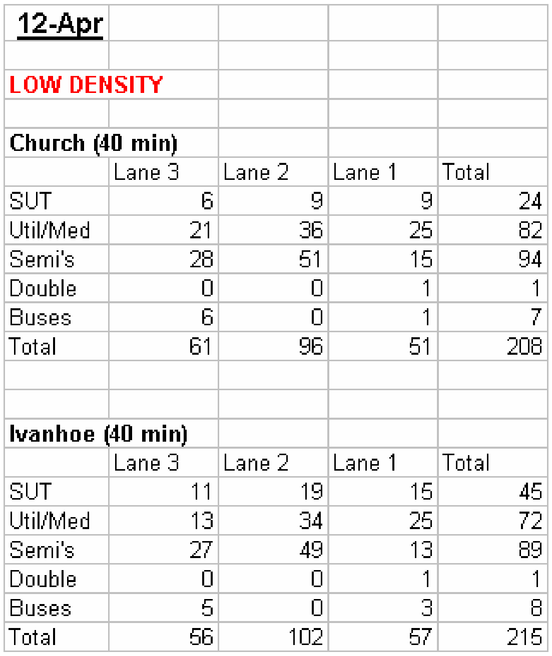
- Example manual volume count from I-4 video camera sites and comparison with corresponding loop counted volume

12-Apr

HIGH DENSITY

	Time frame (min)	Lane 1	Lane 2	Lane 3	Overall	Loops	% Diff.
Church	60	706	747	705	2158		
Ivanhoe	60	756	947	1069	2772	2814	-1.49%
Par	60	1235	1179	1288	3702	3701	0.03%
Kennedy	60	1666	1520	1694	4880	4955	-1.51%

- Example manual truck count from I-4 video camera sites



12-Apr

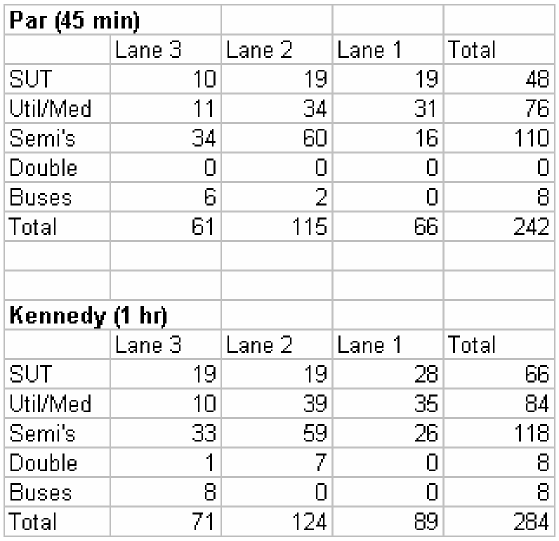
LOW DENSITY

Church (40 min)

	Lane 3	Lane 2	Lane 1	Total
SUT	6	9	9	24
Util/Med	21	36	25	82
Semi's	28	51	15	94
Double	0	0	1	1
Buses	6	0	1	7
Total	61	96	51	208

Ivanhoe (40 min)

	Lane 3	Lane 2	Lane 1	Total
SUT	11	19	15	45
Util/Med	13	34	25	72
Semi's	27	49	13	89
Double	0	0	1	1
Buses	5	0	3	8
Total	56	102	57	215



Par (45 min)

	Lane 3	Lane 2	Lane 1	Total
SUT	10	19	19	48
Util/Med	11	34	31	76
Semi's	34	60	16	110
Double	0	0	0	0
Buses	6	2	0	8
Total	61	115	66	242

Kennedy (1 hr)

	Lane 3	Lane 2	Lane 1	Total
SUT	19	19	28	66
Util/Med	10	39	35	84
Semi's	33	59	26	118
Double	1	7	0	8
Buses	8	0	0	8
Total	71	124	89	284

- Example summary truck count and classification percentages from I-4 video camera sites

LOW DENSITY

	SUT	Util/Med	Semi's	Double	Buses	Total	Truck Total
Church	24	82	94	1	7	208	201
Ivanhoe	45	72	89	1	8	215	207
Par	48	76	110	0	8	242	234
Kennedy	66	84	118	8	8	284	276
Totals	183	314	411	10	31	949	918

