ASSESSMENT OF CAR-FOLLOWING MODELS USING FIELD DATA

By

IRENE S. SORIA

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

2010

To my family, loved ones and professors

ACKNOWLEDGMENTS

I thank my parents for always believing in me, my family for their constant support, and motivation through this journey. I thank my friends and my boyfriend Gabriel for being there for me, motivate me and being patience. I thank my professors and my advisor for their guidance through this path.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Engineering

ASSESMENT OF CAR-FOLLOWING MODELS USING FIELD DATA

By

Irene S Soria

May 2010

Chair: Lily Elefteriadou
Major: Civil Engineering

Computer simulation models are an important tool for analyzing and designing transportation systems. Car-following models are important components of simulation tools, since they describe the behavior of the following vehicle as a function of the lead vehicle trajectory. Over the years, several models, which estimate the following vehicle's trajectory as a function of the speed and acceleration of the lead vehicle reaction time and spacing, have been developed. However, the literature has not reported the applicability and relative merit of various car-following models under different operational conditions such as congestion and driver type. The objective of this study is to assess car-following models using field data under different conditions.

After review of existing car-following models, Gipps (component of AIMSUN simulation program), Pitt (use in CORSIM software), MITSIM (utilize in MIT simulation program), and Modified Pitt were selected. Data were obtained from a database compiled in Jacksonville, Florida. The data were collected by cameras installed in a vehicle and consist of video recordings of the speed, time and distances between the subject vehicle and its surrounding vehicles. Congested, uncongested, and rain with/without congestion were evaluated.

Trajectories from subjects with different types of driving behavior (aggressive, average, and conservative) were obtained. Their field trajectories were compared to the results trajectories obtained by each of the models. An error test, Root Mean Square Error (RMSE), was used for comparing the field data and the results of the models as a key performance indicator. After initial analysis an optimum calibration was performed. The MITSIM model was found to be the best in replicating the trajectories of the drivers in all conditions. The variable best replicated by the models was speed however it is recommended to perform calibrations based on spacing. Three calibration analyses were performed: first using all the data, second using different traffic conditions, and third using each driver type. Results showed that the best results were obtained when the parameters were calibrated by driver type using MITSIM model. The study concluded with recommended calibration parameters, and application guidelines related to the car-following models examined.

CHAPTER 1
BACKGROUND AND OBJECTIVES

Computer simulation programs have been playing an important role in the design and analysis of transportation systems. Simulation modeling applications and tools are being applied by transportation professionals and traffic engineers to address problems related to the design and operations of highways. Today, these professionals use microscopic simulation programs to replicate different highways environments and evaluate different alternatives solutions. These micro-simulation programs have been developed world-wide and their algorithms, characteristics and properties have been based on different algorithms of microscopic driver behavior. These algorithms include lane changing, gap acceptance and car-following.

Car-following models describe the behavior of the following vehicle as a function of the lead vehicle trajectory. Knowing the lead vehicle trajectory and using the car-following models one can be estimate or predict the following vehicle trajectory in response to the lead vehicle's actions. Existing car-following models typically consider the speed of the lead and following vehicles, and the acceleration of the lead vehicle. Some models consider the reaction time of the following vehicle, as well as the spacing, and relative speed. However, existing literature has not reported on the applicability and relative merit of various car-following models under different operational conditions (congested vs. non-congested), and for different types of drivers.

The purpose of this thesis is to asses selected car-following models and their performance against field data under different conditions (congested, uncongested and rain with/without congestion), and for different drivers types (conservative, average and aggressive). Such comparison would result in a better understanding of the models and their capabilities.

More specifically the objectives of this study are to:

1. Calculate the projected trajectories for selected car-following models under different traffic conditions and compare the model-estimated trajectories with those obtained in the field.

2. Compare the following:

    a. Trajectories obtained by the selected models

    b. Trajectories obtained under different traffic conditions (congested vs. uncongested, and rain vs. no rain)

    c. Trajectories obtained among different drivers

3. Provide recommendations regarding improvements to existing car-following models and their application.

Chapter 2 presents a literature review of different car-following models and a discussion of the car-following models selected. In addition it includes previous studies performed comparing field data with car-following models. Chapter 3 describes the methodology used in this study. Chapter 4 explains the field data used and the process of assembling it for this study. Chapter 5 includes an initial analysis of the models using the field data and default values of the parameters for each selected model, while Chapter 6 summarizes the calibration analysis. Lastly conclusions and recommendations are presented in Chapter 7.

CHAPTER 2
LITERATURE REVIEW

The chapter summarizes past research related to the development and evaluation of car-following models. This chapter will be divided in three sections. First will be a review of car-following models while the second subsection will summarize previous research that has been conducted comparing car-following models with field data. The chapter concludes with a summary of the literature findings and recommendations for future research.

Car-Following Models

The literature of car-following theory is extensive and it has been developed since the 1950s. This thesis discusses some of the more prevalent car-following models.

Pipes and Forbes

The pioneers of this theory were Pipes and Reuschel in early 1950s (May 1990). May (1990) explained that Pipes characterized the motion of the vehicles in the traffic stream as following rules suggested in the California Motor Vehicle Code. According to Pipes car-following theory, the minimum safe distance headway increase linearly with speed and the safe time headway continuously decrease with speed and theoretically reach absolute minimum time headway of 1.36 seconds at a speed of infinity (May 1990). Pipes assumed that the movements of the various vehicles of the line obey a following rule suggested by a “rule of thumb” frequently taught in driver training, which is to allow one additional length of a car in front for every ten mi per hour of speed. Equation 2-1 presents Pipes car-following model.

$$x_n - x_{n+1} = b + \tau \dot{x}_{n+1} + L_n \tag{2-1}$$

Where:

- x_n is the position of the front of the nth vehicle,
- x_{n+1} is the position of the front of the (n+1)th vehicle,
- b is the minimum distance between the vehicles when stopped,
- τ is the time gap,
- $\dot{x}_{n+1}$ is the velocity of the (n+1)th vehicle
- L_n is the length of the nth vehicle.

If the Equation 2-1 is differentiated Equation 2-2 will be obtained representing the speed differential.

$$\dot{x}_n - \dot{x}_{n+1} = \tau \times \ddot{x}_{n+1} \tag{2-2}$$

Where:

- $\dot{x}_n$ is the velocity of the nth vehicle,
- $\dot{x}_{n+1}$ is the velocity of the (n+1)th vehicle,
- τ is the time gap,
- $\ddot{x}_{n+1}$ is the acceleration of the (n+1)th vehicle

May (1990) observed that speed increases the minimum distance headway increase and the time headway decreases. In lower speed situations almost every vehicle is in car-following mode and the distance headway is at minimum so there time headway decreases. On the other hand in higher speed situations all the vehicles are not traveling at the same speed and the distance headway between pairs of vehicles varies widely.

Observing Equation 2-1 the spacing between vehicles is a function of the velocity of the follower, the length of the vehicle and the minimum distance that the follower accepts. This equation does not take into consideration the breaking of the lead vehicle in emergency situations and the velocity of the follower. Reaction time and driver behavior are also not considered in this formula.

Forbes approached car-following behavior by taking into consideration the reaction time needed for the following vehicle to perceive the need to decelerate and apply the brakes (May 1990). This is the time gap between the vehicles and this distance should always be equal or greater than the reaction time. Therefore the time headway is equal to the reaction time and the time for the lead vehicle to traverse a distance equivalent to its length. This model is similar of Pipes model so it can be used for lower speed but for higher speeds the pattern changes.

Pipes and Forbes don't consider the acceleration, desired speed of the drivers and the dynamic elements of the following vehicle. They are static models which are useful as simplifying assumptions but they don't consider driver behavior or traffic conditions in detail.

General Motors (GM)

A simple linear model was proposed by Chandler et al. (1958), with the assumption that the response (acceleration or deceleration) of the following vehicle is proportional to the stimuli (relative velocity) between the lead and following vehicles. According to this model a driver accelerates (or decelerates) in response to the velocity changes of the lead vehicle. They proposed an equation that response = F(sensitivity, stimuli), developing a stimulus-response car-following concept. They suggested that drivers apply acceleration or deceleration in proportion to the speed difference between the lead and following vehicles. They developed a linear model with the assumption that the driver of the following vehicle controls the accelerator (or brake) to keep zero relative speed to the leading vehicle (Ahn et al. 2004).

The General Motors research team developed five generations of car-following models, all of which took the form of Response = Sensitivity * Stimuli. GM researcher used test tracks and tunnels field data. This data was collected using a cable and reel apparatus attached to the bumpers of the lead and traveling vehicles. They didn't include “open roadway” data. Herman et al. (1959) explained that a sensitivity parameter was used in the equation to account the differences in the level of response observed for various drivers under different distance headways and traffic stream speed conditions. The model included four special case equations and a single general case equation known as the GM fifth model (Herman et al. 1959). Equation 2-3 represents the GM fifth model.

$$\ddot{x}_{n+1}(t+T) = \frac{\alpha_{l,m}\,[\dot{x}_{n+1}(t+T)]^m}{[x_n(t)-x_{n+1}(t)]^l}\,[\dot{x}_n(t)-\dot{x}_{n+1}(t)] \qquad (2\text{-}3)$$

Where:

- $\dot{x}_n$ is the velocity of the nth vehicle,
- $\dot{x}_{n+1}$ is the velocity of the (n+1)th vehicle,
- $\ddot{x}_{n+1}$ is the acceleration of the (n+1)th vehicle,
- T is the reaction time,
- α is a sensitivity parameter,
- l and m are constants to be calibrated.

The GM experiments included the estimation of a characteristic speed using the sensitivity factors and average distance headway values (Herman et al. 1959). Also the GM research used position, speed and acceleration parameters of two vehicle platoons to estimate driver behavior responses.

The field data revealed significant variation in the sensitivity values across different drivers; however, the model could not accommodate or explain this variation. Researchers explained that this increase of the sensitivity parameter is associated to the relative spacing decreases. The General Motors car-following models do not consider the effect of the inter-vehicle spacing independently of the relative velocity; for example drivers will always accelerate if the relative velocity is positive and decelerate if the relative velocity is negative. On the other hand, in real driving, it is often seen that when the following vehicle is some reasonable distance behind the leading vehicle, the following vehicle can accelerate even if the relative velocity is zero. This model doesn't recognize the preferred speeds or the desire of the following vehicle to drive.

Newell

Zhang and Kim (2005) describe the Newell (1961) car-following model as follows:

$$\dot{x}_n(t+T) = v_f[1 - e^{-\frac{\lambda}{v_f}\times(x_{n-1}(t)-x_n(t)-L)}] \tag{2-4}$$

Where:

- $\dot{x}_n$ is the velocity of the nth vehicle,
- x_n is the position of the front of the nth vehicle,
- x_{n-1} is the position of the front of the (n-1)th vehicle,
- L is the length of the vehicle,
- v_f is the free flow speed,
- λ is the slope of the spacing-speed curve at v=0.

This model states that if the lead vehicle travels at a constant velocity the following vehicle will follow at the same velocity assuming that the velocity of the following vehicle is not its desirable velocity. The model assumes that since vehicles are traveling on a homogeneous road segment, the spacing of the vehicles will remain the same as long as the velocity of the lead vehicle is constant and hasn't changed. However if the lead vehicle alters its velocity and then remains at this new velocity for some time, the trajectory of the follower can be approximated by linear extrapolations. This model follows that each driver adopts her own relation between velocity and spacing and this relation is linear. Newell transformed his car-following model into macroscopic one to describe the average driver behavior and this transformation lead to a linear relation between queued flow and densities (Ahn et al. 2004).

Gazis, Herman, and Rothery (GHR)

Gazis et al. (1961) developed a non-linear car-following model with a sensitivity term that was inversely proportional to the relative spacing. They suggested that the previous car-following models should be modified by adding the psychological factors shown by the Response = Sensitivity * Stimuli model. They recommended adding the response of the driver, the sensitivity term, and stimuli. They proposed a cross-correlation method to estimate the reaction time. The time lag that produces the highest correlation between relative speed and acceleration of the following vehicle was identified as the reaction time.

Initially, the GHR model only controls the actual following behavior. The basic relationship between the leader and the follower vehicle is in this case a stimulus-response action type of function. The GHR model states that the follower's acceleration is proportional to the speed of the follower, the speed difference between the follower and the leader, and the space headway. Brackstone and McDonald (1999) present the GHR car-following model as follows:

$$a_n(t) = c \times v_n^m(t) \times \frac{\Delta v(t-T)}{\Delta x^l(t-T)} \quad (2\text{-}5)$$

Where:

- a_n is the acceleration of vehicle n at time t,
- v the speed of the nth vehicle,
- Δx and Δv, the relative spacing and speeds, respectively between the nth and n + 1 vehicle (the vehicle immediately in front),
- T is the driver reaction time,
- c, l, m, and n are the constants.

Observing Equation 2-5 it can be concluded that if the relative speed between vehicles is zero the reaction time variable is going to disappear; in reality the driver reaction time will always be present no matter the conditions of the traffic.

Eddie

Edie (1961) developed an additional car-following model. He assumed that as the speed of the traffic stream increases, the driver of the following vehicle would be more sensitive to the relative velocity between the lead and following vehicles. Therefore, he introduced the speed of the following vehicle into the sensitivity term of the non-linear model developed by Gazis et al. (1959). Finally, a generalized form of car-following models was proposed Gazis et al. (1961) that allowed various modification of the sensitivity term.

Edie (1961), Newell (1961), and Gazise et al. (1959) studied nonlinear car-following models considering the human factors, and stated that although it is difficult to find a reliable nonlinear model which can represent real following conditions, only a nonlinear model can reflect real car-following situations.

Kikuchi

Chakroborty and Kikuchi (1999) recognized that the reactions of the following vehicle to the lead vehicle might not be based on a deterministic relationship, but rather on a set of approximate driving rules developed through experience. Their approach to modeling these rules consisted of a fuzzy inference system with relationship sets that could be used to describe and quantify the behavior of following vehicles. However, the logic to define the relationship sets is subjective and depends totally on the judgment and approximation of the researchers. No field experiments were conducted to calibrate and validate these fuzzy relationship sets under real driving conditions.

Gipps

This model takes into consideration the desired speed of the following vehicle, the breaking mode and the car-following mode. Gipps model is recognized as a multi regime model. It calculates two speeds: one is the desired speed and the other the speed that will be constrained by the vehicle in front. The minimum of these two speeds is selected to estimate the follower vehicle speed. The equation of car-following is based on the maximum safety deceleration and the distance between vehicles.

Gipps (1981) claimed that the parameters α, l and m in the generalized form of General Motors car-following models have no connection with identifiable characteristics of drivers or vehicles, and argued that the parameters in a model should correspond to obvious characteristics of drivers and vehicles. Therefore, he proposed a model for the response of the following vehicle based on the assumption that each driver sets limits to his desired braking and acceleration rates, and then uses these limits to calculate a safe speed with respect to the preceding vehicle. It was assumed that the driver of the following vehicle selects his speed to ensure that he can bring his vehicle to a safe stop if the vehicle ahead comes to a sudden stop.

Gipps car-following model is represented as follows:

$$v_n(t+\tau) = \min\left\{v_n(t) + 2.5a_n\tau\left(1 - \frac{v_n(t)}{V_n}\right)\left(0.025 + \frac{v_n(t)}{V_n}\right)^{\frac{1}{2}}, b_n\tau + \sqrt{b_n^2\tau^2 - b_n[2[x_{n-1}(t) - S_{n-1} - x_n(t)] - v_n(t)\tau - \frac{v_{n-1}(t)^2}{\hat{b}}]}\right\} \quad (2\text{-}6)$$

Where:

- a_n, is the maximum acceleration which the driver of vehicle n wishes to undertake,

- b_n is the actual most severe deceleration rate that the driver of vehicle n wishes to undertake (b_n< 0),
- $\hat{b}$ is the estimated most severe deceleration rate that the vehicle n-1 is willing to employ,
- S_{n-1} is the effective size of vehicle n; that is the physical length plus a margin into which the following vehicle is not willing to intrude even when at rest,
- v_{n-1} is the speed at which the driver of vehicle n-1 wishes to travel,
- v_n is the speed at which the driver of vehicle n wishes to travel,
- $x_n(t)$ is the location of the front of vehicle n at time t,
- $x_{n-1}(t)$ is the location of the front of vehicle n at time t,
- V_n is the speed at which the driver of vehicle n wishes to travel,
- τ is the apparent reaction time, a constant for all vehicles.

The second term in the equation represent that congested conditions exists and/or vehicles are traveling as fast as the volume of vehicles permit. The first term represent the vehicles traveling freely. The speed of the follower according to Gipps is defined by the minimum of these two equations.

Gipps emphasizes that the only applications of the model in which a smooth transition does not necessarily occur are when the leading vehicle brakes harder than the following vehicle has anticipated or leaves the lane or when a new vehicle moves into the gap between two vehicles. However, these are the circumstances under which real traffic may also exhibit a rapid transition between acceleration and braking (Gipps 1981). If the lead vehicle brakes unexpected or react to changes in the network Gipps equation will not calculate this threshold. It can be assumed that if the follower speed calculated is the minimum in the equation based of the lead trajectory the network is congested or the distance between vehicles is small.

Gipps claims that the model proposed appears to be able to mimic the behavior of real traffic. He discussed that the parameters involved correspond to obvious driver and vehicle characteristics and affect the behavior of the simulated flow in logically consistent ways.

An advantage of the model is its speed calculations, the equation contains square roots and squares but not general powers of variables, so it is relatively fast to evaluate. A critique of this model is that it assumes a constant reaction time for all the drivers in all the situations, considers that the driver is homogeneous and it is difficult to include in the equation different network characteristics.

Pitt

Pitt model is considered as a stimulus response model. The basic assumption is that the following vehicle will maintain a given space headway. This model is similar to the concept of the GM mode calculating the distances between vehicles but adding different constant of calibrations. The Pitt car-following model, Equation 2-7, describes that the follower vehicle will try to maintain minimum space headway equal to d_{ab}.

$$d_{ab} = L + 3.04878 + ku_a + bk\,(u_b - u_a)^2 \tag{2-7}$$

Where:

- d_{ab} = space headway between the lead vehicle B and the follower A from front bumper to front bumper,
- L = lead vehicle (B) length,
- k = the car-following parameter (sensitivity factor),
- u_b & u_a = speed of vehicles lead and follower respectively,
- b = calibration constant defined as 0.1(when $u_a > u_b$) or 0 otherwise.

For the car-following parameter (sensitivity factor) k CORSIM utilizes values from 1.25 for the timid drivers to 0.35 for the aggressive drivers. El Khoury and Hobeika (2006) proposed a range of 1.6 for timid drivers and 0.3 for aggressive drivers. For the length of the vehicle an average vehicle length of 7.62 m (25ft) was used.

This model set a desired amount of headway for individual drivers. Vehicles seek to maintain a minimum car-following distance while not exceeding their maximum speed.

Each of the drivers in this model has a unique, desired headway. If the current distance is not sufficient to maintain the desired headway, the vehicle will decelerate in an effort to attain the desired headway. If the distances are larger than the desired headway the vehicle will attempt to accelerate to achieve the desired headway unless it is at its desired free-flow speed.

The behavior of a lead vehicle is also dependent on the upcoming network characteristics (e.g., changes in lane configuration, turning movements, control, blockages, etc.). The vehicle will scan the upcoming network objects and attempt to adjust its speed or lane in order to react to the objects.

The simulation program CORSIM (CORridor SIMulation) utilizes the Pitt car-following model. This program was developed by the US Federal Highway Administration (FHWA) for simulation of traffic behavior on integrated urban transportation networks of freeway and surface streets. CORSIM combines the NETwork SIMulation (NETSIM) and FREeway SIMulation (FRESIM) models into an integrated package. Both NETSIM and FRESIM simulate traffic behavior at a microscopic level with detailed representation of individual vehicles and their interaction with their physical environment and other vehicles. The FRESIM model utilizes the Pitt car-following model of Equation 2-7 while NETSIM uses the car-following model in Equation 2-8.

$$h = h + \Delta s + \Delta r + SF - SL \quad (2\text{-}8)$$

Where:

- Δs = distance traveled by follower vehicle over time interval Δt,
- Δr = distance traveled by follower vehicle during its reaction time,
- SF = distance required by follower vehicle to come to a complete stop,
- SL = distance required by lead vehicle to come to a complete stop.

Wiedemann and Reiter

Wiedemann and Reiter car-following model uses thresholds or actions points where the driver changes his/her behavior. This model is known as psycho physical model. Figure 2-1 displays the thresholds and regimes of Wiedemmann model.

These thresholds can be categorized in four driving modes:

1. Free driving: no influence of leading vehicles. In this mode the follower vehicle seeks to reach and maintain her/his individually desired speed.

2. Approaching: when passing the approaching point (SDV) threshold. The process of adapting the driver's own speed to the lower speed of the lead vehicle. While approaching, a driver applies a deceleration so that the speed difference of the two vehicles is zero in the moment she/he reaches her/his desired safety distance. Wiedemann and Reiter (1992) include another threshold similar to SDV; CLDV, decreasing speed difference. This threshold is used to model perception of small speed difference at short, decreasing distances. In VISSSIM this threshold is ignored and CLDV is assumed to be equal to SDV.

3. Following: the thresholds SDV, ABX (desired minimum following distance at low speed differences), SDX (the maximum following distance), and OPDV (the increasing speed difference) constitutes the following regime. The driver follows the preceding car without any conscious acceleration or deceleration. She/he keeps the safety distance more or less constant.