Percentages	
SUT	19.9
Util/Med	34.2
Semi's	44.8
Double	1.1

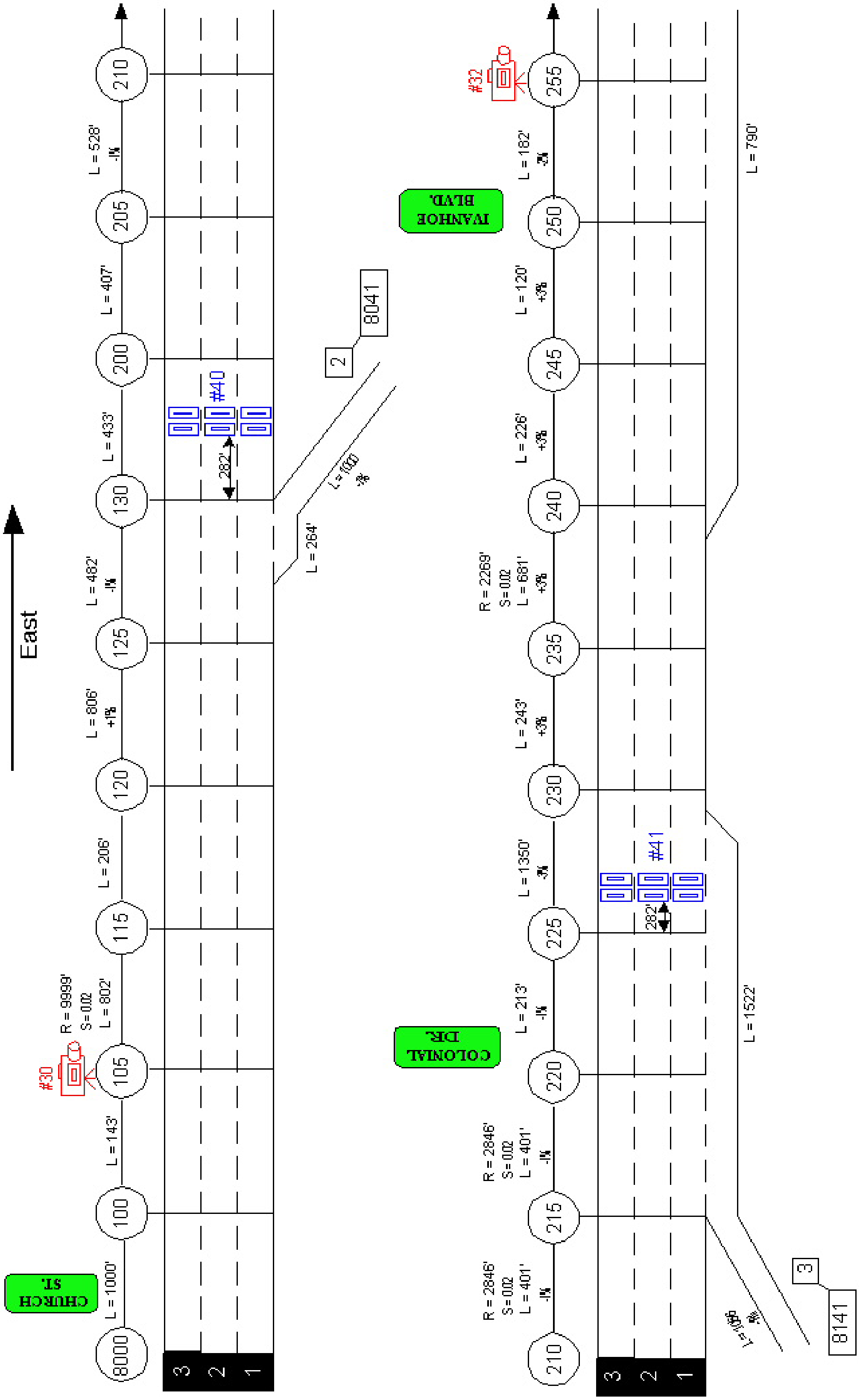
Appendix F. Site Visit Collected Data

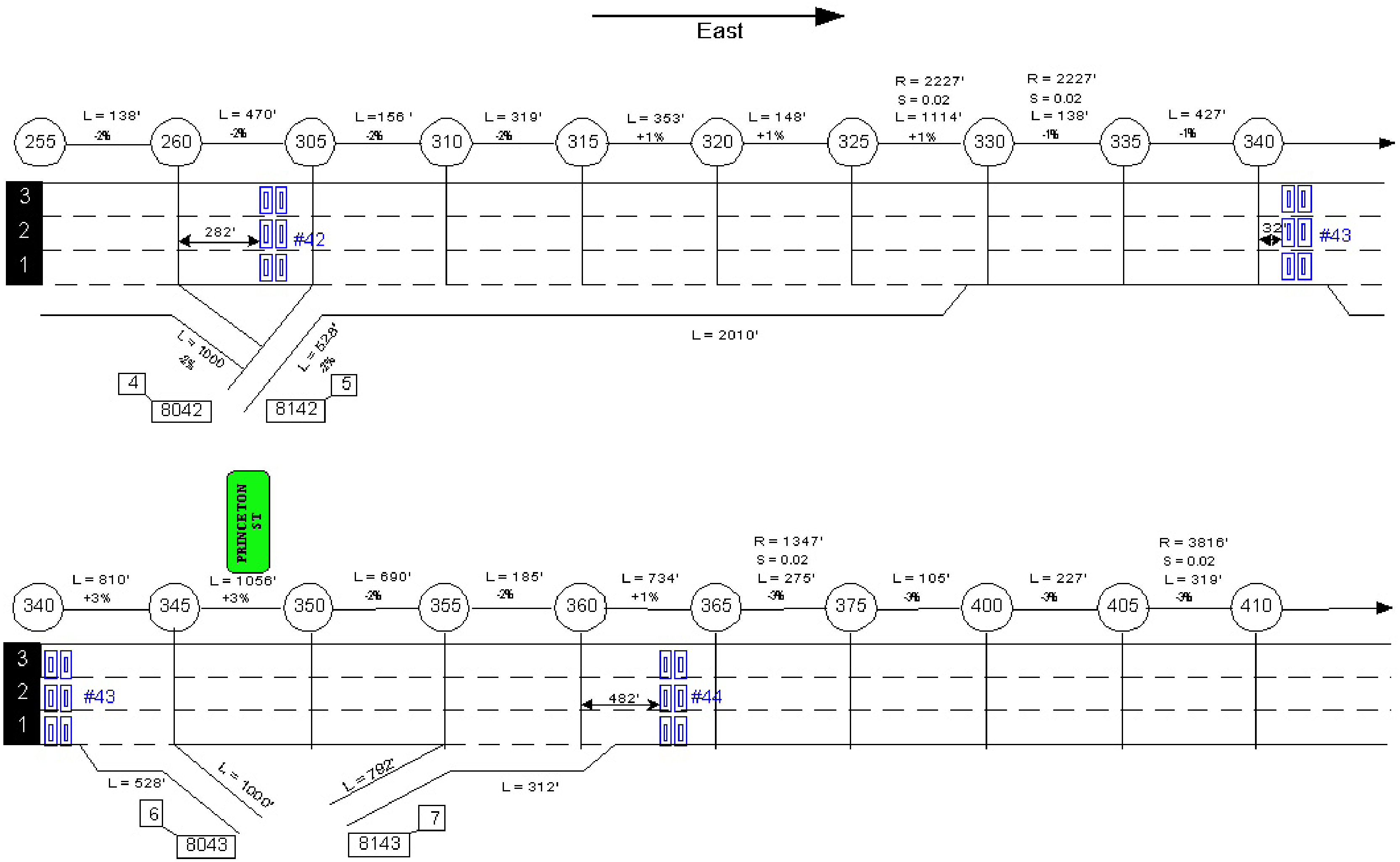
I-4 Field Notes

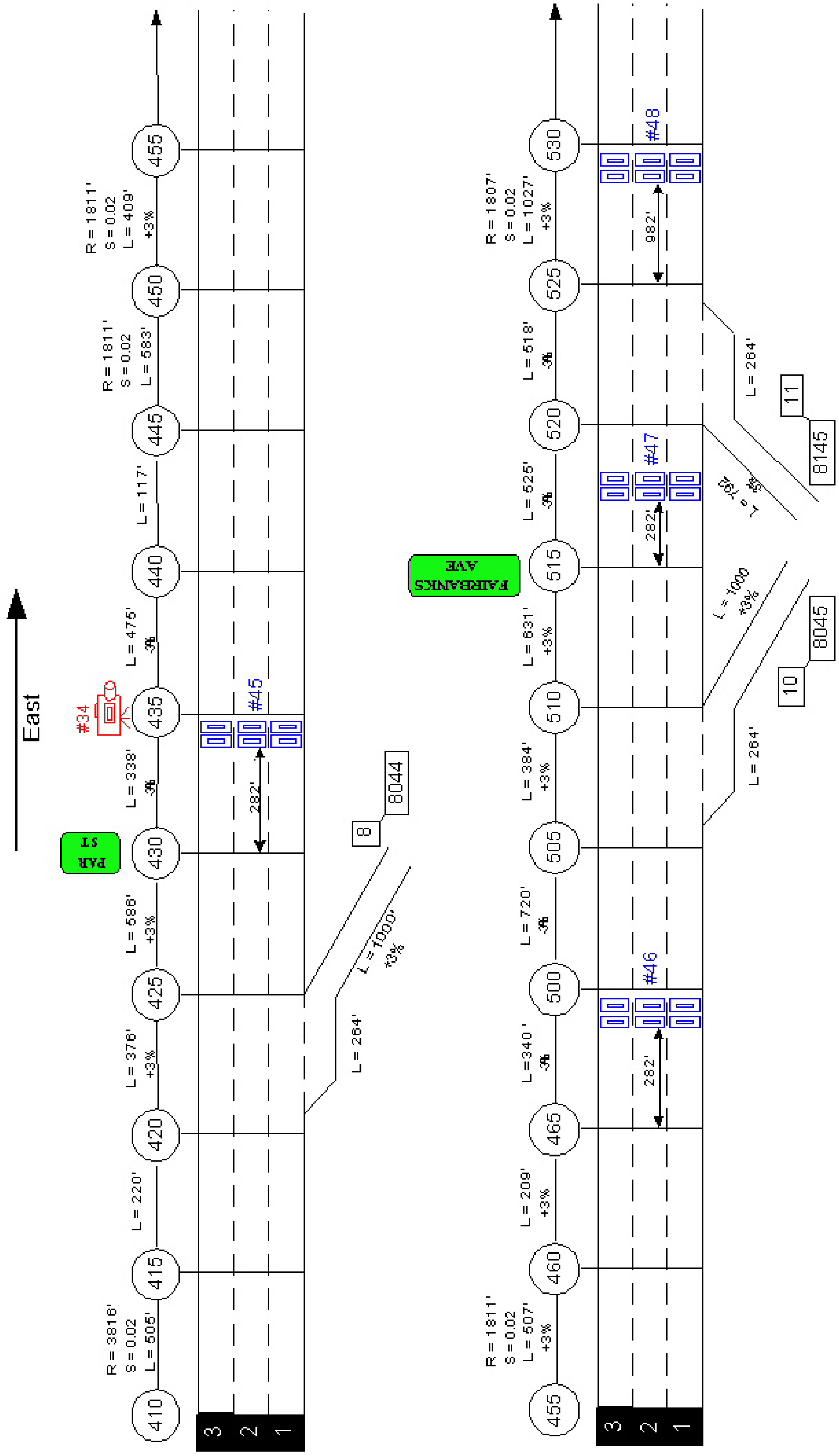
All measurements are mileage readings			Mileage					Warning Signs Mileage			
			Off Ramps		On Ramps						
Cross Street	**Exit/Entry**	**#**	**Begin Decel.**	**Gore**	**Begin Ramp**	**Gore**	**End Accel.**	**1 mi**	**3/4 mi**	**1/2 mi**	**1/4 mi**
Church St											
Washington St											
Robinson St	Exit	40	1.6	1.7						1	
Livingston St											
Amelia St	Exit	41	1.9	1.95	2.09	2.29	2.49				1.75
Colonial Dr	Entry	41		2.29	0	0.2	0.4				
Ivanhoe Blvd	Exit	42	2.85	3	2.99	3.09	3.29	2			
Ivanhoe Blvd	Entry	42		3.09	1.8	1.9	2.1				
New Hamp. St											
Princeton St	Exit	43	3.55	3.65	3.7	3.85	4	3.05			
Princeton St	Entry	43		3.85	2.6	2.75	2.9				
Winter Park Ave											
Par St	Exit	44	4.3	4.35					3.7	4	
Minnesota Ave											
Fairbanks Ave	Exit	45	5.25	5.3	5.37	5.52	5.57		4.5	4.8	
Fairbanks Ave	Entry	45		5.52	4.35	4.5	4.55				
Wymore Rd											
Lee Rd	Exit	46	5.95	6.05	6.27	6.47	6.52		5.35		
Lee Rd	Entry	46		6.47	5.4	5.6	5.65				
Eatonville Rd											
Maitland Blvd	Exit	47A	7.45	7.75							7.4
Maitland Blvd	Exit	47B	7.45	7.95	7.98	8.43	8.48				7.4
Maitland Blvd	Entry	47		8.43	8.2	8.65	8.7				

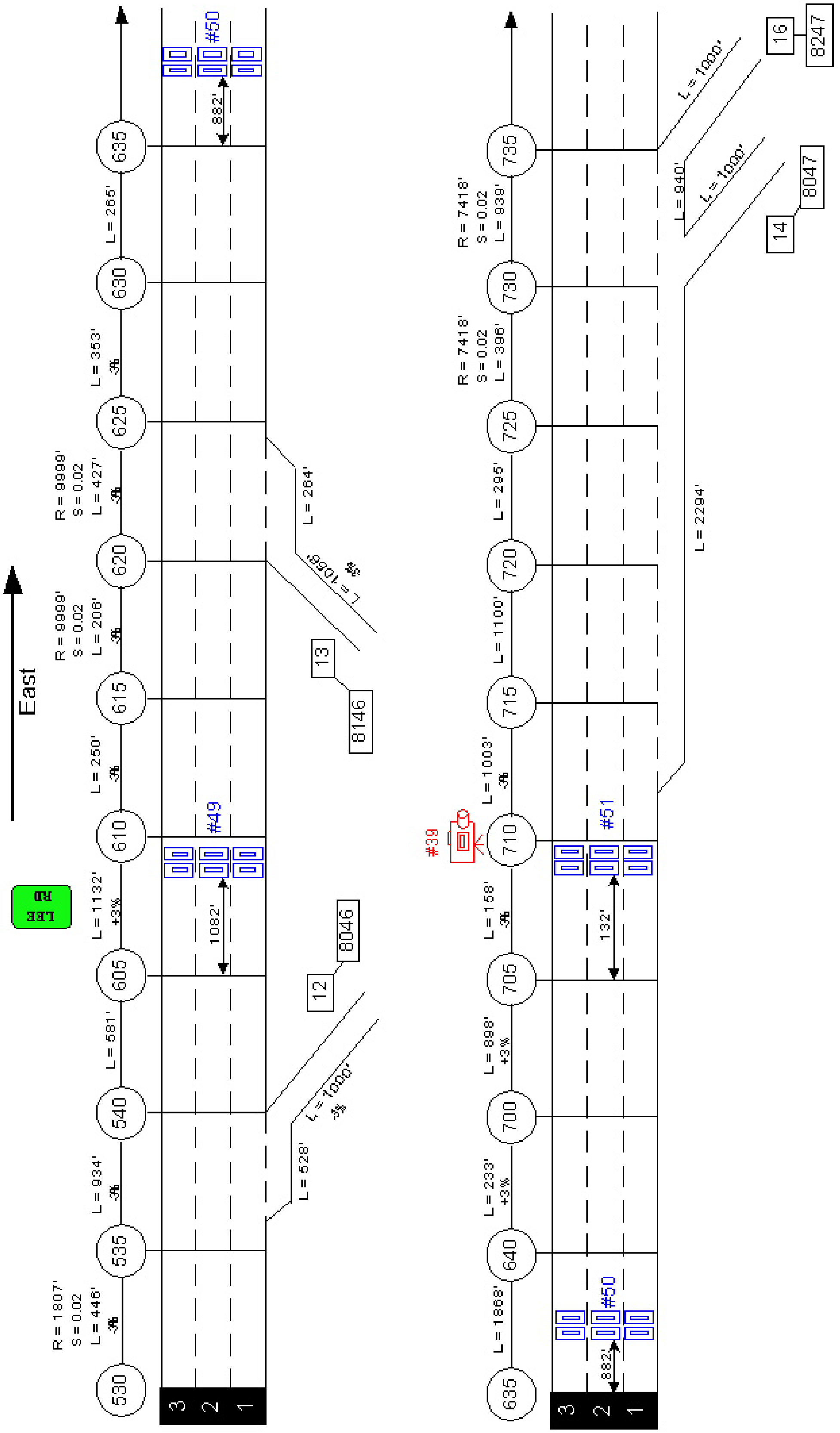
All measurements in ft			Decel. Lane Length	On-Ramp Length	Accel Lane Length	Warning Sign Location			
Robinson St	**Exit**	**40**	528					3696	
Amelia St	**Exit**	**41**	264	1056	1056				1056
Ivanhoe Blvd	**Exit**	**42**	792	528	1056	5280			
Princeton St	**Exit**	**43**	528	792	792	3168			
Par St	**Exit**	**44**	264				3432	1848	
Fairbanks Ave	**Exit**	**45**	264	792	264		4224	2640	
Lee Rd	**Exit**	**46**	528	1056	264		3696		
Maitland Blvd	**Exit**	**47A**	1584	2376	264				1848
Maitland Blvd	**Exit**	**47B**	2640						2904