4. Braking or emergency regime: when the front to rear distance is smaller than ABX the follower adopted the emergency regime. The application of medium to high deceleration rates if the distance falls below the desired safety distance.

This can happen if the preceding car changes speed abruptly, of if a third car changes lanes in front of the observed driver.

For each mode, the acceleration is described as a result of speed, speed difference, distance and the individual characteristics of driver and vehicle. The driver switches from one mode to another as soon as she/he reaches a certain threshold that can be expressed as a combination of speed difference and distance.

For example, a small speed difference can only be realized in small distances, whereas large speed differences force approaching drivers to react much earlier. The ability to perceive speed differences and to estimate distances varies among the driver population, as well as the desired speeds and safety distances. Because of the combination of psychological aspects and physiological restrictions of the driver's perception, the model is called a psycho-physical car-following model.

As noticed each threshold contained calibration parameters. Figure 2-2 provides the assumed calibration parameters that Olstam and Tapani utilized for their research paper. These parameters were based on the parameters used by the VISSIM simulation program. However, there is not clear in the manual and in the references how the values of these parameters were calculated or the explanation for assuming this numbers.

The Wiedemann car-following model is utilized in the simulation program VISSIM. In VISSIM the following car-following models available are:

- Wiedemann 74: Model mainly appropriate for urban traffic
- Wiedemann 99: Model mainly suitable for interurban (motorway) traffic
- No Interaction: Vehicles do not recognize any other vehicles (can be used for a simplified pedestrian behavior).

Wiedemann 74 is based on the concept that the driver of a faster moving vehicle starts to decelerate as she/he reaches her/his individual perception threshold to a slower moving vehicle. Since she/he cannot exactly determine the speed of that vehicle, her/his speed will fall below that vehicle's speed until she/he starts to slightly accelerate again after reaching another perception threshold. This results in an iterative process of acceleration and deceleration. (VISSIM 5.10 manual).

For Wiedemann 74 the safety distance can be calculated as follows:

$$d = AX + BX \qquad (2\text{-}9)$$

Where:

- AX is the average standstill distance that defines the average desired distance between stopped cars. It has a fixed variation of ± 1m,
- BX is calculated in Equation 2-10.

$$BX = (BX\_add + BX\_mult \times z)\sqrt{v} \qquad (2\text{-}10)$$

Where:

- BX_add is the additive part of desired safety distance,
- BX_mult is the multiplic part of the desired safety distance that affects the computation of the safety distance,
- v is the vehicle speed [m/s],
- z is a value of range [0,1] which is normal distributed around 0.5 with a standard deviation of 0.15.

Wiedemann 99 is based in 13 parameters and the safety distance is calculated as follows:

$$dx\_safe = CC0 + CC1 * v \qquad (2\text{-}11)$$

Where:

- $CC0$ is the standstill distance,

- $CC1$ is the time headway, the time (s) that a driver wants to keep. The higher the value, the more cautious the driver is,
- v is the vehicle speed.

There are parameters available in VISSIM based on driver behavior and reaction time; However it is not clear in the manual and in any referenced documents how these parameters affect car-following equation. These parameters are defined as follows:

$CC2$ (Following variation) restricts the longitudinal oscillation or how much more distance than the desired safety distance a driver allows before she/he intentionally moves closer to the car in front. If this value is set to e.g. 10 m, the following process results in distances between dx_safe and $dx\_safe + 10m$. The default value is 4.0 m which results in a quite stable following process.

$CC3$ (Threshold for entering 'Following') controls the start of the deceleration process when a driver recognizes a preceding slower vehicle. In other words, it defines how many seconds before reaching the safety distance the driver starts to decelerate. $CC3$ is a negative number, and controls the time before reaching the safety distance that a driver begins to decelerate. This value does not represent the rate at which the driver decelerates and therefore on Lownes and Machemehl results this parameter has a slight impact on roadway capacity.

$CC4$ and $CC5$ (Following thresholds) control the speed differences during the 'following' state. Smaller values result in a more sensitive reaction of drivers to accelerations or decelerations of the preceding car, for example the vehicles are more tightly coupled. $CC4$ is used for negative and $CC5$ is positive speed differences. The default values result in a fairly tight restriction of the following process.

$CC6$ (Speed dependency of oscillation): Influence of distance on speed oscillation while in following process. If set to 0 the speed oscillation is independent of the distance to the preceding vehicle. Larger values lead to a greater speed oscillation with increasing distance.

$CC7$ (Oscillation acceleration): Actual acceleration during the oscillation process.

$CC8$ (Standstill acceleration): Desired acceleration when starting from standstill (limited by maximum acceleration defined within the acceleration curves)

$CC9$ (Acceleration at 80 km/h (50 mi/hr)) is a car-following parameter that affect the acceleration behavior of the following vehicles when they are traveling at 50 mi/hr (80.5 km/h).

Equation 2-11 depends on the parameter of stopped condition distance $CC0$ that represents the distance that the driver wishes to maintain behind a stopped vehicle on the freeway. The value of this parameter affects in the capacity of a network. Lownes and Machemehl (2006) discovered that high values of $CC0$ reduced the capacity on VISSIM. Lowering this value the capacity of the network increased. This result is reasonable because if the vehicles are closer together the capacity increases. $CC1$ is another parameter that is important, and contributes along with $CC0$ in the calculation of the safety distance maintained by the drivers in the simulation. $CC0$ dominates at low speeds but $CC1$ is very large if the speeds are relatively high. Lownes and Machemehl (2006) explained that as the desired distance between vehicles increases, the greater the distance that must be traversed as the vehicle resumes travel from a stopped or slowing-moving position. When speeds are high the difference in average capacity may not be as great. However, if the speeds are slow the increased distance between vehicles will have a direct effect on capacity (Lownes and Machemehl 2006). $CC1$ is a factor that restricts the longitudinal oscillation of the vehicles in the simulation; it refers to the distance increment beyond the safety distance. Small values of $CC2$ represent that drivers are more aggressive in their car-following behavior, meaning that the driver will speed up or slow down at a higher frequency (Lownes and Machemehl 2006). Lownes and Machemehl (2006) discovered that if the driver is less aggressive and allows a larger distance to grow between vehicles the capacity of the roadway is reduced.

This model takes into consideration that drivers are more alert when they are closer to the vehicle in front of them versus when they are further away. They considered the increase of the sensitivity related to the distance between the vehicles. However the Wiedemann model contained calibration parameters that is unclear how to calculate or their assumed values ranges.

Fritzsche

Fritzsche model is known as psycho physical model. This model is an example of a complex model, featuring twelve parameters to fit. The basic idea is to divide the car-following plane into different regions, with different behaviors. The regions are: following I and II, emergency (the distance between vehicles is too small, so the follower will try to brake as hard as possible), approaching and driving freely. It could be seen easily, that any line in this plane is described by at least two parameters, so one readily ends up with twelve parameters. A variant of this model is being used with the PARAMICS simulation software.

In the model, the car-following process is categorized by five different modes shown in Figure 2-2: the danger mode, the closing in mode, the free driving mode, the following I mode, and the following II mode (Fritzsche 1994). Actions in each of the five modes are determined by speed thresholds and distance thresholds between two trailing vehicles, including perception thresholds of speed difference (PTN/PTP), desired distance (AD), risky distance (AR), safe distance (AS), and braking distance (AB). A positive perception threshold of speed difference (PTP) and a negative perception threshold of speed difference (PTN) are defined to distinguish two situations. When the speed of the following vehicle is faster than the speed of the vehicle immediately ahead of this vehicle (called leading vehicle), PTN is used. Whereas when the speed of the following vehicle is slower than that of the leading vehicle, PTP is introduced.

In the danger mode, the distance between the following vehicle and the leading vehicle is below the risky distance. The following vehicle decelerates as much as possible to avoid a collision.

In the closing in mode, the following vehicle travels at a faster speed than the leading vehicle and the actual speed difference is larger than PTN. The gap between the two vehicles is less than the desired distance but greater than the risky distance. Under this circumstance, the following vehicle decelerates until it slows down to the speed of the leading vehicle.

There are two situations in the free driving mode: the following vehicle drives faster than the leading vehicle, but the gap between the two vehicles is larger than the desired distance, or the following vehicle is slower than the leading vehicle and the gap is larger than the risky distance. In both situations, the following vehicle accelerates to achieve its desired speed until it reaches another regime of thresholds.

In the following I mode, when the actual speed difference is between PTN and PTP and the gap is greater than the risky distance and less than the desired distance, or when the actual speed difference is larger than PTP and the gap is greater than the risky distance and less than the safety distance, the following vehicle makes no conscious actions on deceleration or acceleration.

In the following II mode, the speed of the following vehicle is faster than the leading vehicle and the actual speed difference is larger than PTN. However, the gap is larger than the desired distance or braking distance. Therefore, the following vehicle does not need to make any action and can drive freely.

Figure 2-4 presents Olstam and Tapani default parameters relevant to the thresholds of Paramics.

MITSIM

The car-following used by MITSIM was based on previous research of Herman et al. (1959). It is describe as a stimulus-response model. The model is based on the headway and the relative speed between the lead and the following vehicles. Depending on the headway, a vehicle is classified into one of the three regimes: free following, car-following, and emergency decelerating.

Free flowing regime: If the time headway is larger than a pre-determined threshold h_upper, the vehicle does not interact with the leading vehicle. In this case, if the vehicle’s current speed is lower than its maximum speed, it accelerates at the maximum acceleration rate to achieve its desired speed as quickly as possible. If current speed is higher than the maximum speed, the vehicle decelerates with the normal deceleration rate in order to slow down.

Emergency regime: If a vehicle has headway smaller than a pre-determined threshold h_lower, it is in emergency regime. In this case, the vehicle uses an appropriate deceleration rate to avoid collision and extend its headway.

Car-following regime: If a vehicle has headway between h_lower and h_upper, it is in the car-following regime. In this case the acceleration rate is calculated based on Herman's general car-following model (Yang and Koutsopoulos 1996).

$$a_n = \alpha^{\mp} \frac{v_n^{\beta\mp}}{g_n^{\gamma\mp}} (v_{n-1} - v_n) \tag{2-12}$$

Where:

- v_n is the follower's speed at time (t),
- v_{n-1} is the lead's speed at time (t),
- g_n is the spacing between the follower and the lead vehicle,
- $\alpha, \beta,$ and γ are six model parameters related to driver behavior to be calibrated for the car-following regime (with values i for acceleration and deceleration).

Yang and Koutsopoulos (1996) discussed that the simpler version of MITSIM model utilized $\beta^{\mp} = 0$ and $\gamma^{\mp} = 1$, but this value did not perform well in the model. May and Keller (1967) suggested values of $\beta^{\mp} = 0.8$ and $\gamma^{\mp} = 2.8$, and Ozaki (1993) calibrated using 3 cars driving in a test track and suggested different values for accelerating and decelerating (for accelerating $\beta^{+} = 0.2$ and $\gamma^{+} = -0.2$ and for decelerating $\beta^{-} = 0.9$ and $\gamma^{-} = 1$). However, Yang and Koutsopoulos (1996) suggested $\alpha^{+} = 0.5$, $\beta^{+} = -1$ and $\gamma^{+} = -1$ for acceleration and $\alpha^{-} = 1.25$, $\beta^{-} = 1$ and $\gamma^{-} = 1$ for deceleration. Punzo and Simonelli (2005) utilize the calibrations parameters and the h_upper and h_lower values shown in Figure 2-5.

Modified Pitt

In an attempt to address the criticisms leveled at the Pitt car-following model, Cohen (2002) suggested a modification to the equation. This modification of Pitt model is recognized as stimulus-response model. The Pitt car-following model assumes that the driver decisions are made in the interval t , the Modified Pitt add a variable or R that refers to the reaction time of the driver, therefore the time intervals will be $t + R$ for the Modified Pitt. The modified approach equation now becomes:

$$a_f(t+T) = \frac{K\left\{S_l(t+R) - S_f(t+R) - L_l - hv_f(t+R) + \left[v_f(t+R) - v_l(t+R)\right]T - \frac{1}{2}a_l(t+T)T^2\right\}}{\left[T\left(h + \frac{1}{2}T\right)\right]} \tag{2-13}$$

Where:

- a_f = acceleration of the follower vehicle,
- a_l = acceleration of the lead vehicle,
- t = current simulation time,
- T = simulation time-scan interval,
- R = perception-reaction time (assumed equal for all vehicle),
- K = sensitivity parameter used in modified Pitt car-following model,
- S_l and S_f = position of the lead and follower vehicle respectively at time t + R,
- L_l = length of lead vehicle plus a buffer based on jam density,
- h = time headway parameter used in Pitt car-following model (refers to headway between rear bumper plus a buffer of lead vehicle to front bumper of follower),
- v_l and v_f = speed of the lead and follower vehicle respectively at time t + R.

Comparisons of Car-Following Models with Field Data

This section summarizes previous research that has been conducted comparing car-following models with field data.

The first two investigations comparing the car-following models with field data were by Chandler et al. (1958) and Herman et al. (1959). They compared the GM model with data collected by wire-linked vehicles. Subsequently Treiterer and Myers(1974) and Ozaki (1993) implemented an aerial technique to collect car-following data and calibrate the GM model. The results provided sensitivity parameters m and l for the GM model. However, the data contained high measurement errors due to the inaccuracy of the data collection method.

Chundury and Wolshon (2000) analyzed the CORSIM car-following model with GPS field data collected on a two-lane highway in Baton Rouge, Louisiana for 72 min of total travel time. They recorded the data of two vehicles driving around a rectangular route near the LSU campus. Each vehicle was equipped with a GPS receiver, laptop computer, and GPS receiver antenna. Chundury and Wolshon (2000) found that under the given condition and their assumptions the NETSIM car-following model is accurate in simulating vehicle actions in routine driving conditions, and did not differ significantly with the field data. However, they mentioned that it is necessary to study the use of a wider variety of driver types to complete the study.

Panwai and Dia (2005) evaluated AIMSUN, PARAMICS and VISSIM car-following models with data collected by Robert Bosch GmbH Research Group. The data used in the research paper was speed data under stop-and-go traffic conditions on a single lane in Stuttgart, Germany during the afternoon peak hour. The Robert Bosch GmgH Research Group used an instrumented vehicle to record the difference in speed and headway between the instrumented vehicle and the vehicle immediately in front. The response of the follower vehicle (instrumented vehicle), in terms of acceleration and deceleration, was also recorded. They used the EM (Error Metric formulation) as the key performance indicator. They found that the results showed similar EM on distance values for the psychophysical spacing models used in VISSIM and PARAMICS with better values reported for the Gipps-based models implemented in AIMSUN. The Bosch data used the car-following behavior of only one driver, and the study area was a single lane urban road. However, car-following behavior depends on the driver characteristics and driving environments such as number of lanes. Panwai and Dia (2005) recommended further evaluation of these conditions. They also recommended conducting a sensitivity analysis to evaluate the impacts of simulation time step and different reaction times on the results.

Punzo and Simonelli (2005) tested Newell's model, Gipps model, a continuous response model (Intelligent Driver Model, IDM) and MITSIM model. The data they used was from Naples, Italy and they include two days of observation. For one of the days two different facilities were used: a one-lane urban road and a two-lane suburban highway. The leader of the platoon was the author of the research paper and the data were collected using four instrumented vehicles. If other vehicles intruded in the platoon, the data were discarded. They found that MITSIM is capable of reproducing the experimental data better that the other models with an average error of 12%, whereas the average error for IDM was 16%, and for Newel and Gipps 17%. Comparing these models, Punzo and Simonelli (2005) concluded that the Newell model performed the best on average but MITSIM showed a tendency to over fit the data due to the large number of parameters in the equation. For future research, they recommend analyze different types of roads and traffic characteristics to confirm their findings with other experimental data sets.

Ranjitkar et al. (2005) used a data set collected on a test track. Ten passengers participated in the experiment, the lead driver was a subject on his 50s, and the follower drivers were on their 20s and 30s. The data represent uninterrupted driving conditions with speeds ranging from 20 to 100 km/h. They concluded that the Chandler model performed better that the Gipps and Wiedemann models based on the tested conditions and the calibration parameters.

Kim et al. (2007) analyzed the car-following behavior using an instrumented test vehicle equipped with four set of instrumentation, including an infrared sensor, GPS-inertial distance measuring instrument (DMI), vehicle computer and a digital video camera. These data were collected during peak and non-peak hour periods near Washington, D.C, for 301 car-following time series and an average duration of 99 seconds. The data tested in this research paper observed and analyzed the car-following behavior of subjects that do not know they are part of the experiment. They concluded that there is an oscillatory process in car-following behavior formed by the vehicles desired to keep their following distance. They also concluded that each individual driver has his or her driving rules rather than a deterministic driving law, and their distance can vary over time and space during different driving conditions. The reactions of the follower vehicle caused by the same maneuver in car-following situations repeat themselves over time and space.

Rakha et al. (2010) develop a calibration procedure for CORSIM, AIMSUN, VISSIM, Paramics, and Integration using macroscopic loop detector data. They calibrate the steady-state component of this various car-following models, in another words when the lead vehicle is traveling at similar speeds and both the lead and the following having similar car-following behaviors. They concluded that the Gipps model and the Van Aerde (Integration car-following model) steady-state car-following models provide the highest level of flexibility in capturing different driver and roadway characteristics.

Literature Review Summary

Many theories of car-following have been studied over the years were equations have been improved over time but as discussed in the literature review they assumed that all drivers follow the same driving behavior in different scenarios. These behaviors may differ with different drivers, or even for the same driver and with different conditions, and in fact, possibly with the same driver and nearly identical situations. All of the models examined so far use only a simple set of kinematic variables, such as relative spacing and speeds, instantaneous speeds, etc., to determine follower behavior. Table 2-4 provides a summary of the car-following models with their description, equations and advantages and disadvantages. There are numerous other factors besides basic kinematics that may influence car-following behavior, such as congestion levels, geometric conditions, area type, time of day or week, various human characteristics (e.g., gender, age), and environmental characteristics (weather condition). Effects of road surface conditions and weather, traffic density, and different locations are related to the differences in car-following behavior. However, no further studies have been conducted to incorporate these factors into car-following models.

For this reason, it is very important to compare trajectories obtained during different traffic conditions (congested vs. uncongested) and among different. The study goal is to provide recommendations regarding improvements to existing car-following models and their application.

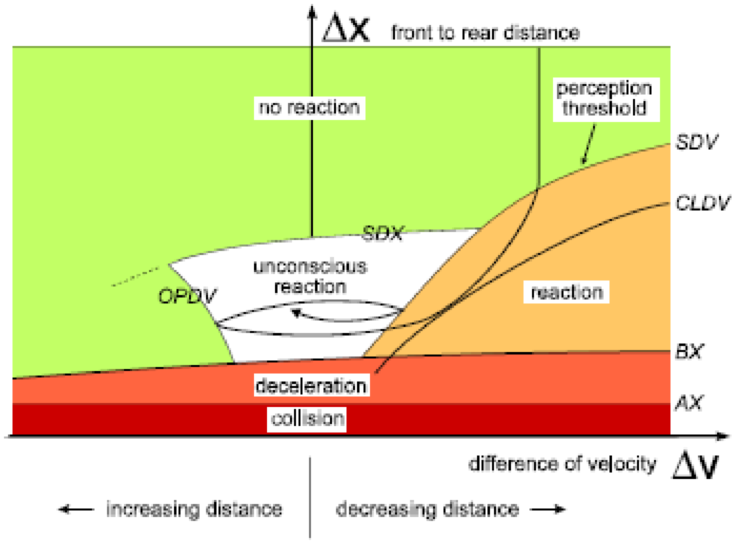

Figure 2-1. Different thresholds and regimes in the Wiedemann car-following model (VISSIM 5.10 User guide)

Table 2-1. Parameters values for Wiedemann car-following model (Olstam and Tapani 2004)

Parameter	Description	Value	Reference
AXadd	Additive calibration parameter	1.25	(Wiedemann and Reiter, 1992)
AXmult	Multiplicative calibration parameter	2.5	(Wiedemann and Reiter, 1992)
BXadd	Additive calibration parameter	2	(Wiedemann and Reiter, 1992)
BXmult	Multiplicative calibration parameter	1	(Wiedemann and Reiter, 1992)
EXadd	Additive calibration parameter	1.5	(Wiedemann and Reiter, 1992)
EXmult	Multiplicative calibration parameter	0.55	(Wiedemann and Reiter, 1992)
OPDVadd	Additive calibration parameter	1.5	(Wiedemann and Reiter, 1992)
OPDVmult	Multiplicative calibration parameter	1.5	(Wiedemann and Reiter, 1992)
CX	Calibration parameter	40*	(PTV)
BNullmult	Multiplicative calibration parameter	0.1	(Wiedemann and Reiter, 1992)
NRND	Normal distributed random number	$N(0.5, 0.15)$**	(Wiedemann and Reiter, 1992)
RND1	Normal distributed driver parameter	$N(0.5, 0.15)$**	(Wiedemann and Reiter, 1992)
RND2	Normal distributed driver parameter	$N(0.5, 0.15)$**	(Wiedemann and Reiter, 1992)
RND4	Normal distributed driver parameter	$N(0.5, 0.15)$**	(Wiedemann and Reiter, 1992)
b_{max}	Max acceleration	$3.5 - \frac{3.5}{40} \times v^*$	(Wiedemann and Reiter, 1992)
b_{min}	Max deceleration	$-20 - \frac{1.5}{60} \times v^*$	(Wiedemann and Reiter, 1992)