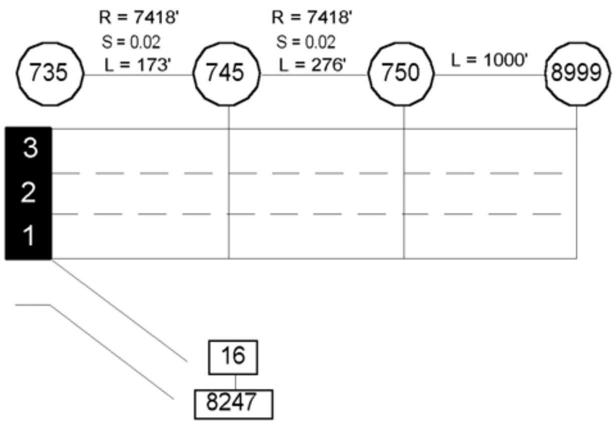
Appendix G. FRESIM Link-Node Diagram of I-4 Network


East
CHURCH ST.
8000
L = 1000'
100
L = 143'
105
#30
R = 9999'
S = 0.02
L = 802'
115
L = 206'
120
L = 806'
+1%
125
L = 482'
-1%
130
L = 433'
282'
#40
200
L = 407'
205
L = 528'
-1%
210
L = 264'
L = 1000'
2
8041
3
2
1
210
R = 2846'
S = 0.02
L = 401'
-1%
215
R = 2846'
S = 0.02
L = 401'
-1%
220
COLONIAL DR.
L = 213'
-1%
225
282'
#41
L = 1350'
230
L = 243'
+3%
235
R = 2269'
S = 0.02
L = 681'
+3%
240
L = 226'
+3%
245
L = 120'
+3%
250
IVANHOE BLVD.
L = 182'
255
#32
L = 1522'
L = 790'
L = 1000'
3
8141
3
2
1


East
R = 2227'
S = 0.02
L = 1114'
+1%
R = 2227'
S = 0.02
L = 138'
-1%
L = 138'
-2%
L = 470'
-2%
L =156 '
-2%
L = 319'
-2%
L = 353'
+1%
L = 148'
+1%
L = 427'
-1%
255
260
305
310
315
320
325
330
335
340
3
2
1
282'
#42
32'
#43
L = 2010'
L = 1000
-2%
L = 528'
-2%
4
8042
5
8142
PRINCETON ST
R = 1347'
S = 0.02
L = 275'
-3%
R = 3816'
S = 0.02
L = 319'
-3%
L = 810'
+3%
L = 1056'
+3%
L = 690'
-2%
L = 185'
-2%
L = 734'
+1%
L = 105'
-3%
L = 227'
-3%
340
345
350
355
360
365
375
400
405
410
3
2
1
#43
482'
#44
L = 528'
L = 1000'
L = 782'
L = 312'
6
8043
7
8143


East
410
415
420
425
430
435
440
445
450
455
R = 3816'
S = 0.02
L = 505'
L = 220'
L = 376'
+3%
L = 586'
+3%
L = 338'
-3%
L = 475'
-3%
L = 117'
R = 1811'
S = 0.02
L = 583'
R = 1811'
S = 0.02
L = 409'
+3%
PAR ST
#34
#45
282'
8
8044
L = 1000'
+3%
L = 264'
3
2
1
455
460
465
500
505
510
515
520
525
530
R = 1811'
S = 0.02
L = 507'
+3%
L = 209'
+3%
L =340 '
-3%
L = 720'
-3%
L = 384'
+3%
L = 631'
+3%
L = 525'
-3%
L = 518'
-3%
R = 1807'
S = 0.02
L = 1027'
+3%
FAIRBANKS AVE
#46
282'
#47
282'
#48
982'
10
8045
L = 1000
+3%
L = 264'
L = 780'
-3%
11
8145
L = 264'
3
2
1


East
LEE RD
530
535
540
605
610
615
620
625
630
635
R = 1807'
S = 0.02
L = 446'
-3%
L = 934'
-3%
L = 581'
L = 1132'
+3%
L = 250'
-3%
R = 9999'
S = 0.02
L = 206'
-3%
R = 9999'
S = 0.02
L = 427'
-3%
L = 353'
-3%
L = 265'
3
2
1
#49
1082'
#50
882'
L = 528'
L = 1000'
-3%
12
8046
13
8146
L = 1056'
-3%
L = 264'
635
640
700
705
710
715
720
725
730
735
L = 1868'
L = 233'
+3%
L = 898'
+3%
L = 158'
-3%
L = 1003'
-3%
L = 1100'
L = 295'
R = 7418'
S = 0.02
L = 396'
R = 7418'
S = 0.02
L = 939'
#50
882'
#51
132'
#39
L = 2294'
L = 940'
L = 1000'
L = 1000'
14
8047
16
8247