* Estimation from graph

** Mean Values have been used

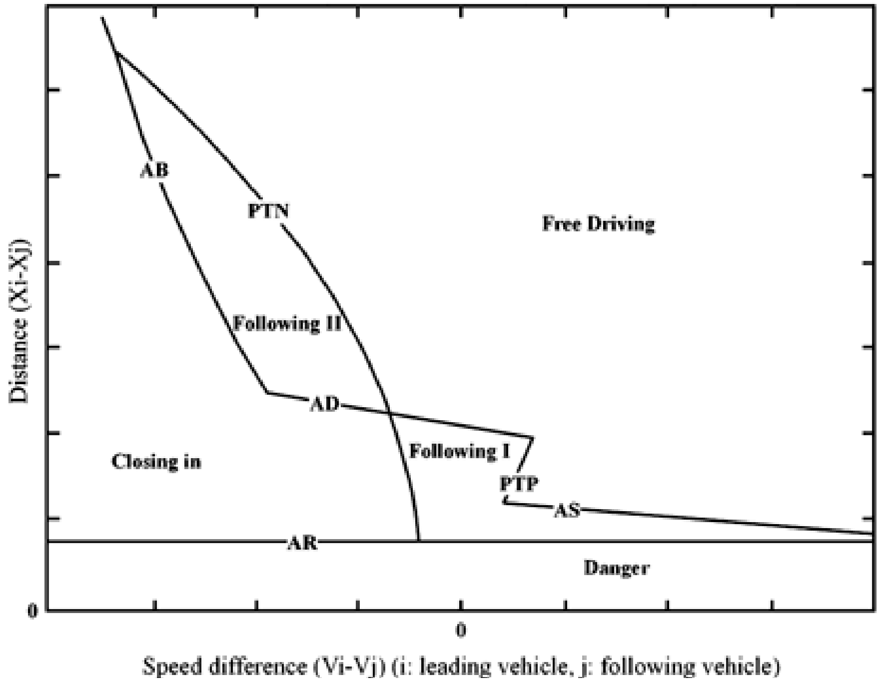

Figure 2-2. Phase diagram presenting the five different modes of Fritzsche car-following model (Fritzsche 1994)

Table 2-2. Parameters values for Frizsche Car-following model (Olstam and Tapani 2004)

Parameter	Description	Value	Reference
S_{n-1}	Effective length, vehicle n-1	6 m	(Fritzsche, 1994)
T_D	Desired time gap	1.8 s	(Fritzsche, 1994)
T_r	Risky time gap	0.5 s	(Fritzsche, 1994)
T_s	Safe time gap	1 s	(Fritzsche, 1994)
Δb_m	Deceleration parameter	0.4 m/s^2*	(Fritzsche, 1994)
f_x	Calibration parameter	0.5*	(Fritzsche, 1994)
k_{PTP}	Calibration parameter	0.001*	(Fritzsche, 1994)
k_{PTN}	Calibration parameter	0.002*	(Fritzsche, 1994)
b_{null}	Acceleration parameter	0.2 m/s^2	(Fritzsche, 1994)
a_n^+	Normal acceleration rate	2 m/s^2	(Fritzsche, 1994)

* Estimation from graph

Table 2-3. Parameters values for MITSIM car-following model (Punzo and Simonelli 2005)

Model	Parameter	Mean	Var	Cv
Gipps	a_n	3.331	4.189	0.614
	b_n	-3.801	5.949	0.642
	$\hat{b}$	-4.783	10.613	0.681
	V_n	16.152	12.28	0.217
	τ_n	0.567	0.024	0.272
MITSIM	$\alpha +$	2.512	1.563	0.498
	$\beta +$	0.150	0.099	2.102
	$\gamma +$	0.509	0.324	1.120
	$\lambda +$	1.073	0.539	0.684
	$\alpha -$	-2.328	2.545	0.685
	$\beta -$	0.861	0.485	0.809
	$\gamma -$	1.116	0.389	0.559
	$\lambda -$	1.293	0.338	0.449
	h_upper	2.044	0.285	0.261
	h_lower	0.289	0.014	0.404
	τ_n	0.580	0.093	0.526

Var = variance Cv = covariance

Table 2-4. Summary of car-following models

Car-following models	Dependent variables	Independent variables	Forms of model	Advantages	Disadvantages
Pipes (1950)	Spacing	$\dot{x}_{n+1}$ (follower speed) L_n (length of the lead vehicle)	$x_n - x_{n+1} = b + \tau\dot{x}_{n+1} + L_n$	Easy to apply It can be used in lower speed situations	Only describes the minimum distance between the vehicles (Don't consider reaction time)
Forbes (1950)	Time Headway $hmin$	Δt (reaction Time) Ln (Length of vehicle) ut (speed of the lead vehicle)	$hmin = \Delta t + (Ln/ut)$	Takes in consideration the needed follower reaction time to decelerate and apply the brakes It can be used in lower speeds situations	Don't consider the desired speed of the following vehicle and the dynamic elements such as behavior of the following vehicle as a function of the lead vehicle.
GM model (1958)	Acceleration $\ddot{x}_{n+1}$	Stimuli (Vel. of lead and follower), Distance, React Time, Sensitivity Parameter	$\ddot{x}_{n+1}(t+T) = \frac{\alpha_{l,m}[\dot{x}_{n+1}(t+T)]^m}{[x_n(t)-x_{n+1}(t)]^l}[\dot{x}_n(t) - \dot{x}_{n+1}(t)]$	Takes in consideration stimulus-response process	This model doesn't recognize the desired of the following vehicle to drive faster Can't explain or implement the variation in the sensitivity values across different drivers Don't consider the effect of the inter-vehicle spacing independently of the relative velocity. (It assumes that drivers will always accelerate if the relative velocity is + and decelerate if the relative velocity is -. In real driving, it is seen that when the follower is some reasonable distance behind the leading vehicle, the following vehicle can accelerate even if the relative velocity is zero. This wouldn't happen in high density traffic.)

Table 2-4. Continued

Car-following models	Dependent variables	Independent variables	Forms of model	Advantages	Disadvantages
(Newell 1961)	Velocity	v_f (FFS) λ (slope of spacing-speed curve at v =o)	$\dot{x}_n(t+T) = v_f[1 - e^{-\frac{\lambda}{v_f}(x_{n-1}(t)-x_n(t)-L)}]$	Consider the desired velocity of the follower vehicle.	Don't consider the reaction time for the drivers and sensitivity parameters. Consider that the characteristics of the drivers and the roads are homogeneous.
(Gazis et al. 1961)	a_n (accel)	Δv (relative speeds) Δx (relative distance) T (reaction time), m, l, c (constants)	$a_n(t) = c v_n^m(t) \frac{\Delta v(t-T)}{\Delta x^l(t-T)}$	Considers the human factors, It assumes that the follower reacts to the change in relative speeds and distances.	Constant are difficult to calibrate. It assumes that the follower reaction disappears when the relative speed is zero.
(Gipps 1981)	$v_n(t+\tau)$ Speed of vehicle n	x_n, S, V_n, a_n	$v_n(t+\tau) = \min\{v_n(t) + 2.5a_n\tau\left(1 - \frac{v_n(t)}{V_n}\right)\left(0.025 + \frac{v_n(t)}{V_n}\right)^{\frac{1}{2}}, b_n\tau + \sqrt{b_n^2\tau - b_n[2[x_{n-1}(t) - S_{n-1} - x_n(t)] - v_n(t)\tau - \frac{v_{n-1}(t)^2}{\hat{b}}]})\}$	Mimic the behavior of real traffic. Speed calculations	Considers the driver's characteristics as homogenous. Don't consider if the leading vehicle brakes harder than the following vehicle or leaves the lane or when a new vehicle moves into the gap between the two vehicles (accel and deceleration emergency responses).

Table 2-4. Continued

Car-following models	Dependent variables	Independent variables	Forms of model	Advantages	Disadvantages
(Wiedemann and Reiter 1992)	Spacing	$CC1$, time headway, v vehicle speed vl vehicle length	$s = CC0 + CC1 \times v + vl + CC2 / 2$	Considers that drivers are more alert Considers the increase of the sensitivity Uses action points	Difficult to approach a validity of these models because of the difficulty in calibrated the individual elements and thresholds Have 9 calibration parameters, some cases are assumed values.
(Fritzsche 1994)	Speed	Twelve parameters	$\Delta v\, ptn/ptp = \mp Kptn/ptp\, (\Delta x \times A)^2 + fx$	Accounts human perception in the definitions of the model regimes Takes in consideration the thresholds for the perception of speed differences	Complex model Twelve parameters to fit
Pitt	d_{ab} Spacing	L, k, u_b, u_a	$d_{ab} = L + 3.04878 + ku_a + bk\,(u_b - u_a)^2$	Considers Network characteristics Considers each driver a unique desired headway	Don't consider different reactions times and weather conditions.

Table 2-4. Continued

Car-following models	Dependent variables	Independent variables	Forms of model	Advantages	Disadv
MITSIM (1996)	Response (Accel)	v_n Follower velocity v_{n-1} Lead velocity g_n = gap distance	$a_n = \alpha^{\mp} \frac{v_n^{\beta\mp}}{g_n^{\gamma\mp}} (v_{n-1} - v_n)$	Consider the desired follower speed. Have 6 calibration parameters providing a better fit of the data.	Assumed model parameters Do not consider the traffic and weather conditions
Modified Pitt (2002)	Acceleration	*K, Sf, Sl, L, h, vf, vl, al, T*	$a_f(t+T) = \frac{K\left\{S_l(t+R) - S_f(t+R) - L_l - hv_f(t+R) + \left[v_f(t+R) - v_l(t+R)\right]T - \frac{1}{2}a_l(t+T)T^2\right\}}{\left[T\left(h + \frac{1}{2}T\right)\right]}$	Considers the reaction time of the drivers	Do not consider different traffic and weather conditions.

CHAPTER 3
METHODOLOGY

The research methodology developed for this thesis is illustrated in Figure 3-1 and described in this chapter. The methodology consists of six steps. These include a literature review of car-following models, selection of the models to be evaluated, initial implementation of the selected models in a spreadsheet program, assembly of the data used in the study, data analysis, and conclusions and recommendations. The remaining of this chapter provides a brief overview of each step.

Car-Following Models Literature Review

A literature review was performed to review existing car-following models and their application. Each car-following model was identified and discussed highlighting their advantages and disadvantages. A review of their equations and parameters was included in Chapter 2. The literature review concluded with a table summarizing the car-following models and their characteristics, as well as recommendations for future research.

Selection of the Models to be Evaluated

Based on the car-following literature review four models were selected to be evaluated in this thesis. After a process of evaluating the equations, parameters, and advantages and disadvantages the following four car-following models were selected:

- Gipps (Used in AIMSUN simulation program, multi regime model)
- Pitt model (Used in CORSIM, stimulus-response model)
- MITSIM model (Used in MIT simulation program, stimulus-response model)
- Modified Pitt model (Modification of Pitt model)

These models were selected because they are used in existing simulation programs and also because they are different from each other, representing various types of car-following models.

Implementation of the Selected Models

The models were implemented in a spreadsheet program assuming the same lead vehicle trajectories, initial speed and distances. A comparison of trajectories and speed differences was made between the resulting car-following trajectories for the four models. This initial implementation helped identify differences between the models and inputs needed from the field data for further calibration.

Field Data Assembly

Field data were obtained from a database consisting of data collected in Jacksonville, Florida. Chapter 4 provides a detailed description of the original database and describes the data obtained for this research. The data were collected by cameras installed in a Honda Pilot SUV, and consist of video recordings of the speed, time and distances between the subject vehicle and its surrounding vehicles. Subjects of different gender and age were observed driving the instrumented vehicle. These data capture various critical factors including driver behavior characteristics. The data were collected under different conditions (congested and uncongested), different times of day (AM/PM peak and off peak periods), and different weather conditions. Data were obtained for selected participants and conditions and organized for further analysis.

Data Analysis

Two data analysis efforts were undertaken, an initial analysis and a calibration analysis. Each of these consists of two steps. First, the lead vehicle trajectory data for each selected participant and condition were entered in an spreadsheet. In each of those files the lead vehicle trajectories were the inputs, and the following vehicle trajectories were the outputs. Second, a comparison of the trajectories of the field data and the estimated trajectories for each of the models was performed.

Initial Analysis

During the initial analysis, the models were implemented using the default values of the parameters. The default values were those suggested in the original development of each model. After the implementation of the data, a comparison of the estimated trajectories for each model and the trajectories of the field data was made. Chapter 5 provides a detailed discussion of the results for each of the selected models.

Calibration Analysis

During the calibration analysis the parameters of each model were calibrated to fit the respective field data. The calibration analysis was performed using the optimization tool “solver” in a spreadsheet program. Chapter 6 provides a detailed description of this tool and the process used for the analysis. This analysis was divided in four different calibrations. First each model was calibrated for each subject and each condition. In the second calibration all the data were used. In the third calibration models were studied by different traffic conditions. The last calibration considered different driver types. Chapter 6 provides a detailed discussion of the four calibration analysis results for each model.

Performance Measurement of Each Model

Each of the selected models predicts different kinematic variables. The Gipps model predicts the speed of the follower; the Pitt model predicts spacing between vehicles, while the MITSIM and Modified Pitt models predict the acceleration of the follower. Ideally each scenario would be calibrated using all three variables (speed, spacing and acceleration). This calibration would require multi-objective optimization that would produce a non-dominant optimum solution. It is difficult for practitioners to perform this optimization. Therefore this analysis was completed taking into consideration one variable at a time. The two performance measures used in the calibration were follower speed and spacing between vehicles.

To obtain a quantitative measure of the difference between the field data and the results of the selected models error tests were performed. Error tests do not contain any restriction or require assumptions about the data set. Most statistical tests require assumptions that the data are normally distributed and mutually independent. However, this is not the case with the data here. The distribution of data is not normal and the simulation and field data are not independent. The following vehicle starts with the same speed and position as in the field data. Therefore, the speed and position of vehicles depend on their previous values. In addition, the leader is the same in the field data as well as in the models. For this reason the results cannot be assumed to be mutually independent. Because of the above reasons, error tests are used to quantitatively measure the closeness of fit of results from the car-following models compared to the field data.

The result is considered to be perfect, if values from simulation and field data are identical. The Root Mean Square Error (RMSE) test is one test which compares quantitatively the results from the car-following models results from field data. The RMSE was computed for the speed and spacing comparison for each of the selected models. The Root Mean Square Root is defined as follows:

$$RMSE = \left\| \frac{y-\bar{y}}{\sqrt{N}} \right\|_2 = \sqrt{\frac{\sum_i (\bar{y}_i - y_i)^2}{N}} \qquad (3\text{-}1)$$

Where

- y is the exact solution (field data),
- $\bar{y}$ is the computed solution (result from the models),
- N is the total number of grid (time, s).

The RMSE measures the deviation of the car-following model results value from the field data. The magnitude of error can be evaluated only by comparing it with the average size of the variable in question. An additional test that does not require comparison with the average size of variable is the RMS percent error defined as follows:

$$RMS\ Percent\ Error = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(\frac{\bar{y_i} - y_i}{y_i} \times 100)^2} \qquad (3\text{-}2)$$

The RMS percent error values tend to be large when smaller values are compared with larger differences. Similarly, it tends to be large when observed values are very small (Bham and Benekohal 2004). Another error test is the mean percent error, which is defined as follows:

$$Mean\ Percent\ Error = \frac{1}{N}\sum_{n=1}^{N}(\frac{\bar{y_i} - y_i}{y_i} \times 100) \qquad (3\text{-}3)$$

The Mean percent error provides the deviation of car-following models results values from the field data as a percent, which provides a quantitative measure of deviation. However the problem with percent errors is that they are close to zero if large positive errors cancel out large negative errors (Pindyck and Rubinfeld, 1998.). To avoid this problem both positive and negative percent errors are also calculated and used in the analysis as they are clearly present if the model is underestimating or overestimating compared to the observed values (Bham and Benekohal 2004). Mean absolute errors can also be calculated to avoid the problem of positive and negative errors canceling out but important information is lost when only the magnitude of errors is known. RMSE are used more often as they tend to penalize large individual errors more heavily (Pindyck and Rubinfeld, 1998). However, low RMSE are only one desirable measure of close fit to field data.

Another statistic used in econometrics is Theil's inequality coefficient, which is defined as follows (Pindyck and Rubinfeld n.d.):

$$U = \frac{\sqrt{\frac{1}{N}\sum_{n=1}^{N}(\bar{y}_i - y_i)^2}}{\sqrt{\frac{1}{N}\sum_{n=1}^{N}(\bar{y}_i)^2}+\sqrt{\frac{1}{N}\sum_{n=1}^{N}(y_i)^2}} \tag{3-4}$$

The numerator of *U* is the RMS error and the scaling of the denominator is such that *U* always falls between 0 and 1. If *U*=0 ($\bar{y}_i = y_i$) for all N, then there is perfect fit. If *U*=1, the performance of the model is as bad as it can possibly be. Hence the Theil's inequality coefficient measures the RMS error in relative terms.

The RMS error percent, mean percent error and Theil's inequality are not presented in this thesis, since their values were showing the same tendency as the RMSE. Therefore the analysis was done using the RMSE.

Conclusions and Recommendations

In the last chapter, this thesis provides calibration parameters, application guidelines, and suggested modifications related to each car-following model studied.

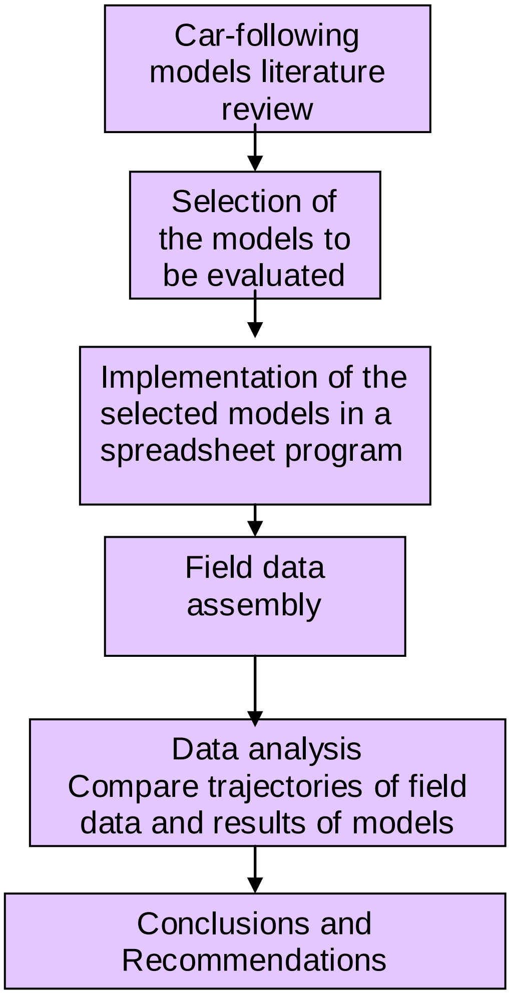

Figure 3-1. Flowchart of the methodology

CHAPTER 4
DATA COLLECTION AND ANALYSIS PLAN

The data collection and analysis plan for this thesis is presented in this chapter. This chapter will be divided in two main sections. The first section will presents the characteristics of the database used in this research. While, the second section will describe the method for selecting the data to be used and the procedures used to extract the data.

Characteristics of the Database

An instrumented vehicle was used to collect driver behavior data from 31 participants, in Jacksonville, Florida. The participants were asked to complete a background survey form that includes their driving habits and demographics information. The following subsections describe the instrumented vehicle used in the data collection, the driving routes and the subjects.

Instrumented Vehicle

The vehicle used to develop this database was a Honda Pilot SUV, owned by the University of Florida - Transportation Research Center (TRC). The instrumented vehicle has a Honeywell Mobil Digital Recorder (HTDR400) system. This system has four wide coverage digital cameras, which capture front, rear, and side images which are recorded in the hard drive of the HTDR400 system. The vehicle also has a GPS where information of vehicle position and speed data is displayed and recorded on the HTDR400 system. The data that the instrumented vehicle can record include geographical position, speed, left-right turn signal activation, video clips and audio recording. A laptop is connected to the system and allows the display of the four cameras through the HTDR400 software. Figure 4-1 provides an internal view of the instrumented vehicle.

Driving Routes

The driving routes that participants followed in AM and PM peak periods are illustrated in Figure 4-2 and Figure 4-3. Each participant conducted two loops during the AM routes and three during the PM routes. These locations were selected by Kondyli (2009) because there in mild to heavy traffic during the AM and PM peak periods, the routes were not complex and they were cameras from Jacksonville Traffic Operations Center.

Description of the Database Subjects

Participants of different gender and ages were selected to participate in the experiment. In addition, different traffic and road scenarios, such as merging, lane changing, congested and uncongested scenarios, and weather conditions, such as rain were collected. The completion of each route was 1 hour to 1 hour and 15 minutes. Table 4-1 presents the characteristics of the 31 subjects observed including gender, age, driving experience, how often they drive, time spent driving and the time of day when the data was collected.

The data obtained through this database are related to the drivers and the environment surroundings. Driver reaction times to events, categorization of drivers with respect to their degree of aggressiveness and relative distances and speeds were obtained from the instrumented vehicle. The process of extracting the data is described in the next section.

Assembly of Data

This section describes the process for selecting the subjects and the corresponding data to be used in this study. The following subsections describe the in-vehicle data processing and the distances, speed, and acceleration calculations for the field data.