R = 7418'
S = 0.02
L = 173'
R = 7418'
S = 0.02
L = 276'
L = 1000'
735
745
750
8999
3
2
1
16
8247

Appendix H. Sample FRESIM Input File for I-4 Network

```
INTERSTATE-4 EASTBOUND FROM CHURCH ST TO MAITLAND BLVD IN ORLANDO, FL          0
LOW DENSITY DATA: THURSDAY, APRIL 12, AND TUESDAY, APRIL 17, 2001
Created by Jaime M Rooney              4  122001  University of Florida    0   1
**** Run Control ****
       1   1      10     7981 0000  21             81355        7781    7581   2
**** Time Period Specifications ****
 300                                                                           3
**** Time Interval ****
                  60                                                           4
**** Reports and Graphics ****
   0       0   0   0   0   0   0   0   0   0   0                               5

**** I-4 Link Geometry ****
    **** Mainline ****
 100 105 115  1430 3                         1                                19
 105 115 120  8030 3                         1                                19
 115 120 125  2060 3                         1                                19
 120 125 130  8060 3                         1                                19
 125 130 200  4820 3 92  264                 1 9                              19
 130 200 205  4330 3                         1                                19
 200 205 210  4070 3                         1                                19
 205 210 215  5280 3                         1                                19
 210 215 220  4010 3                         1                                19
 215 220 225  4010 3 93  401                 2                                19
 220 225 230  2130 4                         1                                19
 225 230 235 13500 4                         1                                19
 230 235 240  2430 3                         1                                19
 235 240 245  6810 3                         1                                19
 240 245 250  2260 4                         1                                19
 245 250 255  1200 4                         1                                19
 250 255 260  1820 4                         9                                19
 255 260 305  1370 3 93  137                 1 9                              19
 260 305 310  4700 3                         1                                19
 305 310 315  1560 3 93  156                 2                                19
 310 315 320  3190 4                         1                                19
 315 320 325  3530 4                         1                                19
 320 325 330  1480 4                         1                                19
 325 330 335 11140 4                         1                                19
 330 335 340  1370 3                         1                                19
 335 340 345  4280 3                         1                                19
 340 345 350  8100 3 92  528                 1 9                              19
 345 350 355 10560 3                         1                                19
 350 355 360  6900 3                         1                                19
 355 360 365  1850 3 93  185                 2                                19
 360 365 375  7340 4                         1                                19
 365 375 400  2750 3                         1                                19
 375 400 405  1060 3                         1                                19
 400 405 410  2270 3                         1                                19
 405 410 415  3190 3                         1                                19
 410 415 420  5040 3                         1                                19
 415 420 425  2210 3                         1                                19
 420 425 430  3760 3 92  264                 1 9                              19
 425 430 435  5850 3                         1                                19
 430 435 440  3390 3                         1                                19
 435 440 445  4750 3                         1                                19
 440 445 450  1160 3                         1                                19
 445 450 455  5840 3                         1                                19
 450 455 460  4090 3                         1                                19
 455 460 465  5070 3                         1                                19
 460 465 500  2090 3                         1                                19
 465 500 505  3400 3                         1                                19
 500 505 510  7190 3                         1                                19
```

```
 505 510 515  3840 3 92  264                 1 9                              19
 510 515 520  6310 3                         1                                19
 515 520 525  5250 3                         1                                19
 520 525 530  5170 3 91  264                 1                                19
 525 530 535 10280 3                         1                                19
 530 535 540  4450 3                         1                                19
 535 540 605  9350 3 92  528                 1 9                              19
 540 605 610  6400 3                         1                                19
 605 610 615 11320 3                         1                                19
 610 615 620  2500 3                         1                                19
 615 620 625  2060 3                         1                                19
 620 625 630  4280 3 91  264                 1                                19
 625 630 635  3530 3                         1                                19
 630 635 640  2650 3                         1                                19
 635 640 700 18680 3                         1                                19
 640 700 705  2340 3                         1                                19
 700 705 710  8980 3                         1                                19
 705 710 715  1580 3                         1                                19
 710 715 720 10020 3                         1                                19
 715 720 725 11000 4                         1                                19
 720 725 730  2950 4                         9                                19
 725 730 735  3960 3 93  396                 1 9                              19
 730 735 745  9400 3 92  940                 1 9                              19
 735 745 750  1730 3                         1                                19
 745 7508999  2760 3                         1                                19
    **** Ramps ****
 130   28041 10001 1                         1                                19
   3 215 220 10561 1                         9                                19
 260   48042 10001 1                         1                                19
   5 305 310  5281 1                         9                                19
 345   68043 10001 1                         1                                19
   7 355 360  7921 1                         9                                19
 425   88044 10001 1                         1                                19
 510  108045 10001 1                         1                                19
  11 520 525  7921 1                         9                                19
 540  128046 10001 1                         1                                19
  13 620 625 10561 1                         9                                19
 730  148047 10001 1                         1                                19
 735  168247 10001 1                         1                                19
    **** Entry Nodes ****
8000 100 105     0 3                         1                                19
8141   3 215     1 1                         1                                19
8142   5 305     1 1                         1                                19
8143   7 355     1 1                         1                                19
8145  11 520     1 1                         1                                19
8146  13 620     1 1                         1                                19

**** Freeway Link Operations ****
    **** Mainline ****
 100 105 0 0     11065                                               100      20
 105 115 0 29999 11065                                               100      20
 115 120 0 0   0 11065                                               100      20
 120 125 1 0   0 11065                                               100      20
 125 130-1 0   0 11065       1056      1056                          100      20
 130 200 0 0   0 11065             300                               100      20
 200 205 0 0   0 11065                                               100      20
 205 210-1 0   0 11065                                               100      20
 210 215-1 22846 11065                                               100      20
 215 220-1 22846 11065                                        481250 100      20
 220 225-1 0   0 11065                                               100      20
 225 230-3 0   0 11065             300                               100      20
 230 235 3 0   0 11065                                               100      20
 235 240 3 22269 11065                                               100      20
```

```
240 245 3 0    0 11065                                              100      20
245 250 3 0    0 11065                                              100      20
250 255-2 0    0 11065                                              100      20
255 260-2 0    0 11065      5280      5280                   481250 100      20
260 305-2 0    0 11065            300                               100      20
305 310-2 0    0 11065                                       481250 100      20
310 315-2 0    0 11065                                              100      20
315 320 1 0    0 11065                                              100      20
320 325 1 0    0 11065                                              100      20
325 330 1 22227 11065                                              100      20
330 335-1 22227 11065                                              100      20
335 340-1 0    0 11065                                              100      20
340 345 3 0    0 11065      3168   50 3168                          100      20
345 350 3 0    0 11065                                              100      20
350 355-2 0    0 11065                                              100      20
355 360-2 0    0 11065                                       481250 100      20
360 365 1 0    0 11065            500                               100      20
365 375-3 21347 11065                                              100      20
375 400-3 0    0 11065                                              100      20
400 405-3 0    0 11065                                              100      20
405 410-3 23816 11065                                              100      20
410 415 0 23816 11065                                              100      20
415 420 0 0    0 11065                                              100      20
420 425 3 0    0 11065      1848      3432                          100      20
425 430 3 0    0 11065                                              100      20
430 435-3 0    0 11065            300                               100      20
435 440-3 0    0 11065                                              100      20
440 445 0 0    0 11065                                              100      20
445 450 0 21811 11065                                              100      20
450 455 3 21811 11065                                              100      20
455 460 3 21811 11065                                              100      20
460 465 3 0    0 11065                                              100      20
465 500-3 0    0 11065            300                               100      20
500 505-3 0    0 11065                                              100      20
505 510 3 0    0 11065      2640      4224                          100      20
510 515 3 0    0 11065                                              100      20
515 520-3 0    0 11065            300                               100      20
520 525-3 0    0 11065                                       481250 100      20
525 530 3 21807 11065           1000                               100      20
530 535-3 21807 11065                                              100      20
535 540-3 0    0 11065      3696      3696                          100      20
540 605 0 0    0 11065                                              100      20
605 610 3 0    0 11065           1100                               100      20
610 615-3 0    0 11065                                              100      20
615 620-3 29999 11065                                              100      20
620 625-3 29999 11065                                       481250 100      20
625 630-3 0    0 11065                                              100      20
630 635 0 0    0 11065                                              100      20
635 640 0 0    0 11065            900                               100      20
640 700 3 0    0 11065                                              100      20
700 705 3 0    0 11065                                              100      20
705 710-3 0    0 11065            150                               100      20
710 715-3 0    0 11065                                              100      20
715 720 0 0    0 11065                                              100      20
720 725 0 0    0 11065                                              100      20
725 730 0 27418 11065      2500      2500                   481250 100      20
730 735 0 27418 11065      2904      2904                          100      20
735 745 0 27418 11065                                              100      20
745 750 0 27418 11065                                              100      20
   **** Ramps ****
130   2-1 0    0 11065                                              100      20
  3 215-1 0    0 11065                                              100      20
260   4-2 0    0 11065                                              100      20
```

```
   5 305-2 0   0 11065                                               100      20
 345    6 0 0   0 11065                                               100      20
   7 355 0 0   0 11065                                               100      20
 425    8 3 0   0 11065                                               100      20
 510   10 3 0   0 11065                                               100      20
  11 520-3 0   0 11065                                               100      20
 540   12-3 0   0 11065                                               100      20
  13 620-3 0   0 11065                                               100      20
 730   14 0 0   0 11065                                               100      20
 735   16 0 0   0 11065                                               100      20
    **** Entry Nodes ****
8000 100 0 0   0 11065                                                        20
8141    3-1 0   0 11065                                                        20
8142    5-2 0   0 11065                                                        20
8143    7 0 0   0 11065                                                        20
8145   11-3 0   0 11065                                                        20
8146   13-3 0   0 11065                                                        20

**** Freeway Turning Movements ****
 100 105 115 100                                                              25
 105 115 120 100                                                              25
 115 120 125 100                                                              25
 120 125 130 100                                                              25
 125 130 200  90   2  10                                                      25
 130 200 205 100                                                              25
 200 205 210 100                                                              25
 205 210 215 100                                                              25
 210 215 220 100                                                              25
 215 220 225 100                                                              25
 220 225 230 100                                                              25
 225 230 235 100                                                              25
 230 235 240 100                                                              25
 235 240 245 100                                                              25
 240 245 250 100                                                              25
 245 250 255 100                                                              25
 250 255 260 100                                                              25
 255 260 305  96   4   4                                                      25
 260 305 310 100                                                              25
 305 310 315 100                                                              25
 310 315 320 100                                                              25
 315 320 325 100                                                              25
 320 325 330 100                                                              25
 325 330 335 100                                                              25
 330 335 340 100                                                              25
 335 340 345 100                                                              25
 340 345 350  99   6   1                                                      25
 345 350 355 100                                                              25
 350 355 360 100                                                              25
 355 360 365 100                                                              25
 360 365 375 100                                                              25
 365 375 400 100                                                              25
 375 400 405 100                                                              25
 400 405 410 100                                                              25
 405 410 415 100                                                              25
 410 415 420 100                                                              25
 415 420 425 100                                                              25
 420 425 430  99   8   1                                                      25
 425 430 435 100                                                              25
 430 435 440 100                                                              25
 435 440 445 100                                                              25
 440 445 450 100                                                              25
 445 450 455 100                                                              25
 450 455 460 100                                                              25
```

```
 455 460 465 100                                                              25
 460 465 500 100                                                              25
 465 500 505 100                                                              25
 500 505 510 100                                                              25
 505 510 515  99  10   1                                                      25
 510 515 520 100                                                              25
 515 520 525 100                                                              25
 520 525 530 100                                                              25
 525 530 535 100                                                              25
 530 535 540 100                                                              25
 535 540 605  98  12   2                                                      25
 540 605 610 100                                                              25
 605 610 615 100                                                              25
 610 615 620 100                                                              25
 615 620 625 100                                                              25
 620 625 630 100                                                              25
 625 630 635 100                                                              25
 630 635 640 100                                                              25
 635 640 700 100                                                              25
 640 700 705 100                                                              25
 700 705 710 100                                                              25
 705 710 715 100                                                              25
 710 715 720 100                                                              25
 715 720 725 100                                                              25
 720 725 730 100                                                              25
 725 730 735  99  14   1                                                      25
 730 735 745  99  16   1                                                      25
 735 745 750 100                                                              25
 745 7508999 100                                                              25
  Ramps
 130   28041 100                                                              25
   3 215 220 100                                                              25
 260   48042 100                                                              25
   5 305 310 100                                                              25
 345   68043 100                                                              25
   7 355 360 100                                                              25
 425   88044 100                                                              25
 510  108045 100                                                              25
  11 520 525 100                                                              25
 540  128046 100                                                              25
  13 620 625 100                                                              25
 730  148047 100                                                              25
 735  168247 100                                                              25
   Entry Nodes
8000 100 105 100                                                              25
8141   3 215 100                                                              25
8142   5 305 100                                                              25
8143   7 355 100                                                              25
8145  11 520 100                                                              25
8146  13 620 100                                                              25

**** Loop Detectors ****
 130 200   1 300   6   6   2  40                                              28
 130 200   2 300   6   6   2  40                                              28
 130 200   3 300   6   6   2  40                                              28
 225 230   2 300   6   6   2  41                                              28
 225 230   3 300   6   6   2  41                                              28
 225 230   4 300   6   6   2  41                                              28
 260 305   1 300   6   6   2  42                                              28
 260 305   2 300   6   6   2  42                                              28
 260 305   3 300   6   6   2  42                                              28
 340 345   1  50   6   6   2  43                                              28
 340 345   2  50   6   6   2  43                                              28
```

```
 340 345   3  50   6   6   2  43                                              28
 360 365   1 500   6   6   2  44                                              28
 360 365   2 500   6   6   2  44                                              28
 360 365   3 500   6   6   2  44                                              28
 430 435   1 300   6   6   2  45                                              28
 430 435   2 300   6   6   2  45                                              28
 430 435   3 300   6   6   2  45                                              28
 465 500   1 300   6   6   2  46                                              28
 465 500   2 300   6   6   2  46                                              28
 465 500   3 300   6   6   2  46                                              28
 515 520   1 300   6   6   2  47                                              28
 515 520   2 300   6   6   2  47                                              28
 515 520   3 300   6   6   2  47                                              28
 525 530   11000   6   6   2  48                                              28
 525 530   21000   6   6   2  48                                              28
 525 530   31000   6   6   2  48                                              28
 605 610   11100   6   6   2  49                                              28
 605 610   21100   6   6   2  49                                              28
 605 610   31100   6   6   2  49                                              28
 635 640   1 900   6   6   2  50                                              28
 635 640   2 900   6   6   2  50                                              28
 635 640   3 900   6   6   2  50                                              28
 705 710   1 150   6   6   2  51                                              28
 705 710   2 150   6   6   2  51                                              28
 705 710   3 150   6   6   2  51                                              28
 remove705 710   4 150   6   6   2  51      28

**** Lane Add/Drop ****
 225 230   2 1    908 1500                                                    32
 235 240   1 1    556    0                                                    32
 325 330   2 1   1034 1500                                                    32
 360 365   2 1    127 1500                                                    32
 710 715   1 1    500    0                                                    32

**** Entry Link Volumes ****
8000 1005307   6   0  100                                    28 33 39          50
8141   3 850   2   0  100                                   100                50
8142   5 630   2   0  100                                   100                50
8143   7  60   1   0  100                                   100                50
8145  11  50   1   0  100                                   100                50
8146  13  95   1   0  100                                   100                50

**** Point Processing ****
   0   1 300                                          20   1   0              64
404142434445464748495051                                                      67
 100  90  80  70  60  50  40  30  20  10  10                                  68
      14                                                                      70

**** Vehicle Type Specifications ****
Single Unit Truck
   3  25              20                                                      71
Utility and Medium Trucks
   4  30              32                                                      71
Semitrailer
   5  60              47                                                      71
Double bottom trailer
   6  73               1                                                      71
Intercity Bus
   7  40                 100                                                  71

**** Sub-network Delimeter ****
   0                                                                         170
```