First, the researcher observed the time series of speed and flow provided by the Jacksonville Traffic Operations Center and Kondyli (2009) and identified the time periods where the freeway was congested (AM and PM) and when it was uncongested. Concurrently with the instrumented vehicle experiment, traffic-related data were collected. Speed time-series plots at all detector stations along the freeway segment were accessible in the database for all days of the data collection. Visual observations of the time-series revealed the breakdown locations and times during the AM and the PM peak periods. It was also recorded in the database whether those time periods had rainy conditions. Drivers that drove under all scenarios were selected for further evaluation.

Next, the researcher identified and categorized the time intervals by facility (e.g. divided the time intervals in arterial, freeway movements and on/off ramp movements). Only the freeway intervals were considered in this study. The driver characteristics such as age, and gender were also obtained.

To evaluate the aggressiveness of the driver the criteria used by Kondyli (2009) were implemented. Three types of driver behavior were considered by Kondyli (2009): aggressive, average and conservative behavior. The criterion of “selfishness” for each participant throughout the entire duration of their driving task was applied. Drivers that exhibit high degree of “selfishness” and consider primarily their own status on the road are regarded as aggressive. Drivers that act primarily as a response to the other vehicles' actions are considered to be conservative. Drivers that consider both their own status but also the effect of their actions to the other vehicles are categorized as average. The driver types were quantitatively categorized on the following two criteria: (i) number of discretionary lane changes and (ii) observed speeds when driving under free-flowing and not car-following conditions. Participants had generally limited opportunities for performing discretionary lane changes and for driving on the inside (faster) lanes. As such, participants that performed up to two lane changes and/or followed a speed 5 mi/hr (2.23 m/s) higher than the speed limit were considered to be conservative. Participants that performed up to five lane changes and/or drove at a speed up to 10 mi/hr (4.47 m/s) over the speed limit were considered to be average. Participants that performed at least six lane changes and/or drove at speeds up to 15 mi/hr (6.71 m/s) over the speed limit (or 10 mi/hr (4.47 m/s) over the limit under raining conditions) were categorized as aggressive.

Table 4-2 summarizes the results of the driver behavior analysis for all participants. This table also includes their background survey responses on their degree of aggressiveness as this is perceived by themselves and by their friends or family, their stated driving speed and lane changing activity.

The corresponding time intervals for congested and uncongested conditions for each driver were obtained and organized. Next, the data based on the longest time interval that one vehicle follows the same lead vehicle were selected. After organizing and recording these time intervals, the researcher selected those with time intervals of at least 20 seconds. These time intervals were analyzed in depth on a second-by-second basis. Table 4-3 provides an example of the data obtained for a freeway interval and for a single vehicle. The next section provides a description of the process to obtain car-following information from the instrumented vehicle.

Description of In-Vehicle Data Processing

The video data collected from the instrumented vehicle cameras were used to estimate parameters related to spacing between vehicles and lead and follower vehicle speeds. The instrumented vehicle was the follower vehicle and only the front camera of the vehicle was used to obtain the spacing between the lead and follower. Images were extracted from the front camera at 1 s time resolution. When participants were following a vehicle the image extraction would start and it would end as soon as one of three things occured:

1. The follower changes lanes and has a new leader
2. A new vehicle enters in front of follower
3. The 20 s of following the same lead vehicle was reached

Along with the extracted frames, the instrumented vehicle (follower) speed was obtained from the GPS system. The following section presents the processing techniques to obtain the estimated distances between vehicles.

Method for Extracting Information from the Digital Cameras

The method used to obtain measurements of distance from the front camera is described in this section. Procedures based on Psarianos et al. (2001) were implemented to extract the data from the cameras installed on the instrumented vehicle. This method was developed for measuring lane widths but it was modified to account for distances along the road axis. This basic geometry is described in Figure 4-4, in which O is the perspective center and M is the image center.

In Figure 4-4 the camera constant is c, while y_B is the y image coordinate of points B and B′ on the road surface. If Y_0 is the camera height measured above ground level, then the scale of the image at a distance Z_B is:

$$\frac{c}{Z_B} = -\frac{y_B}{Y_0} = \frac{\Delta x_B}{\Delta X_B} \quad (4\text{-}1)$$

Where:

ΔX_B is the lane width BB',

Δx_B is the corresponding length measured in the image.

Equation 4-1 was first used to estimate the camera height Y_0 from known widths (range from 6 to 20 ft (1.83 m to 6.10 m)) measured with a tape measure. The camera height for the front camera is estimated as 3.96 ft ± 0.30 ft (1.21 m ± 0.09 m).

Next, the camera constant c was estimated for the front camera given known lane widths ΔX_B, and distances Z_B, according to Equation 4-2:

$$c = -Z_B \frac{y_B}{Y_0} = Z_B \frac{\Delta x_B}{\Delta X_B} \quad (4\text{-}2)$$

Then, the constant c of the camera was used for estimating the distance Z_b from any point of the road B, by using the extracted images from the cameras.

Distances, Speed and Acceleration Calculations

A snapshot for each second was evaluated in AutoCad. Using AutoCad the researcher calculated the distances between the vehicles and using the camera constant c described above the estimated distance was calculated.

The distance between vehicles (subject/follower and the lead) is estimated for each consecutive frame using the method applied for measuring distances from still images explained in the previous subsection. Although the distances obtained from the instrumented vehicle are approximations the values were close to the field data.

However, an instrumented vehicle with infrared sensor will provide more accurately measures of distances. These distances are used for the calculations of the lead vehicle that will be the input for the model. Therefore, an estimation error may be affecting the final performance of the models.

The follower/subject speed is directly obtained from the GPS. The acceleration is calculated as the speed change rate every second. The speed of the lead vehicle is estimated through consecutive frames using equations of motion. The lead speed was calculated as follows:

$$Lead\ speed = \frac{(Follower\ \ speed_{\ t-1} + Follow\ er\ speed_{\ t})}{2} + \frac{(Spacing_{\ t} - Spacing_{\ t-1})}{\Delta Time} \qquad (4\text{-}3)$$

Table 4-4 presents second-by-second data for the time interval highlighted in Table 4-3. The second column of Table 4-3 presents the speed of the follower vehicle obtained from the GPS system. This speed was converted to meters per second to be used as inputs in the models tested. The fourth column (y-y_f) provides the distances extracted using AutoCad from the still images of the video snapshots. The next two columns provide the spacing (in ft and in m) calculated using Equation 4-2 and solving for Z_b. The last two columns provide the lead speeds (in mi/hr and in m/s) calculated using Equation 4-3.

Table 4-5 presents the inputs used to obtain models estimates. The lead vehicle’s speed for every second, and the follower vehicle speed and spacing during the first time interval are used as input in each car-following model. The highlighted area consists of output information which changes with every model.

Figure 4-1. Inside view of the TRC instrumented vehicle

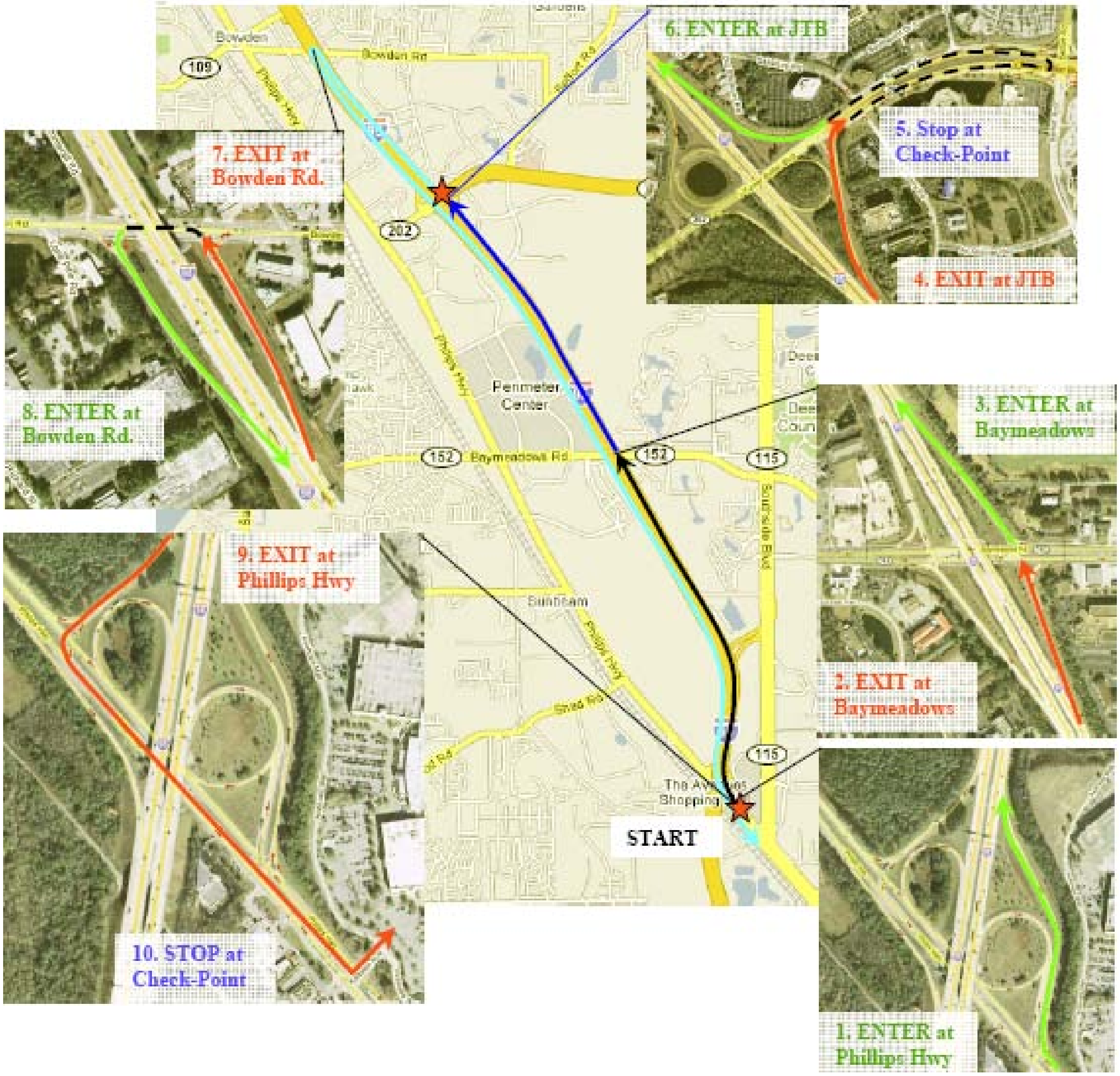

Figure 4-2. AM route (Kondyli 2009)

Table 4-1. Description of Figure 4-2 (Kondyli 2009)

Number	Description
1	Enter I-95 NB through Phillips Hwy on-ramp
2	Exit at Baymeadows Rd. off-ramp
3	Enter I-95 NB through Baymeadows Rd. on-ramp
4	Exit at J.T. Butler off-ramp
5	Stop at designated check-point on J.T. Butler Blvd.
6	Enter I-95 NB through J.T. Butler on-ramp
7	Exit at Bowden Rd.
8	Enter I-95 SB through Bowden Rd. on-ramp
9	Exit at Phillips Hwy off-ramp
10	Stop at designated check-point on Phillips Hwy (The Avenues Shopping Mall parking lot)

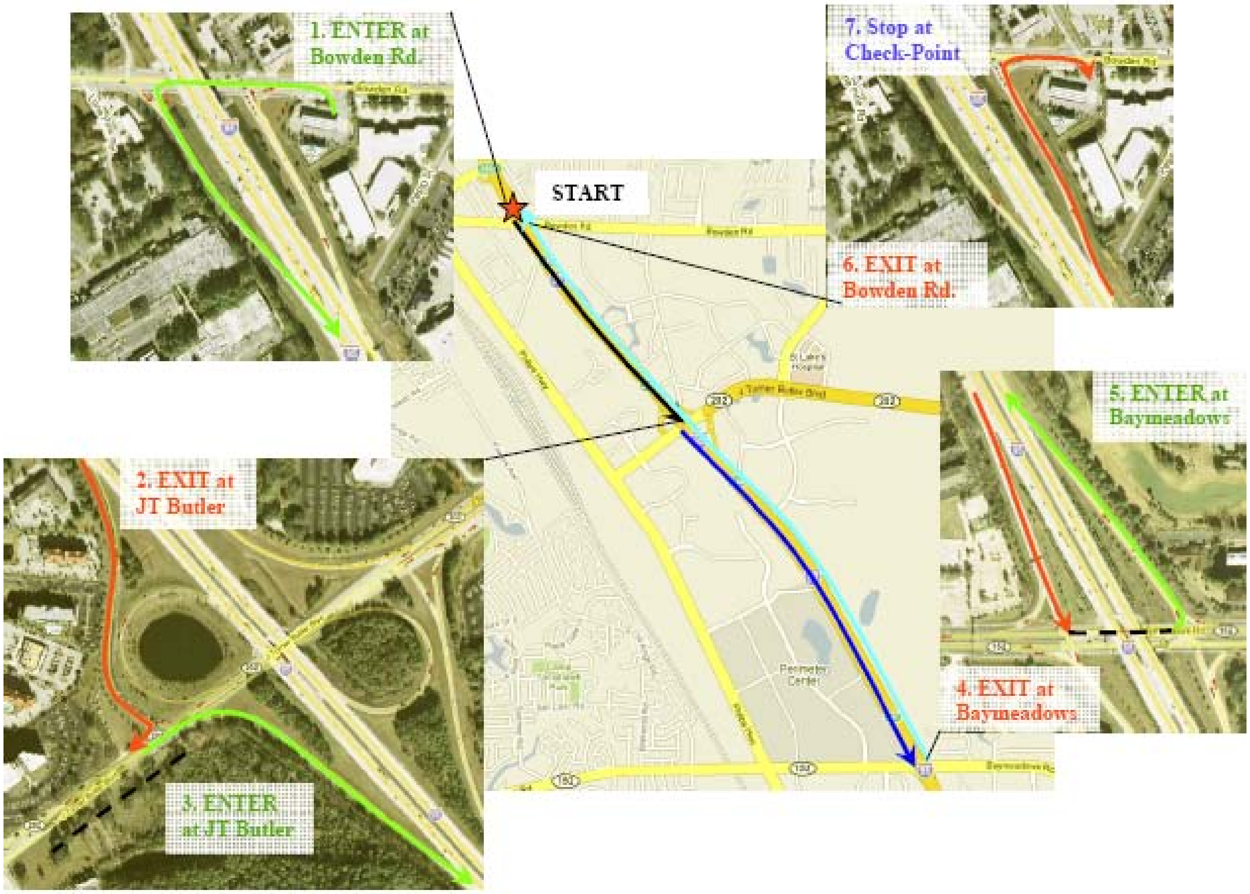

Figure 4-3. PM route (Kondyli 2009)

Table 4-2. Description of Figure 4-3 (Kondyli 2009)

Number	Description
1	Enter I-95 SB through Bowden Rd. on-ramp
2	Exit at J.T. Butler Blvd. off-ramp
3	Enter I-95 SB through J.T. Butler Blvd. on-ramp
4	Exit at Baymeadows Rd.
5	Enter I-95 NB at Baymeadows Rd.
6	Exit at Bowden Rd. off-ramp
7	Stop at designated check-point on Bowden Rd. (parking lot)

Table 4-3. Characteristics of instrumented vehicle experiment participants (Kondyli 2009)

Id	Gender	Age group	Race	Experience	Occupation	Driving frequency	Hours per week	Peak/ non-peak	Vehicle ownership
10	Male	55-65	Caucasian	>=10 years	Retired military	Everyday	4-8 hrs	Peak	Pickup/suv
47	Male	25-35	Caucasian	>=10 years	Clerk	Everyday	8-14 hrs	Peak	Sedan/coupe
49	Male	18-25	Caucasian	3-9 years	Full time student	Everyday	<4 hrs	Peak	Sedan/coupe
52	Male	25-35	Caucasian	>=10 years	Professional driver	Everyday	4-8 hrs	Peak	Pickup/suv
63	Male	25-35	Caucasian	>=10 years	Full time student	Everyday	8-14 hrs	Peak	Pickup/suv
65	Male	25-35	Caucasian	>=10 years	Safety ranger	Everyday	<4 hrs	Peak	Sedan/coupe
69	Female	25-35	Afr/ american	>=10 years	Full time student	Everyday	4-8 hrs	Peak	Pickup/suv
71	Female	18-25	Asian-caucasian	3-9 years	Customer service	Usually	4-8 hrs	Peak	Sedan/coupe
72	Male	25-35	Caucasian	>=10 years	Property manager	Everyday	8-14 hrs	Peak	Sedan/coupe
73	Female	45-55	Caucasian	>=10 years	Office manager	Everyday	<4 hrs	Peak	Sedan/coupe
76	Male	25-35	Caucasian	>=10 years	University staff	Never	<4 hrs	Non-peak	Sedan/coupe
23	Male	45-55	Caucasian	>=10 years	Military	Usually	4-8 hrs	Peak	Pickup/suv
27	Male	45-55	Caucasian	>=10 years	Qual. Assurance	Everyday	8-14 hrs	Peak	Sedan/coupe
32	Male	55-65	Caucasian	>=10 years	Pilot	Sometimes	4-8 hrs	Non-peak	Sedan/coupe
37	Female	45-55	Caucasian	>=10 years	Housewife	Everyday	4-8 hrs	Non-peak	Pickup/suv
51	Female	25-35	Caucasian	>=10 years	Admin. Assistant	Everyday	4-8 hrs	Peak	Pickup/suv
59	Male	18-25	Asian	1-3 years	Full time student	Never	<4 hrs	Non-peak	Sedan/coupe
60	Male	45-55	Caucasian	>=10 years	Police officer	Everyday	8-14 hrs	Peak	Sedan/coupe
61	Male	25-35	Caucasian	>=10 years	Pc refresh manager	Everyday	8-14 hrs	Peak	Sedan/coupe
67	Male	35-45	Afr/ american	>=10 years	Cook	Everyday	8-14 hrs	Non-peak	Sedan/coupe
68	Female	18-25	Caucasian	1-3 years	Full time student	Everyday	4-8 hrs	Peak	Sedan/coupe
74	Female	45-55	Caucasian	>=10 years	Internet business	Usually	8-14 hrs	Peak	Sedan/coupe
17	Female	45-55	Afr/ american	>=10 years	Secretary	Everyday	8-14 hrs	Peak	Sedan/coupe
18	Female	35-45	Caucasian	>=10 years	Officer	Everyday	>14 hrs	Peak	Sedan/coupe
19	Female	45-55	Caucasian	>=10 years	Admin. Assistant	Everyday	<4 hrs	Peak	Pickup/suv
50	Female	25-35	Caucasian	>=10 years	Housewife	Everyday	4-8 hrs	Peak	Pickup/suv
56	Male	35-45	Afr/ american	>=10 years	Sales	Everyday	8-14 hrs	Peak	Sedan/coupe
58	Male	18-25	Caucasian	3-9 years	Full time student	Everyday	8-14 hrs	Peak	Sedan/coupe
66	Male	35-45	Asian	1-3 years	Drafter	Everyday	<4 hrs	Non-peak	Pickup/suv
70	Male	45-55	Caucasian	>=10 years	Professional driver	Everyday	>14 hrs	Peak	Sedan/coupe
75	Female	55-65	Caucasian	>=10 years	Sales & marketing	Usually	8-14 hrs	Peak	Sedan/coupe

Table 4-4. Driver behavior types based on actual observations and background survey form(Kondyli 2009)

	Field observations			Background survey responses			
Id	DLC	Driving (FFS)	Driver type	Lane changing	Driving speed	Aggressiveness	Aggressiveness by others
10	7	77 mi/h	Aggressive	Very often	75 to 80 mi/h	Somewhat aggressive	Somewhat aggressive
47	5	71 mi/h	Aggressive	Very often	70 to 75 mi/h	Somewhat aggressive	Somewhat conservative
49	16	72 mi/h	Aggressive	Very often	70 to 75 mi/h	Somewhat aggressive	Somewhat aggressive
52	6	68 mi/h (rain)	Aggressive	Very often	70 to 75 mi/h	Somewhat aggressive	Somewhat aggressive
63	12	78 mi/h	Aggressive	Sometimes	70 to 75 mi/h	Somewhat conservative	Very conservative
65	9	79 mi/h	Aggressive	Very often	75 to 80 mi/h	Somewhat aggressive	Somewhat aggressive
69	16	67 mi/h (rain)	Aggressive	Sometimes	70 to 75 mi/h	Somewhat conservative	Very conservative
71	7	75 mi/h	Aggressive	Sometimes	70 to 75 mi/h	Somewhat conservative	Somewhat aggressive
72	7	78 mi/h	Aggressive	Very often	70 to 75 mi/h	Somewhat aggressive	Somewhat aggressive
73	6	77 mi/h	Aggressive	Very often	>80 mi/h	Somewhat aggressive	Very aggressive
76	6	79 mi/h	Aggressive	Very often	75 to 80 mi/h	Somewhat aggressive	Somewhat conservative
23	4	68 mi/h	Average	Very often	70 to 75 mi/h	Somewhat conservative	Very conservative
27	5	68 mi/h	Average	Sometimes	75 to 80 mi/h	Somewhat aggressive	Somewhat aggressive
32	4	71 mi/h	Average	Sometimes	75 to 80 mi/h	Somewhat aggressive	Somewhat conservative
37	4	71 mi/h	Average	Sometimes	70 to 75 mi/h	Somewhat aggressive	Somewhat aggressive
51	4	75 mi/h	Average	Very often	75 to 80 mi/h	Somewhat conservative	Somewhat aggressive
59	5	68 mi/h	Average	Sometimes	70 to 75 mi/h	Somewhat aggressive	Very aggressive
60	4	71 mi/h	Average	Very often	70 to 75 mi/h	Somewhat aggressive	Somewhat aggressive
61	5	74 mi/h	Average	Very often	75 to 80 mi/h	Somewhat aggressive	Somewhat aggressive
67	4	73 mi/h	Average	Sometimes	75 to 80 mi/h	Somewhat conservative	Somewhat aggressive
68	4	70 mi/h	Average	Very often	70 to 75 mi/h	Somewhat conservative	Somewhat aggressive
74	4	72 mi/h	Average	Sometimes	70 to 75 mi/h	Somewhat conservative	Somewhat conservative
17	0	60 mi/h	Conservative	Sometimes	< 65 mi/h	Very conservative	Very conservative
18	2	70 mi/h	Conservative	Sometimes	70 to 75 mi/h	Somewhat conservative	Somewhat conservative
19	2	65 mi/h	Conservative	Sometimes	70 to 75 mi/h	Somewhat conservative	Somewhat conservative
50	2	71 mi/h	Conservative	Very often	70 to 75 mi/h	Very conservative	Somewhat conservative
56	2	67 mi/h	Conservative	Sometimes	70 to 75 mi/h	Somewhat conservative	Somewhat aggressive
58	2	71 mi/h	Conservative	Sometimes	70 to 75 mi/h	Somewhat conservative	Somewhat conservative
66	0	68 mi/h	Conservative	Sometimes	70 to 75 mi/h	Somewhat conservative	Somewhat conservative
70	2	69 mi/h	Conservative	Very often	70 to 75 mi/h	Somewhat aggressive	Very aggressive
75	1	70 mi/h	Conservative	Sometimes	70 to 75 mi/h	Somewhat conservative	Somewhat conservative

Table 4-5. Trajectory of a single vehicle along with the corresponding conditions

Time intervals		Comments	Difference
7:51:53	7:52:11	Right lane/ new car	0:00:18
7:52:12	7:52:22	Right lane/ new car	0:00:10
7:52:23	7:52:35	Right lane/ new car	0:00:12
7:52:36	7:52:39	Middle/ new car	0:00:03
7:52:40	7:53:33	Left/ new car	0:00:53
7:53:34	7:54:02	No cong/ left/ car	0:00:28
7:54:03	7:54:20	Left/ new car	0:00:17
7:58:25	7:58:31	Left/ car	0:00:06
7:58:32	7:58:35	Left/ new car]	0:00:03
7:58:36	8:02:35	Change lane/new car/ cong	0:03:59
8:02:36	8:04:29	New car/ con	0:01:53
8:04:30	8:05:20	New car/ con	0:00:50
8:08:53	8:10:21	Car/con/left	0:01:28
8:10:22	8:11:16	New car/ cong/ left	0:00:54

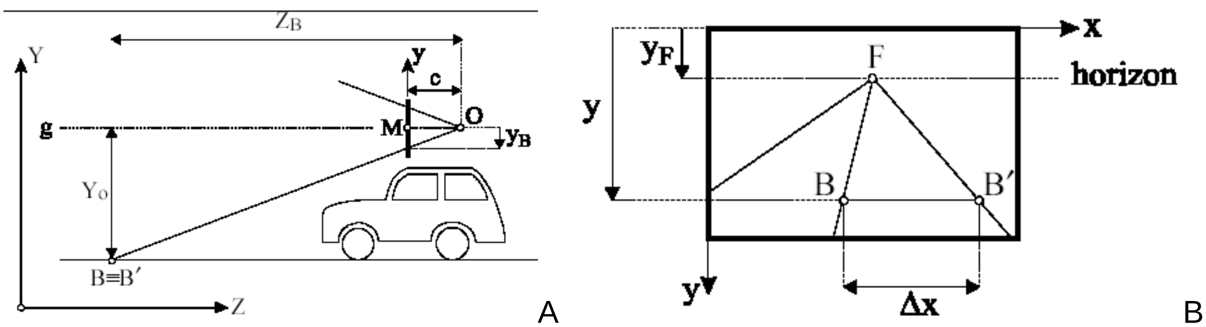

Figure 4-4. Image geometry with A) Horizontal camera axis and B) Measurements on the digital image.(Psarianos et al., 2001)

Table 4-6. Second by second data for the time interval highlighted in Table 4-3

Time	Follower vehicle Speed mi/hr	m/s	$y-y_f$	Gap Spacing (ft)	Spacing (m)	Lead vehicle Speed mi/hr	m/s
8:03:00	9	4.0	0.6463	44.21	13.48		
8:03:01	9	4.0	0.6266	45.60	13.90	9.9	4.421154817
8:03:02	9	4.0	0.6167	46.33	14.12	9.5	4.221804804
8:03:03	9	4.0	0.6258	45.65	13.92	8.5	3.795858182
8:03:04	9	4.0	0.6448	44.31	13.51	8.1	3.592344688
8:03:05	9	4.0	0.6356	44.95	13.70	9.4	4.19434752
8:03:06	9	4.0	0.626	45.64	13.91	9.5	4.208887814
8:03:07	10	4.5	0.6533	43.73	13.33	8.2	3.644291544
8:03:08	10	4.5	0.7074	40.39	12.31	7.7	3.430954033
8:03:09	10	4.5	0.6361	44.91	13.69	13.1	5.816270892
8:03:10	10	4.5	0.6635	43.06	13.13	8.7	3.882382304
8:03:11	11	4.9	0.6497	43.97	13.41	11.1	4.943823369
8:03:12	11	4.9	0.6515	43.85	13.37	10.9	4.852072151
8:03:13	11	4.9	0.722	39.57	12.06	8.1	3.591298584
8:03:14	12	5.4	0.701	40.76	12.43	12.3	5.470334141
8:03:15	12	5.4	0.7737	36.93	11.26	9.4	4.17283669
8:03:16	11	4.9	0.7676	37.22	11.35	11.7	5.200035802
8:03:17	11	4.9	0.754	37.89	11.55	11.5	5.092327175
8:03:18	10	4.5	0.7664	37.28	11.37	10.1	4.480888387
8:03:19	10	4.5	0.7592	37.63	11.47	10.2	4.551576859
8:03:20	10	4.5	0.7153	39.94	12.18	11.6	5.144318974
8:03:21	10	4.5	0.6701	42.64	13.00	11.8	5.260858898
8:03:22	10	4.5	0.6821	41.89	12.77	9.5	4.217147461

Table 4-4. Inputs used in the implementation of each model

Time (s)	Lead vehicle Accel ft/s^2	Speed mi/h	ft/s	Pos ft	m	Follower vehicle Accel ft/s^2	Speed mi/h	ft/s	m/s	Pos ft	m	Spacing ft	m
1	0	9.95	14.59	45.60	13.9	0.00	9	13.20	4.02	0	0	45.6	13.9
2		9.50	13.93										
3		8.54	12.53										
4		8.08	11.85										
.		9.44	13.84										
.		9.47	13.89										
n		8.20	12.03										

CHAPTER 5
INITIAL ANALYSIS AND RESULTS COMPARISON

Initial analysis of the field data and results are presented in this chapter. The results for the Gipps, Pitt, MITSIM, and Modified Pitt models were compared to the field data. The analysis was completed in a spreadsheet application. The models were first analyzed with the default parameters used in the original references with a modification of the free flow speed of the follower vehicle and the length of the vehicle. A calculation example of each model application also is presented. The units used to present the calculations and results were the same units that the model was developed. Equivalent values in other system units are shown in parenthesis.

Chapter 6 presents the model calibration undertaken where the parameters of each model were modified to obtain results as close as possible to the field data. This chapter is divided in five sections. The first four sections present the results of the implementation of the models in a spreadsheet program. Finally, the last section provides a comparison of these four models.

Gipps Model

This section provides the assumptions used in applying the Gipps model and an example of its application. Detailed results by driver under different conditions are presented in Appendix B. Gipps (1981) defined the car following model as follows:

$$v_n(t+\tau) =$$

$$\min\left\{v_n(t) + 2.5a_n\tau\left(1-\frac{v_n(t)}{V_n}\right)\left(0.025+\frac{v_n(t)}{V_n}\right)^{\frac{1}{2}}, b_n\tau + \right.$$

$$\left.\sqrt{b_n^2\tau^2 - b_n[2[x_{n-1}(t) - S_{n-1} - x_n(t)] - v_n(t)\tau - \frac{v_{n-1}(t)^2}{\hat{b}}]}\right)\} \qquad (5\text{-}1)$$

Where:

- a_n= maximum acceleration which the driver of vehicle n wishes to undertake (m/s^2),
- b_n= actual most severe deceleration rate that the driver of vehicle n wishes to undertake (b_n< 0) (m/s^2),
- $\hat{b}$ = estimated most severe deceleration rate that the vehicle n-1 is willing to employ (m/s^2),
- S_{n-1} = effective size of vehicle n; that is the physical length plus a margin into which the following vehicle is not willing to intrude even when at rest (m),
- v_{n-1} = speed at which the driver of vehicle n-1 wishes to travel (m/s),
- v_n = speed at which the driver of vehicle n wishes to travel (m/s),
- $x_n(t)$ = location of the front of vehicle n at time t (m),
- $x_{n-1}(t)$ = location of the front of vehicle n at time t (m),
- V_n = speed at which the driver of vehicle n wishes to travel (m/s),
- τ = apparent reaction time, a constant for all vehicles (s).

The assumptions used in this initial analysis were the following:

- a_n, is the maximum acceleration which the driver of vehicle n wishes to undertake = 2 m/s^2 (4.47 mi/hr-s),
- b_n is the actual most severe deceleration rate that the driver of vehicle n wishes to undertake (b_n< 0) = –3.0 m/s^2 (–6.7 mi/hr-s),
- $\hat{b}$ is the estimated most severe deceleration rate that the vehicle n-1 is willing to employ = –3.50 m/s^2 (–7.83 mi/hr-s),
- S_{n-1} is the effective size of vehicle n; that is the physical length plus a margin into which the following vehicle is not willing to intrude even when at rest = 6.5m (21.33 ft),
- V_n = speed at which the driver of vehicle n wishes to travel = Free Flow Speed (FFS) of each subject,
- τ = apparent reaction time, a constant for all vehicles = 0.667 s.

Table 5-1 presents all the inputs used which were obtained from the field data.

The highlighted cells in the table consist of kinematics variables of the lead and follower vehicle to be calculated. These were calculated with equations of motion and with the Gipps model. The results are provided in Table 5-2. The values in the second row are calculated with the following equations.

The acceleration of the lead vehicle is calculated as follows:

$$a_{lead}\ (t) = \frac{(v_{lead}\ (t) - v_{lead}\ (t-1))}{\Delta time} \tag{5-2}$$

The acceleration of the lead vehicle in the second time interval (second and third column in Table 5-2) are calculated as follows:

$$a_{lead}\ (2\ \mathrm{s}) = \frac{\left(4.2\frac{\mathrm{m}}{\mathrm{s}} - 4.4\frac{\mathrm{m}}{\mathrm{s}}\right)}{1\ \mathrm{s}} = -0.2\,\frac{\mathrm{m}}{\mathrm{s}^2}\left(-0.7\,\frac{\mathrm{ft}}{\mathrm{s}^2}\right)$$

The position of the lead vehicle is calculated using the Equation 5-3.

$$S_{lead}\ (t) = S_l\,(t-1) + v_{lead}\ (t-1) \times \Delta time + 0.5\ \times a_{lead}\ (t) \times \Delta time^2 \tag{5-3}$$

The position of the lead vehicle in the second time interval (sixth and seventh column in Table 5-2) is calculated as follows:

$$S_{lead}\ (2\mathrm{s}) = 13.9\ \mathrm{m} + 4.4\,\frac{\mathrm{m}}{\mathrm{s}} \times 1\ \mathrm{s} + 0.5\ \times \left(-0.2\,\frac{\mathrm{m}}{\mathrm{s}^2}\right) \times (1\mathrm{s})^2 = 18.25\ \mathrm{m}\ (59.85\ \mathrm{ft})$$

The speed of the follower vehicle is calculated using the Equation 5-4.

$$v_{follower}\ (t) = \min\left\{v_{follower}\ (t) + 2.5 a_n \tau\left(1 - \frac{v_{follower}\ (t-1)}{V_n}\right)\left(0.025 + \frac{v_{follower}\ (t-1)}{V_n}\right)^{\frac{1}{2}},\ b_n\tau + \sqrt{b_n^2\tau^2 - b_n[2\left[x_{lead}\,(t-1) - S_{n-1} - x_{follower}\,(t-1)\right] - v_{follower}\ (t-1)\tau - \frac{v_{\mathrm{lead}}\ (t-1)^2}{\hat{b}}]}\right\} \tag{5-4}$$

The speed of the follower vehicle in the second time interval (tenth and eleventh column in Table 5-2) is calculated as follows:

$v_{follower}$ (2 s) =

$$min\left\{4.02\,\frac{\text{m}}{\text{s}} + 2.5 \times 2\,\frac{\text{m}}{\text{s}^2} * 0.67\text{ s} \times \left(1 - \frac{\frac{4.02\text{m}}{\text{s}}}{32.4\frac{\text{m}}{\text{s}}}\right) \times \left(0.025 + \frac{4.02\frac{\text{m}}{\text{s}}}{32.4\frac{\text{m}}{\text{s}}}\right)^{\frac{1}{2}}, -3.0\,\frac{\text{m}}{\text{s}^2} * 0.67\text{ s} + \right.$$

$$\left.\sqrt{\left(-3.0\,\frac{\text{m}}{\text{s}^2}\right)^2 \times (0.67\text{ s})^2 - -3.5\,\frac{\text{m}}{\text{s}^2}\left[2 \times [13.9\text{ m} - 6.5\text{ m} - 0\text{ m}] - 4.02\,\frac{\text{m}}{\text{s}} \times 0.67\, s - \frac{\left(4.22\frac{\text{m}}{\text{s}}\right)^2}{-3.5\,\frac{\text{m}}{\text{s}^2}}\right])}\right\} =$$

$$min\left\{5.15\,\frac{\text{m}}{\text{s}}, 5.46\,\frac{\text{m}}{\text{s}}\right\} = 5.15\,\frac{\text{m}}{\text{s}}\ \left(16.9\,\frac{\text{ft}}{\text{s}}\right)$$

The acceleration of the follower vehicle is calculated using Equation 5-5.

$$a_{follower}\ (\text{t}) = \frac{(v_{follower}\ \ (t) - v_{follower}\ \ (t-1))}{\Delta time} \tag{5-5}$$

The acceleration of the follower vehicle in the second time interval (eighth and ninth column in Table 5-2) is calculated as follows:

$$a_{follower}\ (2\text{ s}) = \frac{\left(5.15\frac{\text{m}}{\text{s}} - 4.02\frac{\text{m}}{\text{s}}\right)}{1\text{ s}} = 1.13\,\frac{\text{m}}{\text{s}^2}\left(3.7\,\frac{\text{ft}}{\text{s}^2}\right)$$

The position of the follower vehicle is calculated using Equation 5-6.

$$S_{follower}\ (t) = S_f\,(t-1) + v_{follower}\ (t-1) \times \Delta time + 0.5\ \times a_{follower}\ (t) \times \Delta Time^2 \tag{5-6}$$

The position of the follower vehicle in the second time interval (twelfth and thirteenth column in Table 5-2) is calculated as follows:

$$S_{follower}\,(2\text{s}) = 0\text{ m} + 5.15\,\frac{\text{m}}{\text{s}} \times 1\text{ s} + 0.5\ \times \left(1.13\,\frac{\text{m}}{\text{s}^2}\right) \times (1\text{s})^2 = 4.6\text{ m (15.0 ft)}$$

The spacing between vehicles is calculated using Equation 5-7.

$$Spacing\ (t) = S_l\ (t) - S_f\ (t) \tag{5-7}$$

The spacing between vehicles in the second time interval (fourteenth and fifteenth column in Table 5-2) is calculated as follows:

$$Spacing\ (2\text{s}) = 18.25\text{ m} - 4.6\text{ m} = 13.6\text{ m (44.7 ft)}$$

Gipps model predicted the variable speed more accurately. The differences between the field data and the Gipps speed results were 4.47 mi/hr to 13.42 mi/hr (2m/s to 6m/s). On the other hand the differences between the spacing between vehicles were 9.84 ft to 207.9 ft (3.0 m to 63.38 m). Gipps car-following model predicts the follower speed thus it was expected that this variable was the best predicted by the model. In all of the cases the spacing was overestimated and the majority of the Gipps speed results were lower than the field data. The RSME values for speed were better than the spacing values.

Comparing between conditions, the Gipps model predicted the trajectories under congested scenarios more accurately. The differences between the field data and the Gipps results for the follower speed in congested conditions were 4.47 mi/hr to 8.41 mi/hr (2 m/s to 3.76 m/s) and the differences for spacing were from 9.84 ft to 32.8 ft (3 m to 10.0 m). For uncongested the differences between the field data and the Gipps speed results were from 6.7 mi/hr to 13.42 mi/hr (3 m/s to 6 m/s) and for the differences between spacing were from 46.98 ft to 207.9 ft (14.32 m to 63.68 m). The RSME for spacing under rainy congested conditions varied from 2.17 to 3.80, for congested it varied from 1.60 to 3.73, and for uncongested and uncongested with rain were 5.49 to 20.81 and 8.29 to 45.92 respectively. Therefore the Gipps model predicted congested conditions more accurately than uncongested. For rainy conditions the RSME for speed varied from 0.45 to 0.79, for congested conditions the RSME for speed was from 0.72 to 1.19 and for uncongested and uncongested with rain were 1.17 to 6.42 and from 1.54 to 2.69 respectively. The result of RSME for speed in rainy congested conditions was the lowest of all conditions. Gipps models predicted rainy congested conditions more accurate.

Comparing between drivers, the results for the average driver were closer to the field data, having a lower value of RMSE for spacing and speed. The highest values of RMSE were for the most conservative ones or the most aggressive ones. The defaults parameter values in the Gipps car-following model are better predicting average driver but a better calibration and analysis of the parameters is needed.

Pitt Model

This section provides the assumptions used in applying the Pitt model and an example of its application. Detailed results by driver under different conditions are presented in Appendix B. The Pitt model equation is as follows:

$$d_{ab} = L + 3.04878 + ku_a + bk\,(u_b - u_a)^2 \tag{5-8}$$

Where:

- d_{ab} = space headway between the lead vehicle B and the follower A from front bumper to front bumper (m),
- L = lead vehicle (B) length (m),
- k = the car-following parameter (sensitivity factor) (s),
- u_b & u_a = speed of vehicles lead and follower respectively (m/s),
- b = calibration constant defined as 0.1(when $u_a > u_b$) or 0 otherwise.

The assumptions used in this initial analysis were the following:

- L, lead vehicle (B) length = 7.622 m (25 ft),
- k, the car-following parameter (sensitivity factor) for conservative drivers = 0.35 seconds, for aggressive drivers = 1.25 seconds (CORSIM Default distribution of car-following sensitivity factors).

Table 5-1 presents all the inputs used which were obtained from the field data. The highlighted cells in the table consist of kinematics variables of the lead and follower vehicle to be calculated. These were calculated with equations of motion and with the Pitt model. The results are provided in Table 5-3. The acceleration and position of the lead vehicle were calculated with Equation 5-2 and Equation 5-3 respectively.

The spacing (last column in Table 5-3) are calculated using Equation 5-9.

$$d_{ab}(t) = L + 3.04878 + ku_{follower}(t-1) + bk\,(u_{lead}(t-1) - u_{follwer}(t-1))^2 \quad (5\text{-}9)$$

Where:

b = calibration constant defined as 0.1(when $u_{follower} > u_{lead}$) or 0 otherwise

The spacing between vehicles in the second time interval (last columns in Table 5-3) is calculated as follows:

The $u_{follower}(t-1) < u_{lead}(t-1)$, therefore $b = 0$

$$d_{ab}(2\text{ s}) = 7.62\text{m} + 3.04878 + 0.35s \times 4.02\frac{m}{s} + 0 \times 0.35s\,(4.421\,m/s - 4.02\text{ m/s})^2 =$$

$$12.1\text{ m } (39.6\text{ ft})$$

The position of the follower vehicle is calculated using the following equation:

$$S_{follower}(t) = S_{lead}(t) - d_{ab}(t) \quad (5\text{-}10)$$

The position of the follower vehicle in the second time interval is calculated as follows:

$$S_{follower}(2\text{s}) = 18.2\text{ m} - 12.1\text{ m} = 6.1\text{ m } (20.1\text{ ft})$$

The speed of the follower vehicle is calculated using Equation 5-11.

$$v_{follower}(\text{t}) = \sqrt{v_f(\text{t}-1)^2 + 2a_{follower}(\text{t}-1) \times (S_{follower}(t) - S_{follower}(t-1))} \quad (5\text{-}11)$$

The speed of the follower vehicle in the second time interval (tenth and eleventh column Table 5-3) is calculated as follows:

$$v_{follower}\ (2\text{s}) = \sqrt{\left(4.02\,\frac{\text{m}}{\text{s}}\right)^2 +\ 2 \times 2\,\frac{\text{m}}{\text{s}^2} \times (6.1\ \text{m} - 0\ \text{m})} = 5.3\,\frac{\text{m}}{\text{s}}\ (\ 17.5\,\frac{\text{ft}}{\text{s}})$$

The acceleration of the follower vehicle is calculated using Equation 5-12.

$$a_{follower}\ (\text{t}) = \frac{(v_{follower}\quad (t) - v_{follower}\quad (t-1))}{\Delta time} \tag{5-12}$$

The acceleration of the follower vehicle in the second time interval (eighth and ninth column Table 5-3) is calculated as follows:

$$a_{follower}\ (2\ \text{s}) =\ \frac{\left(5.3\frac{\text{m}}{\text{s}} - 4.02\frac{\text{m}}{\text{s}}\right)}{1\ \text{s}} =\ 1.3\,\frac{\text{m}}{\text{s}^2}\,(4.3\,\frac{\text{ft}}{\text{s}^2})$$

For some subjects the Pitt model predicted more accurately the variable speed and for others the spacing variable. However the overall RMSE was lower for the speed variable. The differences between the field data and the Pitt result for speed were from 7 mi/hr to 32.7 mi/hr (3.13 m/s to 14.62 m/s). The differences between the field data and the Pitt result for the spacing were from 7.22 ft to 85 ft (2.20 m to 25.88 m). For all the subjects in all conditions Pitt model predicted a higher speed than the field data. The spacing between vehicles in some intervals was higher than the field data and in other was lower.