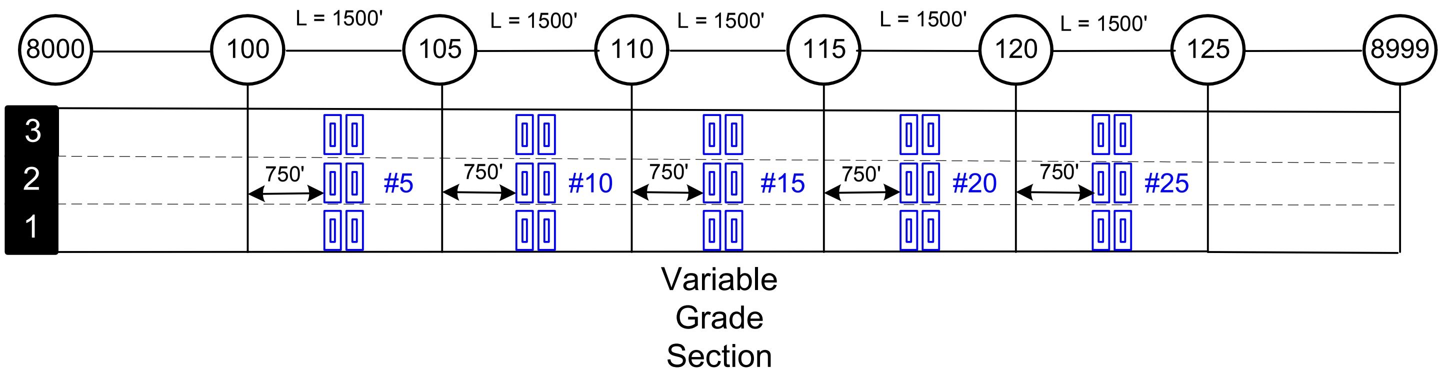
```
**** Bus Routes ****
   18000 100 105 115 120 125 130 200 205 210 215 220 225 230 235 240 245 250 187
   1 255 260 305 310 315 320 325 330 335 340 345 350 355 360 365 375 400 405 187
   1 410 415 420 425 430 435 440 445 450 455 460 465 500 505 510 515 520 525 187
   1 530 535 540 605 610 615 620 625 630 635 640 700 705 710 715 720 725 730 187
   1 735 745 7508999                                                         187
   1 450                                                                     189

**** Node Coordinates ****
     Mainline
8000       0    1000                                                         195
 100    1000    1000                                                         195
 105    1143    1000                                                         195
 115    1945    1000                                                         195
 120    2151    1000                                                         195
 125    2957    1000                                                         195
 130    3439    1000                                                         195
 200    3872    1000                                                         195
 205    4279    1000                                                         195
 210    4807    1000                                                         195
 215    5208    1000                                                         195
 220    5609    1000                                                         195
 225    5822    1000                                                         195
 230    7172    1000                                                         195
 235    7415    1000                                                         195
 240    8096    1000                                                         195
 245    8322    1000                                                         195
 250    8442    1000                                                         195
 255    8624    1000                                                         195
 260    8762    1000                                                         195
 305    9232    1000                                                         195
 310    9388    1000                                                         195
 315    9707    1000                                                         195
 320   10060    1000                                                         195
 325   10208    1000                                                         195
 330   11322    1000                                                         195
 335   11460    1000                                                         195
 340   11887    1000                                                         195
 345   12697    1000                                                         195
 350   13753    1000                                                         195
 355   14443    1000                                                         195
 360   14628    1000                                                         195
 365   15362    1000                                                         195
 375   15637    1000                                                         195
 400   15742    1000                                                         195
 405   15969    1000                                                         195
 410   16288    1000                                                         195
 415   16793    1000                                                         195
 420   17013    1000                                                         195
 425   17389    1000                                                         195
 430   17975    1000                                                         195
 435   18313    1000                                                         195
 440   18788    1000                                                         195
 445   18905    1000                                                         195
 450   19488    1000                                                         195
 455   19897    1000                                                         195
 460   20404    1000                                                         195
 465   20613    1000                                                         195
 500   20953    1000                                                         195
 505   21673    1000                                                         195
 510   22057    1000                                                         195
 515   22688    1000                                                         195
 520   23213    1000                                                         195
```