Comparing between conditions, the Pitt model predicted the trajectories under congested conditions more accurately. The differences between the field data and the Pitt results for speed under congested conditions were from 7 mi/hr to 32.7 mi/hr (3.13 m/s to 14.62 m/s) and the differences for spacing were from 7.22ft to 49.54 ft (2.20 m to 15.10 m). For uncongested the differences between the field data and the Pitt speed results were from 9.77 mi/hr to 31.6 mi/hr (4.37 m/s to 14.16 m/s) and for the differences between spacing were from 14.4 ft to 85 ft (4.39 m to 25.91 m). Pitt model predicted the trajectories of the vehicles for the congested scenarios more accurately than the overall uncongested scenarios. The RSME for spacing in rainy congested conditions varied from 1.22 to 4.06. The RSME for spacing in congested it varied from 2.19 to 9.18, and for uncongested and uncongested with rain were 2.54 to 15.93 and 8.51 to 14.98 respectively. Therefore the Pitt model predicted congested conditions more accurately than uncongested. The RSME for speed was higher than the RSME for spacing for rainy congested conditions. However for uncongested and congested conditions the RSME for speed was lower than spacing. For the rainy congested the RSME for speed varied from 1.89 to 5.36. For congested conditions the RSME for speed was from 1.25 to 10.36 and for uncongested and uncongested with rain were 2.77 to 10.15 and from 6.98 to 13.52 respectively. The results of RSME for speed in rainy congested conditions were the lowest of all, concluding that the Pitt models predicted the congested rainy conditions more accurate.

Comparing between drivers, Pitt model predicted a better spacing and speed for conservative and aggressive drivers. However the lowest overall RSME for spacing and speed in each condition was for the aggressive drivers. The defaults parameter values in the Pitt car-following model are better predicting conservative and aggressive driver but a better calibration and analysis of the parameters is needed.

MITSIM Model

This section provides the assumptions used in applying the MITSIM model and an example of its application. Detailed results by driver under different conditions are presented in Appendix B. MITSIM car-following model is defined as follows:

$$a_n = \alpha^{\mp} \frac{v_n^{\beta\mp}}{g_n^{\gamma\mp}} (v_{n-1} - v_n) \tag{5-13}$$

Where:

- v_n= follower's speed (m/s),
- v_{n-1} = lead's speed (m/s),
- g_n = spacing between the follower and the lead vehicle minus the lead vehicle length, $g_n = x_{n-1} - x_n - L_{n-1}$ (m),
- $\alpha^{\pm}, \beta^{\pm}, and\ \gamma^{\pm}$ = six model parameters related to driver behavior to be calibrated for the car-following regime (with values $\pm$ for acceleration and deceleration).

The assumptions used in this initial analysis were the following:

- L_{n-1}, lead vehicle length = 7.62 m (25 ft)
- $\alpha^{\pm}, \beta^{\pm}, and\ \gamma^{\pm}$, six model parameters related to driver behavior to be calibrated for the car-following regime (with values $+$ for acceleration when $u_{follower} \leq u_{lead}$ and $-$ for deceleration when $u_{follower} > u_{lead}$) = $\alpha^+ = 0.5$, $\beta^+ = -1$ and $\gamma^+ = -1$ and $\alpha^- = 1.25$, $\beta^- = 1$ and $\gamma^- = 1$.

Table 5-1 presents all the inputs used which were obtained from the field data. The highlighted cells in the table consist of kinematics variables of the lead and follower vehicle to be calculated. These were calculated with equations of motion and with the MITSIM model. The results are provided in Table 5-4. The acceleration and position of the lead vehicle were calculated with Equation 5-2 and Equation 5-3 respectively. The values in the second row are calculated with the following equations.

The acceleration of the follower is calculated using Equation 5-14.

$$a_{follower}\ (\mathrm{t}) = \alpha^{\mp} \frac{v_{follower}^{\beta\mp}}{g_n^{\gamma\mp}} (v_{lead}\ (\mathrm{t}-1) - v_{follower}\ (\mathrm{t}-1)) \qquad (5\text{-}14)$$

Where:

$\alpha^{\pm}, \beta^{\pm}, and\ \gamma^{\pm}$, six model parameters related to driver behavior to be calibrated for the car-following regime (with values $+$ for acceleration when $u_{follower} \leq u_{lead}$ and $-$ for deceleration when $u_{follower} > u_{lead}$) = $\alpha^+ = 0.5$, $\beta^+ = -1$ and $\gamma^+ = -1$ and $\alpha^- = 1.25$, $\beta^- = 1$ and $\gamma^- = 1$.

The acceleration of the follower vehicle in the second time interval (eighth and ninth column Table 5-4) is calculated as follows:

$u_{follower} \leq u_{lead}$ = used values + for acceleration = $\alpha^{+} = 0.5$, $\beta^{+} = -1$ and $\gamma^{+} = -1$

$$a_{follower}\ (\mathrm{t}) = 0.5 \times \frac{\left(4.02\frac{\mathrm{m}}{\mathrm{s}}\right)^{-1}}{(13.9\ \mathrm{m})^{-1}} \times \left(4.421\frac{\mathrm{m}}{\mathrm{s}} - 4.02\frac{\mathrm{m}}{\mathrm{s}}\right) = 0.69\ m/s^2 (2.27\ \frac{\mathrm{ft}}{s^2})$$

The speed of the follower is calculated using the following equation:

$$v_{follower}\ (\mathrm{t}) = v_f\ (\mathrm{t}-1) + a_{follower}\ (\mathrm{t}) \times \Delta\mathrm{time} \qquad (5\text{-}15)$$

The speed of the follower vehicle in the second time interval (tenth and eleventh column Table 5-4) is calculated as follows:

$$v_{follower}\ (2\mathrm{s}) = 4.02\frac{\mathrm{m}}{\mathrm{s}} + 0.69\ \mathrm{m}/s^2 \times 1\ \mathrm{sec} = 4.7\frac{\mathrm{m}}{\mathrm{s}}\ (15.5\ \mathrm{ft/s})$$

The position of the follower is calculated using Equation 5-16

$$S_{follower}\ (t) = S_f\ (t-1) + v_{follower}\ (t-1) \times \Delta time + 0.5 \times a_{follower}\ (t) \times \Delta Time^2 \qquad (5\text{-}16)$$

The position of the follower vehicle in the second time interval is calculated as follows:

$$S_{follower}\ (2\mathrm{s}) = 0\ \mathrm{ft} + 4.02\frac{\mathrm{m}}{\mathrm{s}} \times 1\ \mathrm{sec} + 0.5 \times \left(0.69\frac{\mathrm{m}}{\mathrm{s}^2}\right) \times (1\mathrm{s})^2 = 4.37\ \mathrm{m}\ (14.3\ \mathrm{ft})$$

The spacing between vehicles is calculated using the following equation:

$$Spacing\ (t) = S_l\ (t) - S_f\ (t) \qquad (5\text{-}17)$$

The spacing between vehicles in the second time interval (lasts column in Table 5-4) is calculated as follows:

$$Spacing\ (2\mathrm{s}) = 18.2\ \mathrm{m} - 4.4\ \mathrm{m} = 13.9\ \mathrm{m}\ (45.4\ \mathrm{ft})$$

MITSIM model predicted the variable speed more accurately. The differences between the field data and the MITSIM model result for speed were from 2.57 mi/hr to 10.5 mi/hr (1.15 m/s to 4.69 m/s). On the other hand the differences between the spacing were from 8.9 ft to 65 ft (2.71 m to 19.82 m). The RSME values for speed were better than the spacing values.

Comparing between conditions, MITSIM model predicted the trajectories under congested scenarios more accurately. The differences between the field data and the MITSIM results for speed under congested scenarios were from 2.57 mi/hr to 6.8 mi/hr (1.15 m/s to 3.04 m/s) and the differences for spacing were from 8.9 ft to 43.6 ft (2.71 m to 13.29 m). For uncongested the differences between the field data and the MITSIM speed results were from 6 mi/hr to 10.5 mi/hr (2.68 m/s to 4.69 m/s) and for the differences between spacing were from 30 ft to 65 ft (9.14 m to 19.82 m).

The RSME for spacing under rainy congested conditions varied from 1.28 to 2.85, for congested conditions it varied from 1.67 to 6.77, and for uncongested and rain uncongested were 6.18 to 14.98 and 4.62 to 10.47 respectively. The RSME for speed comparison was lower than the RSME for spacing, consistent with other models. For the rain congested the RSME for speed varied from 0.46 to 0.93, for congested conditions was from 0.82 to 1.19 and for uncongested and rain uncongested were 1.05 to 2.10 and from 1.09 to 2.83 respectively. The result of RSME for speed in rainy congested conditions was the lowest of all. MITSIM models predicted the rainy congested conditions more accurate.

Comparing between driver types, the highest values of RMSE for spacing were for the conservative and aggressive drivers. On the other hand the highest values of RSME for speed were for the average drivers. The lowest values of RSME for spacing were for aggressive drivers and the lowest values of RMSE for spacing were for average drivers. For a better understanding of these behavior a better calibration and analysis of the parameters is needed.

Modified Pitt Model

This section provides the assumptions used in applying the Modified Pitt model and an example of its application. Detailed results by driver under different conditions are presented in Appendix B. Cohen, (2002) defined the Modified Pitt car following model as follows:

$$a_f(t+T) = \frac{K\left\{S_l(t+R) - S_f(t+R) - L_l - hv_f(t+R) + \left[v_f(t+R) - v_l(t+R)\right]T - \frac{1}{2}a_l(t+T)T^2\right\}}{\left[T\left(h+\frac{1}{2}T\right)\right]} \quad (5\text{-}18)$$

Where:

- a_f = acceleration of the follower vehicle (ft/s^2),
- a_l = acceleration of the lead vehicle (ft/s^2),
- t = current simulation time (s),
- T = simulation time-scan interval (s),
- R = perception-reaction time (assumed equal for all vehicle) (s),
- K = sensitivity parameter used in Modified Pitt car following model,
- S_l and S_f = position of the lead and follower vehicle respectively at time t + R (ft),
- L_l = length of lead vehicle plus a buffer based on jam density (ft),
- h = time headway parameter used in Pitt car following model (refers to headway between rear bumper plus a buffer of lead vehicle to front bumper of follower) (s),
- v_l and v_f = speed of the lead and follower vehicle respectively at time t + R (ft/s).

The assumptions used in this initial analysis were the following:

- T, simulation time-scan interval = 1 s
- R, perception-reaction time (assumed equal for all vehicle) = 1 s
- K, sensitivity parameter used in modified Pitt car following model = 0.35
- L_l, length of lead vehicle plus a buffer based on jam density = 32 ft
- h, time headway parameter used in Pitt car following model = 1.5 s

An example of the calculation process is described below. The calculations for two time intervals are discussed.

Table 5-1 presents all the inputs used which were obtained from the field data. The highlighted cells in the table consist of kinematics variables of the lead and follower vehicle to be calculated. These were calculated with equations of motion and with the Modified Pitt model. The results are provided in Table 5-5. The acceleration and position of the lead vehicle were calculated with Equation 5-2 and Equation 5-3 respectively. The values in the second row are calculated with the following equations. The acceleration of the follower vehicle is calculated using Equation 5-19.

$$a_{follower}\ (t+R) = \frac{K\left\{S_l(t) - S_f(t) - L_l - hv_f(t) + \left[v_f(t) - v_l(t)\right]T - \frac{1}{2}a_l(t+R)T^2\right\}}{\left[T\ (h + \frac{1}{2}T)\right]} \tag{5-19}$$

The acceleration of the follower vehicle in the second time interval (sixth column Table 5-5) is calculated as follows:

$$a_{follower}\ (2s) = \frac{0.35\left\{45.60\ \mathrm{ft} - 0\mathrm{ft} - 32\ \mathrm{ft} - 1.5\ \mathrm{s} \times 13.2\frac{\mathrm{ft}}{\mathrm{s}} + \left[13.2\frac{\mathrm{ft}}{\mathrm{s}} - \frac{14.58\mathrm{ft}}{\mathrm{s}}\right]1\mathrm{s} - \frac{1}{2} \times -0.65\ \mathrm{ft/s^2} \times 1\mathrm{s}^2\right\}}{\left[1\mathrm{s}\ (1.5\mathrm{s} + \frac{1}{2} \times 1\mathrm{s}\ )\right]} =$$

$$-1.271\mathrm{ft/s^2}(-0.3875\,\frac{\mathrm{m}}{\mathrm{s}^2})$$

The speed of the follower vehicle is calculated as follows:

$$v_{follower}\ (t+\mathrm{R}) = v_f\ (t) + \ a_{follower}\ (t+\mathrm{R}) \times \Delta\mathrm{time} \tag{5-20}$$

The speed of the follower vehicle in the second time interval (seventh column Table 5-5) is calculated as follows:

$$v_{follower}\ (2\mathrm{s}) = 14.58\,\frac{\mathrm{ft}}{\mathrm{s}} - 1.271\ \times 1\ \mathrm{s} = 11.93\,\frac{\mathrm{ft}}{\mathrm{s}}\ (3.637\ \mathrm{m/s})$$

The position of the follower vehicle is calculates using the following equation:

$$S_{follower}\ (t+R) = S_f\ (t) + \ v_{follower}\ (t) \times \Delta time + \ 0.5\ \times a_{follower}\ (t+R) \times \Delta Time^2 \tag{5-21}$$

The position of the follower vehicle in the second time interval (ninth column Table 5-5) is calculated as follows:

$$S_{follower}\ (2\mathrm{s}) = 0\ \mathrm{ft} + 13.2\,\frac{\mathrm{ft}}{\mathrm{s}} \times 1\ \mathrm{s} + 0.5\ \times \left(-1.271\,\frac{\mathrm{ft}}{\mathrm{s}^2}\right) \times (1\mathrm{s})^2 = 12.56\ \mathrm{ft}\ (3.83\ \mathrm{m})$$

The spacing between vehicles is calculated using Equation 5-22

$$Spacing\ (t+R) = S_l\ (t+R) - S_f\ (t+R) \qquad \text{(5-22)}$$

The spacing between vehicles in the second time interval (last column in Table 5-5) is calculated as follows:

$$Spacing\ (2s) = 59.85\ \mathrm{ft} - 12.56\ \mathrm{ft} = 47.29\ \mathrm{ft}\ (14.41\ \mathrm{m})$$

Modified Pitt model predicted the variable speed more accurately. The differences between the field data and the Modified Pitt result for speed were from 1.95 mi/hr to 34.39 mi/hr (0.87 m/s to 15.38 m/s). On the other hand the differences between the spacing were from 55.92 ft to 231.37 ft (17.05 m to 38.38 m). The speed results were more accurate than the spacing. Modified Pitt assumes that the follower vehicle will maintain a minimum safe distance. This safe distance is calculated as follows:

$$Safe\ distance = h \times follower\ speed\ (t+R) \qquad \text{(5-23)}$$

If this safe distance is calculated for the first interval the value will be:

$$Safe\ distance = 1.5\mathrm{s} \times 14.58\,\frac{\mathrm{ft}}{\mathrm{s}} = 21.87\ \mathrm{ft}\ (6.66\ \mathrm{m})$$

This safe distance value is higher than the actual spacing that the follower vehicle is using (13.2 ft, 4.02 m) Therefore from the first interval the Modified Pitt is assuming a distance that is much bigger, consequently the other intervals are going to be affected by this assumption. For a better understanding of these behavior a better calibration and analysis of the parameters is needed.

Comparing between conditions, the Modified Pitt model predicted more accurately the trajectories in congested conditions. The differences between the field data and the Modified Pitt results for speed under congested scenarios were from 1.95 mi/hr to 15.21 mi/hr (0.87 m/s to 6.80 m/s) and the differences for spacing were from 19.15 ft to 78.56 ft (5.84 m to 23.95 m). For uncongested the differences between the field data and the Modified Pitt model speed results were from 8.94 mi/hr to 33.50 mi/hr (4 m/s to 14.98 m/s) and for the differences between spacing were from 58.48 ft to 231.37 ft (17.53 m to 70.54 m).

The RSME for spacing in rainy congested varied from 9.44 to 13.4, congested conditions varied from 3.83 to 12.13, and for uncongested and rain uncongested were 20.84 to 43.15 and 8.13 to 36.23 respectively. The RSME for speed comparison were lower than the RSME for spacing, being consistent with the other models results. For the rain uncongested the RSME for speed varied from 2.36 to 3.58, for congested conditions the RSME for speed was from 0.41 to 3.53 and for uncongested and rain uncongested were 6.83 to 10.56 and from 3.81 to 9 respectively. The result of RSME for speed in congested conditions was the lowest of all conditions. The Modified Pitt models predicted the congested conditions more accurate.

Comparing between driver types, the results for the average driver were closer to the field data, having a lower value of RMSE for spacing and speed. The highest values of RMSE were for the most conservative ones. The defaults values of the parameters in the Modified Pitt car-following model were better predicting average driver but a better calibration and analysis of the parameters is needed.

Summary of the Initial Analysis

Figure 5-1 to 5-8 provides comparison graphs of different conditions for the average driver. From these Figures and the results discussed above, it can be concluded that all the models predicted more accurately the follower speed. The RMSE values for speed overall were lower than the RMSE for spacing. The model with the lowest difference between the speed and the field data was MITSIM with an overall RMSE of 111 for spacing and 23.84 for speed. Pitt model has the highest difference between the speed and the field data (RMSE speed value of 97.15), and Modified Pitt the highest difference in spacing (RMSE spacing value of 342.14).

From the Figures 5-1 to 5-8 it can be concluded that comparing between conditions, all the models predicted better the congested conditions than the uncongested scenario. MITSIM was the best model to predict the congested conditions. For uncongested conditions, the model that predicts more accurately the speed was MITSIM, and for the spacing was Pitt. In addition for the two congested conditions (rain congested and congested) the rain congested was more accurately to the field data, except for Modified Pitt that predicted better the congested condition.

Comparing between driver types, overall the average driver was the closest to the field data, and the highest vales of RMSE were for the conservative and the aggressive driver. The results showed that the best model predicting the average driver behavior was MITSIM and for the aggressive and conservative drivers the spacing was best predicted by Pitt and the speed by MITSIM.

These results were using the default values of each model thus a better calibration and analysis of the parameters is needed.

Table 5-1. Inputs used in the implementation of each model

Time (s)	Lead vehicle						Follower vehicle							Spacing	
	Acel		Speed		Position		Acel		Speed			Position			
	m/s²	ft/s²	m/s	ft/s	ft	m	m/s²	ft/s²	ft/s	m/s	mi/hr	ft	m	ft	m
1	0	0	4.4	14.5	45.6	13.9	0	0	13.2	4.0	9.0	0	0	45.6	13.9
2			4.2	13.9											
.			3.8	12.5											
.			3.5	11.8											
n			4.2	13.8											

* Highlighted cells will be the different outputs of each model

Table 5-2. Results of the Gipps model implementation

Time (s)	Lead vehicle						Follower vehicle						Spacing	
	Accel		Speed		Position		Accel		Speed		Position			
	m/s²	ft/s²	m/s	ft/s	ft	m	m/s²	ft/s²	ft/s	m/s	ft	m	ft	m
1	0.0	0.0	4.4	14.5	45.6	13.9	0.0	0.0	13.2	4.0	0.0	0.0	45.6	13.9
2	-0.2	-0.7	4.2	13.8	59.8	18.2	1.1	3.7	16.9	5.2	15.0	4.6	44.7	13.6
3	-0.4	-1.4	3.8	12.5	72.9	22.2	0.0	-0.1	16.8	5.1	31.9	9.7	41.0	12.5
4	-0.2	-0.7	3.6	11.8	85.0	25.9	-0.9	-2.9	13.9	4.2	47.3	14.4	37.8	11.5
5	0.6	2.0	4.2	13.8	97.8	29.8	-0.1	-0.4	13.5	4.1	60.9	18.6	36.9	11.2

Table 5-3. Results of the Pitt model implementation

Time (s)	Lead vehicle						Follower vehicle						Spacing	
	Accel		Speed		Position		Accel		Speed		Position			
	m/s²	ft/s²	m/s	ft/s	ft	m	m/s²	ft/s²	ft/s	m/s	ft	m	ft	m
1	0.0	0.0	4.4	14.5	45.6	13.9	0.0	0.0	13.2	4.0	0.0	0.0	45.6	13.9
2	-0.2	-0.7	4.2	13.8	59.8	18.2	1.3	4.3	17.5	5.3	20.1	6.1	39.6	12.1
3	-0.4	-1.4	3.8	12.5	72.9	22.2	0.8	2.7	20.2	6.2	31.6	9.6	41.3	12.6
4	-0.2	-0.7	3.6	11.8	85.0	25.9	0.4	1.3	21.6	6.6	42.3	12.9	42.7	13.0
5	0.6	2.0	4.2	13.8	97.8	29.8	0.2	0.7	22.3	6.8	54.2	16.5	43.6	13.3

Table 5-4. Results of the MITSIM model implementation

Time (s)	Lead vehicle Accel		Speed		Position		Follower vehicle Accel		Speed		Position		Spacing	
	m/s^2	ft/s^2	m/s	ft/s	ft	m	m/s^2	ft/s^2	ft/s	m/s	ft	m	ft	m
1	0.0	0.0	4.4	14.5	45.6	13.9	0.0	0.0	13.2	4.0	0.0	0.0	45.6	13.9
2	-0.2	-0.7	4.2	13.8	59.8	18.2	0.7	2.3	15.5	4.7	14.3	4.4	45.4	13.9
3	-0.4	-1.4	3.8	12.5	72.9	22.2	-0.5	-1.5	13.9	4.2	29.0	8.8	43.9	13.4
4	-0.2	-0.7	3.6	11.8	85.0	25.9	-0.4	-1.4	12.6	3.8	42.3	12.9	42.8	13.0
5	0.6	2.0	4.2	13.8	97.8	29.8	-0.2	-0.7	11.9	3.6	54.5	16.6	43.3	13.2

Table 5-5. Results of the Modified Pitt model implementation

Time (s)	Lead vehicle Accel (ft/s^2)	Speed (ft/s)	Pos (ft)	Pos (m)	Follower vehicle Accel (ft/s^2)	Speed (ft/s)	Speed (m/s)	Pos (ft)	Pos (m)	Spacing ft	m
1	0.0	14.5	45.6	13.9	0.0	13.2	4.0	0.0	0.0	45.6	13.9
2	-0.7	13.8	59.8	18.2	-1.3	11.9	3.6	12.6	3.8	47.3	14.4
3	-1.4	12.5	72.9	22.2	-0.7	11.3	3.4	24.2	7.4	48.9	14.9
4	-0.7	11.8	85.0	25.9	-0.1	11.1	3.4	35.3	10.8	50.0	15.2
5	2.0	13.8	97.8	29.8	-0.1	11.0	3.4	46.4	14.1	51.8	15.8

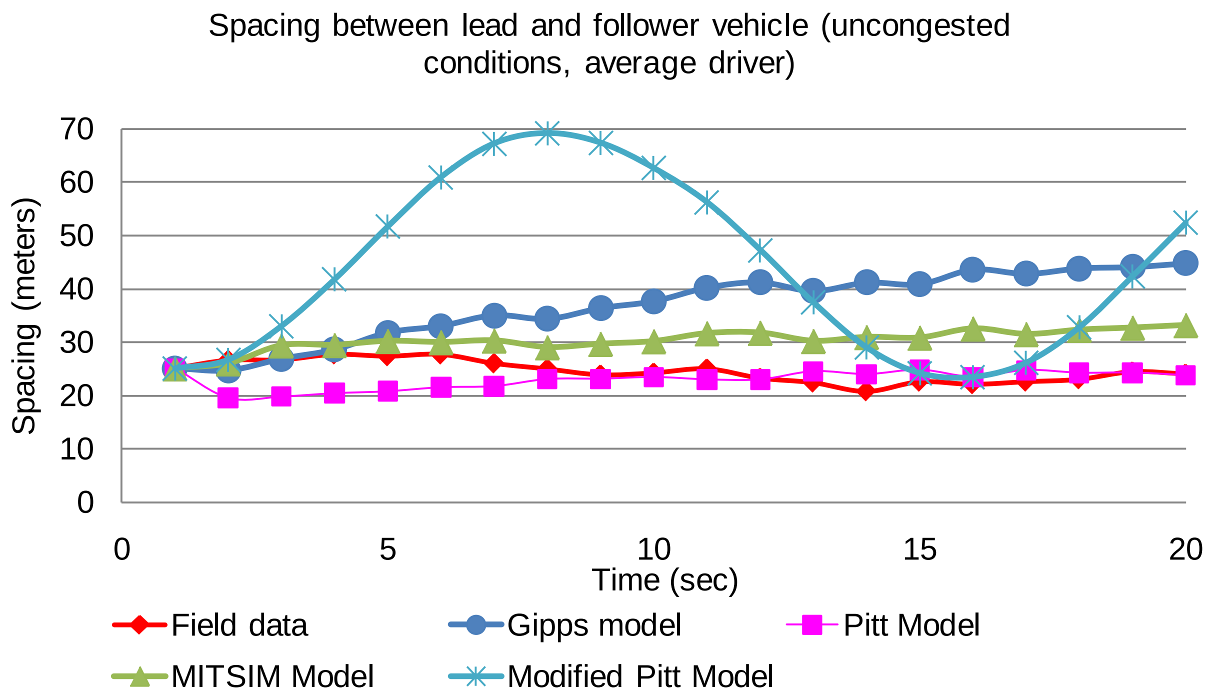

Figure 5-1. Spacing between lead and follower vehicle for each time interval (uncongested condition, subject 67)

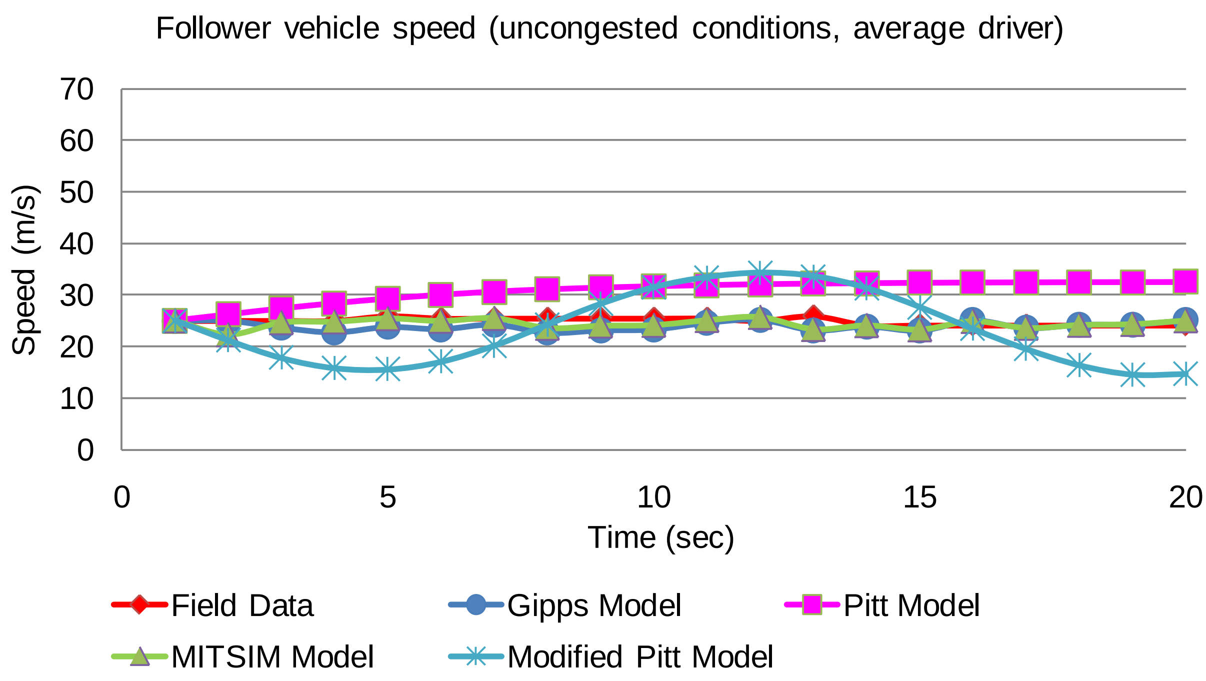

Figure 5-2. Follower vehicle speed for each time interval (uncongested condition, subject 67)

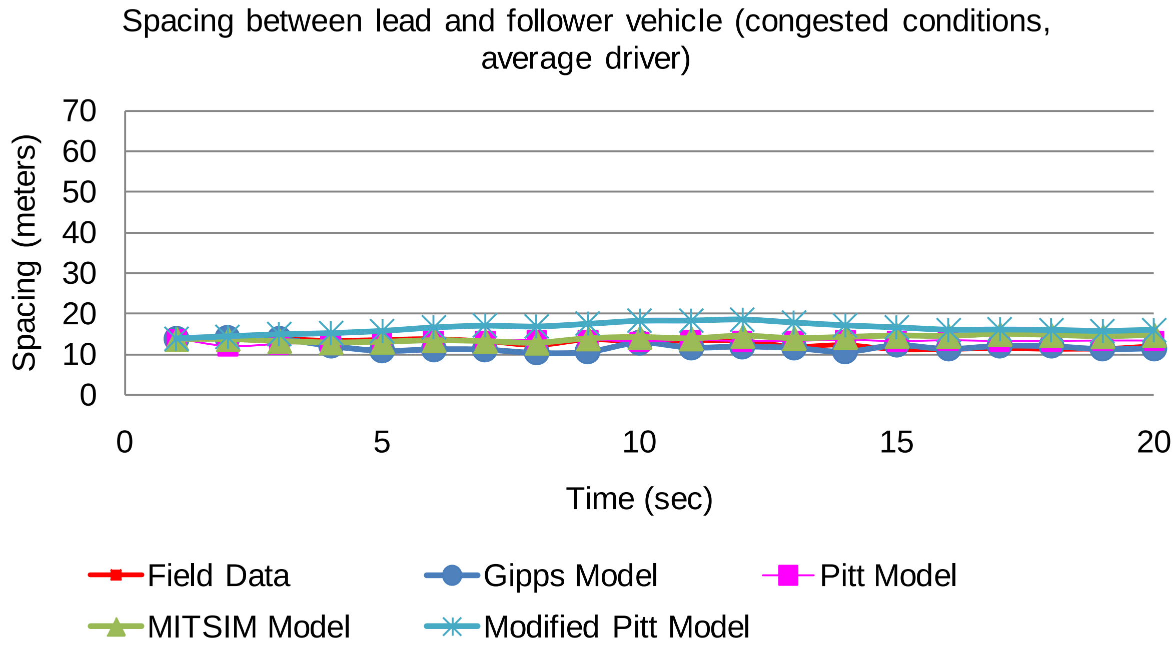

Figure 5-3. Spacing between lead and follower vehicle for each time interval (congested condition, subject 67)

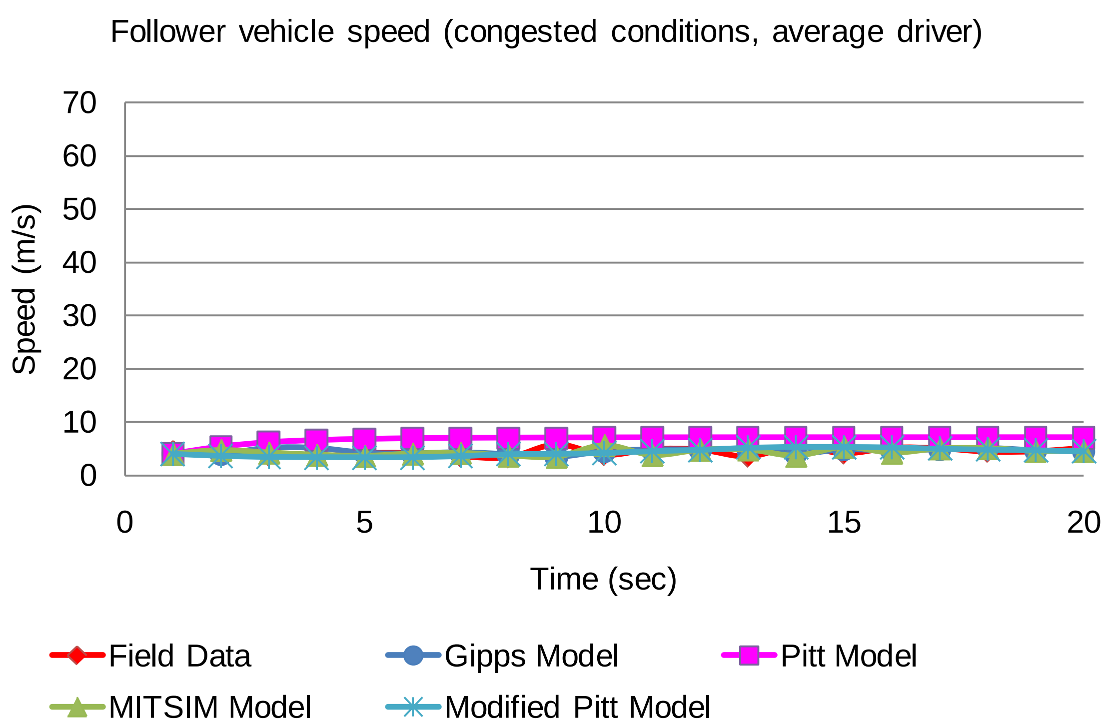

Figure 5-4. Follower vehicle speed for each time interval (congested condition, subject 67)

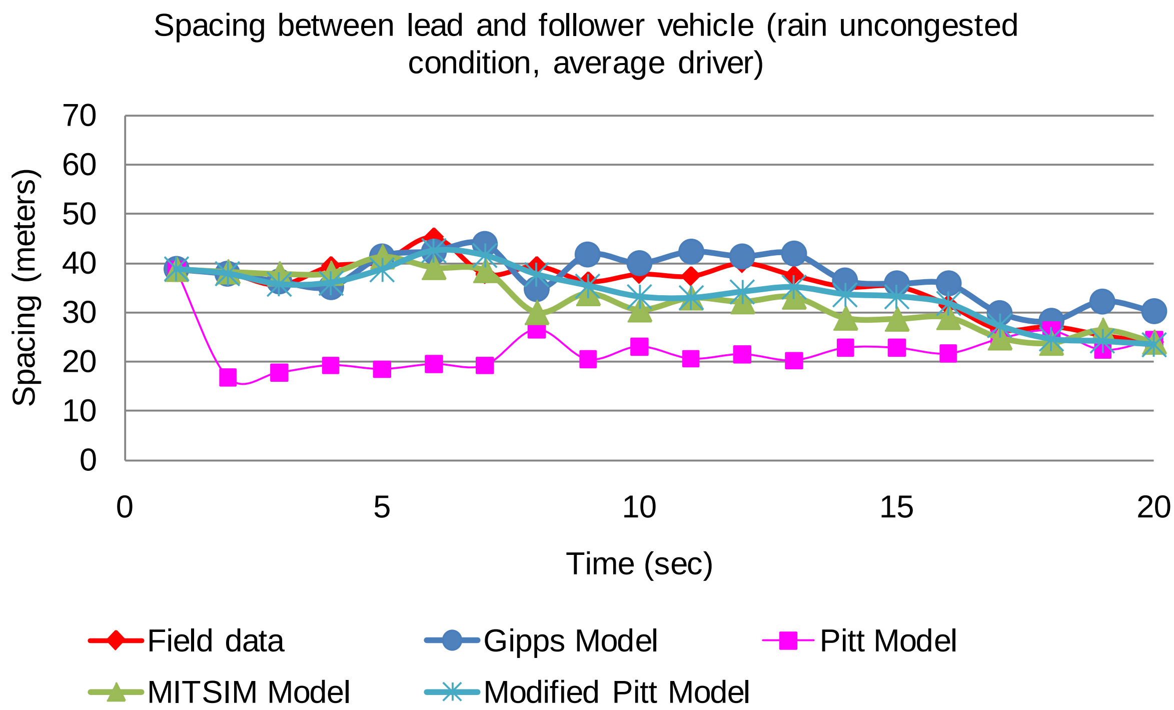

Figure 5-5. Spacing between lead and follower vehicle for each time interval (rain uncongested condition, subject 67)

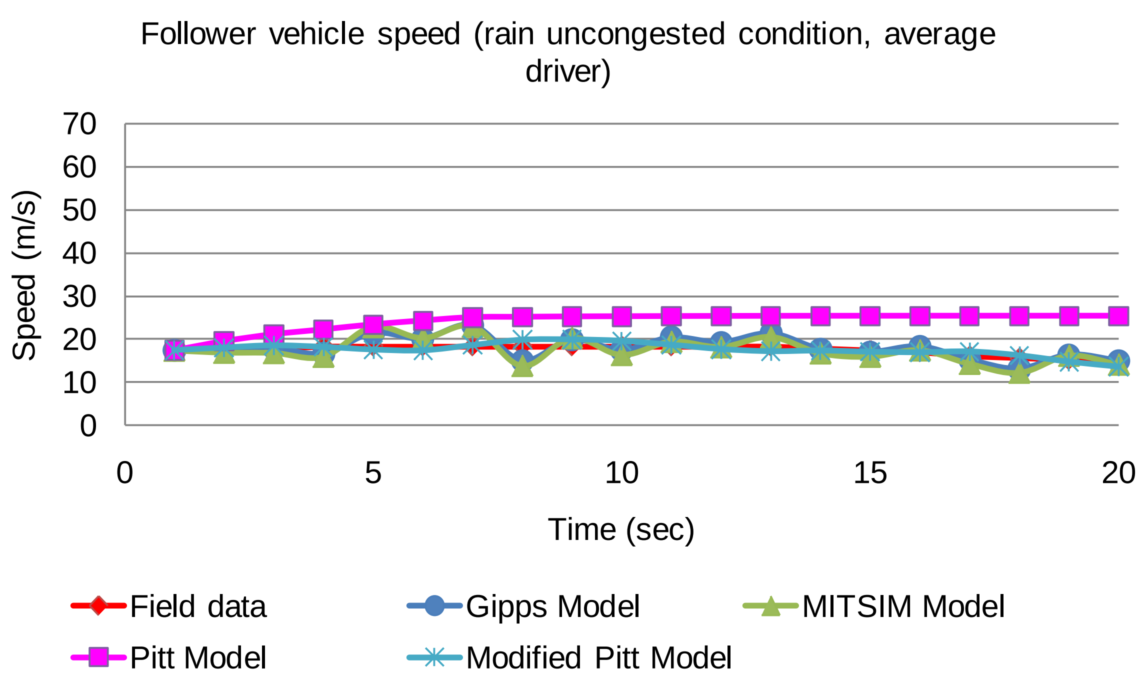

Figure 5-6. Follower vehicle speed for each time interval (rain uncongested condition, subject 67)

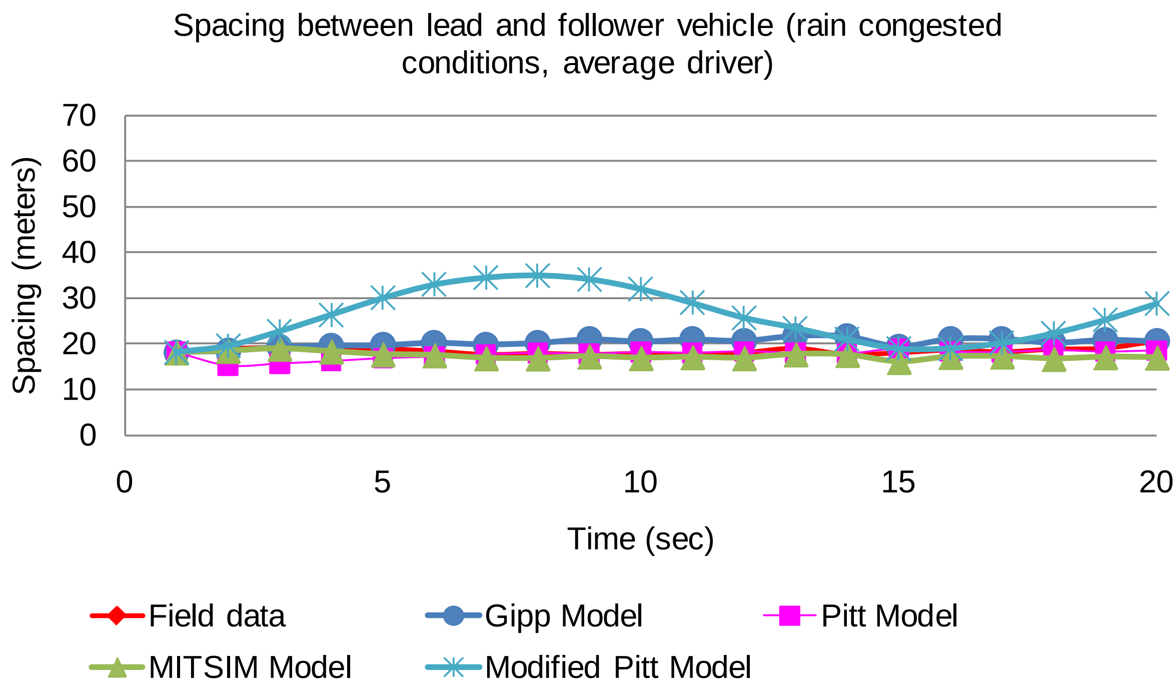

Figure 5-7. Spacing between lead and follower vehicle for each time interval (rain congested condition, subject 67)

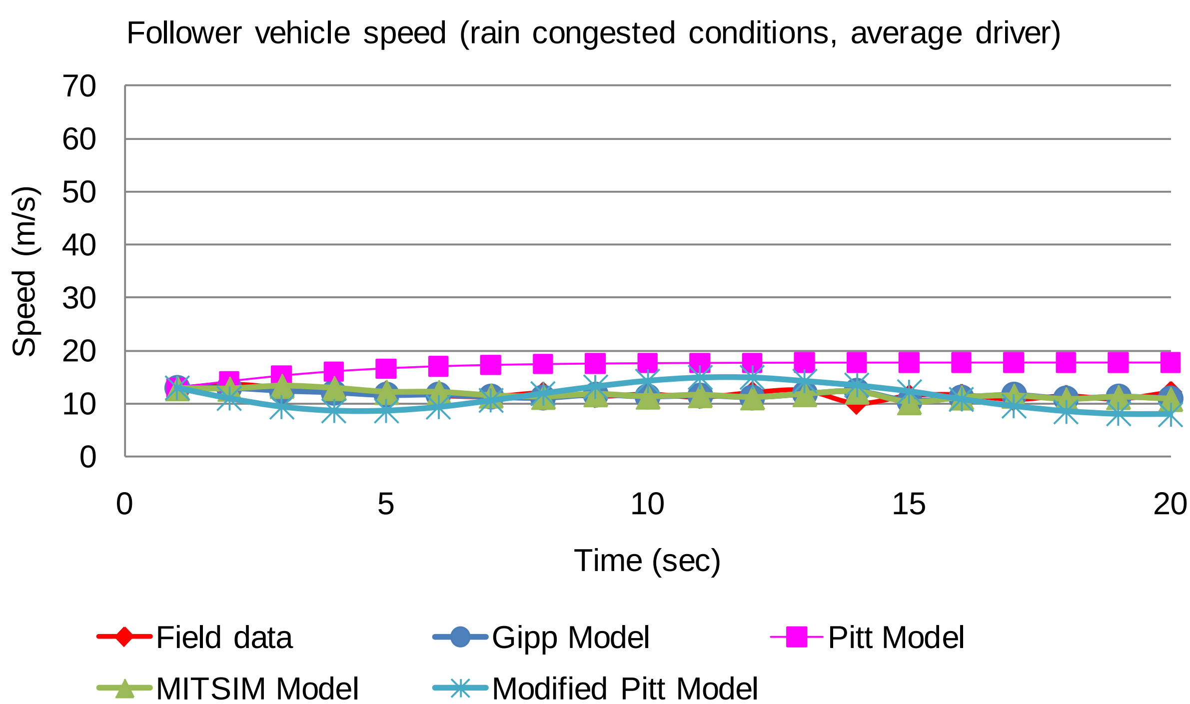

Figure 5-8. Follower vehicle speed for each time interval (rain congested condition, subject 67)

CHAPTER 6
CALIBRATION ANALYSIS

This chapter provides a calibration analysis for the parameters of each car-following model. Based on the initial analysis, calibration of the parameters for each model was conducted by minimizing the RMSE for speed and spacing differences. The optimization tool in a spreadsheet program was used to provide values of the parameters that minimize the RMSE value. As mentioned in Chapter 5 the closest to zero the value of RMSE is, the closest the results of the models will be to the field data.