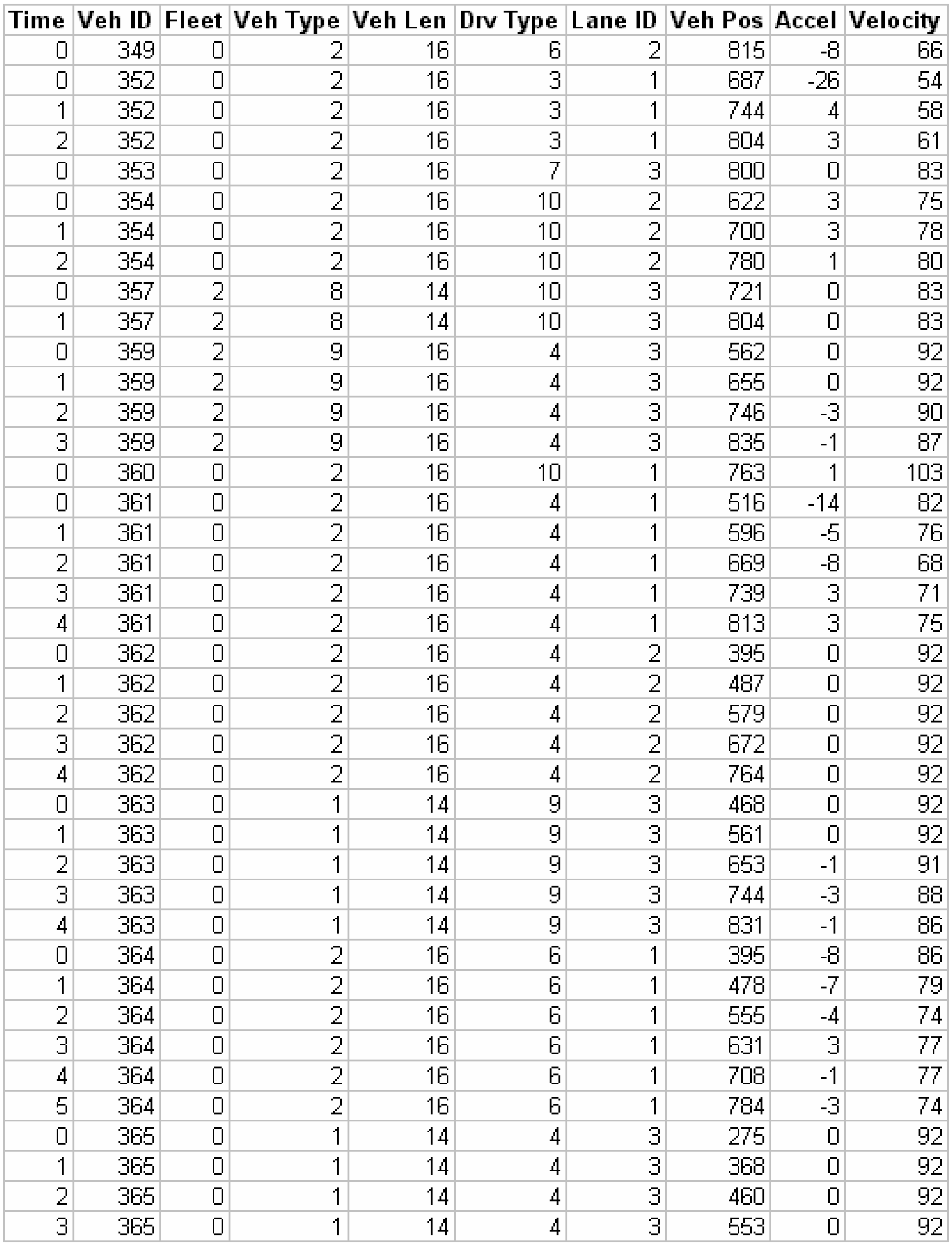
```
 525   23731    1000                                                         195
 530   24758    1000                                                         195
 535   25204    1000                                                         195
 540   26138    1000                                                         195
 605   26779    1000                                                         195
 610   27911    1000                                                         195
 615   28161    1000                                                         195
 620   28367    1000                                                         195
 625   28794    1000                                                         195
 630   29147    1000                                                         195
 635   29412    1000                                                         195
 640   31280    1000                                                         195
 700   31513    1000                                                         195
 705   32411    1000                                                         195
 710   32569    1000                                                         195
 715   33572    1000                                                         195
 720   34672    1000                                                         195
 725   34967    1000                                                         195
 730   35363    1000                                                         195
 735   36302    1000                                                         195
 745   36475    1000                                                         195
 750   36751    1000                                                         195
8999   37751    1000                                                         195
     Ramps
   2    4305     500                                                         195
8041    4405     450                                                         195
   3    4293     472                                                         195
8141    4193     422                                                         195
   4    9628     500                                                         195
8042    9728     450                                                         195
   5    8775     736                                                         195
8142    8675     686                                                         195
   6   13563     500                                                         195
8043   13663     450                                                         195
   7   13757     604                                                         195
8143   13657     554                                                         195
   8   18255     500                                                         195
8044   18355     450                                                         195
  10   22923     500                                                         195
8045   23023     450                                                         195
  11   22527     604                                                         195
8145   22427     554                                                         195
  12   27004     500                                                         195
8046   27104     450                                                         195
  13   27452     472                                                         195
8146   27352     422                                                         195
  14   36229     500                                                         195
8047   36329     450                                                         195
Remove  15   36758     100
195
Remove8147   36658     000
195
  16   37168     500                                                         195
8247   37268     450                                                         195

**** Termination ****
   1   0   0                                                                 210
```

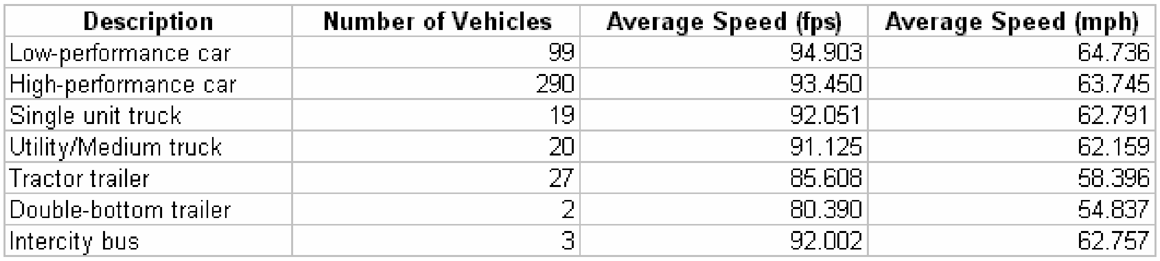
Appendix I. FRESIM Link-Node Diagram of Experimental Section


8000
100
105
110
115
120
125
8999
L = 1500'
L = 1500'
L = 1500'
L = 1500'
L = 1500'
3
2
1
750'
750'
750'
750'
750'
#5
#10
#15
#20
#25
Variable
Grade
Section

Appendix J. Sample Excerpt of TSD Output and Summary Data in Microsoft Excel



Time	Veh ID	Fleet	Veh Type	Veh Len	Drv Type	Lane ID	Veh Pos	Accel	Velocity
0	349	0	2	16	6	2	815	-8	66
0	352	0	2	16	3	1	687	-26	54
1	352	0	2	16	3	1	744	4	58
2	352	0	2	16	3	1	804	3	61
0	353	0	2	16	7	3	800	0	83
0	354	0	2	16	10	2	622	3	75
1	354	0	2	16	10	2	700	3	78
2	354	0	2	16	10	2	780	1	80
0	357	2	8	14	10	3	721	0	83
1	357	2	8	14	10	3	804	0	83
0	359	2	9	16	4	3	562	0	92
1	359	2	9	16	4	3	655	0	92
2	359	2	9	16	4	3	746	-3	90
3	359	2	9	16	4	3	835	-1	87
0	360	0	2	16	10	1	763	1	103
0	361	0	2	16	4	1	516	-14	82
1	361	0	2	16	4	1	596	-5	76
2	361	0	2	16	4	1	669	-8	68
3	361	0	2	16	4	1	739	3	71
4	361	0	2	16	4	1	813	3	75
0	362	0	2	16	4	2	395	0	92
1	362	0	2	16	4	2	487	0	92
2	362	0	2	16	4	2	579	0	92
3	362	0	2	16	4	2	672	0	92
4	362	0	2	16	4	2	764	0	92
0	363	0	1	14	9	3	468	0	92
1	363	0	1	14	9	3	561	0	92
2	363	0	1	14	9	3	653	-1	91
3	363	0	1	14	9	3	744	-3	88
4	363	0	1	14	9	3	831	-1	86
0	364	0	2	16	6	1	395	-8	86
1	364	0	2	16	6	1	478	-7	79
2	364	0	2	16	6	1	555	-4	74
3	364	0	2	16	6	1	631	3	77
4	364	0	2	16	6	1	708	-1	77
5	364	0	2	16	6	1	784	-3	74
0	365	0	1	14	4	3	275	0	92
1	365	0	1	14	4	3	368	0	92
2	365	0	1	14	4	3	460	0	92
3	365	0	1	14	4	3	553	0	92



Description	Number of Vehicles	Average Speed (fps)	Average Speed (mph)
Low-performance car	99	94.903	64.736
High-performance car	290	93.450	63.745
Single unit truck	19	92.051	62.791
Utility/Medium truck	20	91.125	62.159
Tractor trailer	27	85.608	58.396
Double-bottom trailer	2	80.390	54.837
Intercity bus	3	92.002	62.757