The optimization tool in , called “solver” includes input locations to specify the solution or target cell location, and whether the goal is to maximize, minimize, or attain a specific value for this cell (Wraith and Or 1998). The location of the variable cell(s) (e.g. parameters in the models) whose value(s) may be altered to achieve the desired target cell (e.g. RMSE) goal is specified, and constraints may be imposed on any cells involved in the problem. Constraints (e.g. specified ranges for each parameter) take the form of a relationship among a variable, an arithmetic operator (≤, =, ≥, integer), and a constant. “solver” provides options to change the maximum time, maximum iterations, precision and tolerance of the iterative optimization. Wraith and Or (1998) indicated that for minimization a user may use a tangent or quadratic approach to obtain the local minimum of basic variables in each iteration.

This chapter is divided in five sections. First, each model was calibrated for each subject and each condition. Second, a calibration was performed using all the data. Third a calibration considering different traffic conditions was conducted. Fourth, a calibration considering different driver types was performed. The last section presents the summary of findings.

Parameter Calibration for Each Subject and Condition

Gipps Model

This section provides the parameter values after calibration using the optimization tool “solver” in a spreadsheet program. Using previous literature the ranges of constrains were defined.

Gipps (1981) suggested that a_n = N $(1.7{,}0.32)$ m/s^2

Based on this, to obtain a 99% confidence level a three standard deviation range was used:

a_n = $(1.7 \pm 3 \times 0.32) = (1.43, 1.97)$ m/s^2 $(3.20, 4.41)$ mi/hr-s

b_n = $-2 \times a_n$ m/s^2

Using the computed a_n ranges the b_n ranges are:

b_n = $-2 \times (1.43, 1.97) = (-2.86, -3.94)$ m/s^2 $(-6.40, -8.81)$ mi/hr-s

$\hat{b}$ = $(-3, \frac{(b_n - 3)}{2})$ m/s^2

Using the computed b_n ranges the $\hat{b}$ ranges are:

$\hat{b}$ = $(\frac{(-2.86-3)}{2}, \frac{(-3.94-3)}{2})$ = $(-2.93, -3.47)$ m/s^2 $(-6.55, -7.76)$ mi/hr-s

Other research papers have suggested different ranges for the Gipps car-following parameters. For the parameter a_n ,Wilson (2001) suggested a_n ≥ 0 m/s^2 (0 mi/hr-s); Panwai and Dia (2005) suggested a_n = 2.5 m/s^2 (5.59 mi/hr-s); May (1990) suggested acceleration rates values from 0.89 m/s^2 to 1.47 m/s^2 (2 mi/hr-s to 3.3 mi/hr-s); and Punzo and Simonelli (2005) suggested a_n = 3.331 m/s^2 (7.45 mi/hr-s), with a variance 4.189. However, Punzo and Simonelli (2005) suggested acceleration rates that were too high in comparison with the other papers. Therefore only the value of 3.331 m/s^2 (7.45

mi/hr-s) was considered in the final selected range. The final a_n range used for the optimization of the speed and spacing RSME are: a_n = [0,3.3] m/s2 [0,7.38] mi/hr-s

For the parameter, b_n , Punzo and Simonelli (2005) suggested b_n = –3.801 m/s^2 (–8.50 mi/hr-s), Panwai and Dia (2005) suggested b_n = –4.5 m/s^2 (-10.06 mi/hr-s), May (1990) suggested values from –1.47 m/s^2 to –2.36 m/s^2 (–3.3 mi/hr-s to –5.3 mi/hr-s), and Ranjitkar et al. (2005) suggested b_n = –3.47 m/s^2 (–7.76 mi/hr-s), with a standard deviation 0.49. Therefore the final range used for b_n are: b_n = [–5, –1.5] m/s2 [–11.18, –3.35] mi/hr-s

For the parameter, $\hat{b}$, Wilson (2001) suggested $\hat{b}$ ≥ 0 m/s^2 (0 mi/hr-s) in congested scenarios, Punzo and Simonelli (2005) suggested $\hat{b}$ = –4.783 m/s^2 (–10.69 mi/hr-s), with a variance 10.613, Panwai and Dia (2005) suggested $\hat{b}$ = 8 m/s^2 (17.89 mi/hr-s), and Ranjitkar et al. (2005) suggested $\hat{b}$ = –4.04 m/s^2 (–9.03 mi/hr-s), with a standard deviation 0.54. Therefore the final range for the $\hat{b}$ parameter used in the optimization is: $\hat{b}$ = [–8, –2] m/s2 [–17.9, –4.47] mi/hr-s

Tables 6-1 to 6-4 present the parameters values after calibration. After calibration for uncongested conditions $b_n \approx \hat{b}$, this is consistent with the findings from Rakha et al. (2007). They indicated that in uncongested conditions speed is insensitive to traffic flow and density and the speed-headway relationship will be linear, while the flow-density curve will be an inverted v-shape. The $b_n \geq \hat{b}$ behavior was not considered in this study. Wilson (2001) studied the Gipps car-following model and concluded that $b_n \geq \hat{b}$ behavior produced unrealistic solutions. He indicated $b_n \geq \hat{b}$ behavior produced multiple solutions inside the square root of the equation. Therefore given the unrealistic behavior for such behavior and that these are not recommended for simulation software this case was not consider in the study.

Results show that the Gipps model predicted speed more accurately. The RMSE for speed was lower than the RMSE for spacing. Both, in the initial analysis and after calibration Gipps was the second best model in predicting spacing. Table 6-1 to 6-4 presents RMSE values before and after calibration and the parameters values used for each driver in each condition. Consistent with the initial analysis the condition best predicted by the Gipps model was the rain congested condition. The highest value of RMSE was for uncongested conditions. In uncongested conditions drivers have more flexibility to increase and decrease their speed. Therefore their behavior in these conditions is difficult to replicate. In addition, the driver performance best predicted in the initial analysis and after calibration was for the average driver.

Pitt Model

This section provides the parameter values after calibration using the optimization tool “solver” in a spreadsheet program. Using previous literature the ranges of constrains were defined.

CORSIM default values for k (driver sensitivity parameter) vary from 0.35 to 1.25. The k value for aggressive driver value is 0.35 and for the conservative (timid) driver 1.25. Khoury and Hobeika (2006) suggest range from 0.3 to 1.6. The value of b (calibration constant) is 0.1 if the follower vehicle speed is higher than the lead vehicle, zero otherwise. The final intervals used for the optimization were for k from 0 to 2 and for b from 0 to 0.1. The ranges of k were increased more than the suggested ones based on an initial calibration performed by the researcher. In this initial calibration value of k from 0.3 to 1.6 were used. When calibrating the model the optimum value for k was 0.3 for some subjects. Therefore it was necessary to observed if increasing the ranges the optimization parameters values will stay the same as the initial calibration or will change to a new value.

Tables of RMSE results before and after calibration are included in Appendix C. When calibrating the Pitt model by spacing $b \approx 0$, and when calibrating it for speed $b \approx 0.10$, except for the subject 68 (average driver) which uses the same value of b for both calibrations. k calibrated by speed has a bigger value that the k calibrated by the spacing, in another words when calibrating the spacing the model is assuming a more aggressive driver. This behavior was consistent with values obtained for b parameter. When calibrating spacing b was close to zero, in other words the lead has a higher speed therefore the follower will accelerate or be more aggressive trying to reach their desired speed.

The initial analysis showed that the followers' speed was the best variable predicted by the Pitt model. After calibration the lowest values of RMSE were for the spacing variable. The Pitt model in the initial analysis and after calibration was the model with the highest RMSE for the followers speed. The RMSE for speed decreased from 97.15 to 94.27 but in comparison to the other models has the highest values of RMSE. The Pitt model in the initial analysis and after calibration was the second model predicting better the spacing between vehicles. The Pitt car-following model calculates the spacing variable thus it was expected that this variable was the best predicted

After calibration the Pitt model predicted better congested conditions. The worst condition predicted in the initial analysis and after calibration was the uncongested condition. In addition, after calibration the best driver replicated by Pitt was the aggressive and conservative driver. This result is consistent with the initial analysis.

MITSIM Model

This section provides the parameters values after calibration using the optimization tool “solver” in a spreadsheet program. Using previous literature the ranges of constrains were defined.

May and Keller (1967) suggested a $\beta^{\pm} = 0.8$ and $\gamma^{\pm} = 2.8$; Ozaki (1993) suggested a $\beta^{+} = 0.2$, $\gamma^{+} = -0.2$, $\beta^{-} = 0.9$, and $\gamma^{-} = 1$; Yang and Koutsopoulos (1996) suggested an initial $\beta^{\pm} = 0$ and a $\gamma^{\pm} = 1$, however they discussed that for an initial calibration these values can be used but they did not performed well. They concluded that the MITSIM parameters should be: $\alpha^{+} = 0.5$, $\beta^{+} = -1$, $\gamma^{+} = -1$, $\alpha^{-} = 1.25$, $\beta^{-} = 1$, and $\gamma^{-} = 1$

Olstam and Tapani (2004) suggested $\alpha^{+} = 2.15$, $\beta^{+} = -1.67$, $\gamma^{+} = -0.85$, $\alpha^{-} = 1.55$, $\beta^{-} = 1.08$, and $\gamma^{-} = 1.65$. In addition Punzo and Simonelli (2005) suggested $\alpha^{+} = 2.512$, variance 1.563, $\beta^{+} = 0.150$, variance 0.099, $\gamma^{+} = 0.509$, variance 0.324, $\alpha^{-} = -2.328$, variance 2.54, $\beta^{-} = 0.861$, variance 0.485, and $\gamma^{-} = 1.116$, variance 0.389.

Finally, the MITSIM car-following model parameters ranges used for optimizing the speed and spacing RSME were:

- $\alpha^{+} = [0.5, 4]$
- $\beta^{+} = [-2, -1]$
- $\gamma^{+} = [-1,3]$
- $\alpha^{-} = [-5, 2]$
- $\beta^{-} = [0,2]$
- $\gamma^{-} = [-1,3]$

Tables of RMSE before and after calibration are included in Appendix C. The MITSIM model is difficult to calibrate because of the larger number of parameters and degrees of freedom it has. MITSIM utilizes parameters that are not easily interpreted to known driver or vehicles factors and therefore hard to calibrate (Olstam and Tapani 2004). On the other hand, this amount of parameters and degrees of freedoms make possible the use in different traffic situations, and capable of reproducing the experimental data better than other models.

The MITSIM model predicts the speed variable more accurately. This result was observed also in the initial analysis. The RMSE for speed were lower than the RMSE for spacing. MITSIM in the initial analysis and after calibration was the model with the lowest value of RMSE for speed and spacing. For all conditions the values of RMSE for spacing and speed was minimized.

The MITSIM model predicts best congested conditions, and between the congested conditions rainy congested was the best predicted. The worst condition predicted in the initial analysis and after calibration for MITSIM was the uncongested. MITSIM initial analysis shows that overall it predicted better the spacing for average drivers and speed for aggressive drivers. After calibration overall the spacing and speed for aggressive drivers was the best driver type predicted by MITSIM. MITSIM overall was the best model replicating the field data after calibration. This can be explained by the numerous parameters that the model has providing a better fit to the field data.

Modified Pitt Model

This section provides the parameters values after calibration using the optimization tool “solver” in a spreadsheet program. Cohen (2002) suggested values of K from 0.5 to 1. However, the ranges of K were increased more than the suggested ones based on an initial calibration performed by the researcher. The final intervals used for the optimization were for K from 0 to 2, h from 0.5 s to 2 s, and L_l from 22 ft to 32 ft. (6.7 m to 9.76 m).

Tables of RMSE results before and after calibration are included in Appendix C. K calibrated by spacing has a bigger value that the K calibrated by the speed, in other words when calibrating the spacing the models is assuming a more sensitive driver. The Modified Pitt car-following model is sensitive to the K parameter. In the initial results the values of RMSE were the highest values, after calibrating this K parameter the values of RMSE were lower. K values are defined as a spring constant factor that oscillates depending on the desired FFS and the time to return to an equilibrium condition. Cohen (2002) recommended K values of 0.5 to 1; however this thesis shows that when calibrating this parameter for each driver in each condition the K values are much lower.

The Modified Pitt model predicted the variable speed more accurately. The Modified Pitt model in the initial analysis presented to be the one of the models with the highest value of RMSE for spacing and speed, this behavior was the same after calibration. The RMSE for spacing decreased from 342.14 to 128.11 but in comparison to the other models it has the highest values of RMSE.

In the initial analysis the best condition predicted by the model was the congested condition but after calibration the best was the rain congested condition. The highest RMSE values were for the uncongested condition, similar to the other models. In addition, after calibration the best driver replicated by Modified Pitt was the average driver.

Summary: Parameters Calibration for Each Model

Figure 6-1 to 6-8 provides comparison graphs of different conditions for the average driver. From this Figures and the results discussed above it can be concluded that all the models generally predicted more accurately the follower speed. Punzo and

Simonelli (2005) explained that speed deviations and spacing deviations from the field data have a different meaning. They explained that when a model is calibrated on the basis of speed, an error made by the model in calculating the speed between t-1 and t causes an error in the space traveled in the same interval. This is kept equal for all the followings instants where the variable of spacing will increase or decreased by this amount of error in the subsequent instants. They concluded that is easier to fit the models on the basis of speed measurements than the spacing.

Based on the calibrations analysis the preferred variable for calibrating the models was the spacing. Punzo and Simonelli (2005) explained, by calibration on the basis of speed, the values of error test calculated for spacing are higher. Calibrating the models for speed will imply a nonneglible error for spacing therefore they suggest spacing as the most reliable measurement of performance.

From the Figures 6-1 to 6-8 it can be concluded that comparing between conditions, all the models predicted better the congested conditions than the uncongested scenario. The MITSIM model was the best in predicting the different conditions. The Second best was the Gipps model, while Pitt was the third best. The Modified Pitt model was the most inaccurate of all four models for all conditions.

Comparing the models by driver type, Pitt predicted overall more accurately the spacing and MITSIM the speed of conservative and aggressive drivers. MITSIM was the best model predicting average driver behavior.

Calibration for Each Model using All Data

Calibration was completed using the “solver” tool in a spreadsheet program. After the optimum calibration process describe in the previous section the researcher concluded that the error tests when calibrating the spacing are better that when calibrating the speed. This result is consistent with previous studies that explained that when calibrating the speed error test for the spacing variable are more sensitive and higher than the optimum ones. When calibrating the spacing or both error test are minimize or the change in error test is not considerably higher that the initial analysis. Therefore the calibration using all the field data for each model was done minimizing the sum of the RMSE for spacing. The target cell to minimize was the sum of the spacing RMSE for all drivers in all conditions. The parameter constrains (ranges of values) were the same as those used in the previous section. Results of parameters values for each model and RMSE values before and after calibration are presented in Tables 6-7 to 6-28.

The best models overall in this analysis predicting the field data were the Pitt model for spacing values and the MITSIM model for speed values. Comparing the models by traffic condition, every model fit differently the conditions, however the best condition predicted by all the models was the rain congested condition. Overall for both rainy conditions (congested and uncongested) MITSIM was the best model in predicting the speed and spacing. For the congested condition Gipps predicted a more accurately results and for the uncongested condition Pitt predicted a better spacing and MITSIM a better follower speed. Comparing the models by driver type, for conservative and aggressive drivers, the Pitt model predicted a better spacing and MITSIM a better speed. In addition, MITSIM was the best model predicting average driver.

Calibration by Condition

Calibration by traffic condition was completed using the “solver” tool in a spreadsheet program. The target cell to minimize was the sum of the spacing RMSE for all drivers in each conditions for each model (e.g. RMSE for each condition for each model was calculated and optimize; the different traffic conditions were consider one at the time). The parameter constrains (ranges of values) were the same used as those in the previous section. Results of parameters values for each traffic condition of each model and RMSE values before and after calibration are presented in Tables 6-29 to 6-52.

The Gipps model results shows that three of the fourth conditions used the same maximum acceleration, only the congested condition has a different value. In addition, the absolute values of the deceleration were bigger in the uncongested conditions than the congested. This can be explained based on the interaction of the vehicles in these conditions. In uncongested scenarios the vehicles are farther apart and traveling in high speed so the deceleration in case of emergency or sudden stop of the leader results in higher deceleration rate.

The Pitt model results shows that the values of the sensitivity parameter, k, are a higher value in rain uncongested conditions assuming that the drivers are more conservative in this conditions and more aggressive in the congested conditions. For the Modified Pitt model the K values for the congested conditions are higher than the uncongested. This behavior can be explained in the existence of a higher sensitivity in congested conditions than the uncongested scenarios. Overall the models predicting more accurately the field data were MITSIM for the spacing variable and Gipps for the speed variable.

Comparing the models by traffic condition, it was found that every model fit differently the conditions. However the best condition predicted by all the models was the rain congested condition. For congested conditions Gipps predicted better both variables. For rain uncongested MITSIM was the best model, however for rain congested conditions MITSIM predicted a better spacing and Modified Pitt a more accurate speed. For the uncongested conditions Pitt predicted a better spacing and Gipps a more accurately follower speed.

Comparing the models by driver type, for conservative drivers, the Pitt model predicted an accurately spacing but Modified Pitt a better follower speed. For aggressive drivers, MITSIM was the best model replicating the driver behavior, and for average driver the Gipps model was best for all conditions.

Calibration by Driver Type

Calibration by driver type was completed using the “solver” tool in a spreadsheet program. The target cell to minimize was the sum of the spacing RMSE for each driver type in all conditions for each model (e.g. RMSE for each driver type for each condition and model was calculated and optimize, the different driver types were consider one at the time). The parameter constrains (ranges of values) were the same used as those in the previous section. Results of the parameters values for each driver type in each model and RMSE values before and after calibration are presented in Tables 6-53 to 6-76.

Gipps results shows that the values of the maximum acceleration were similar for all the drivers, however the deceleration rates were higher for the extreme drivers (conservatives and aggressive) than the average drivers. For the Pitt model results shows that k parameters values for conservative and aggressive drivers are lower than the average drivers. In addition, the Pitt model for this analysis was providing unrealistic results for conservative drivers in rain congested conditions.

The parameters of K for the Modified Pitt model were also higher for the average drivers and lower for conservative and aggressive drivers. The values of time headway, h, and length of the vehicle plus a buffer, L_l, are lower for aggressive drivers. Aggressive drivers tend to be closer to the lead vehicle therefore this result was expected. Overall the model that performed the best in this analysis was the MITSIM model for both variables.

Comparing the models by condition, every model fit differently the conditions. For congested, and rain congested conditions Gipps predicted an accurate spacing and speed. However, for rain uncongested conditions Pitt were the best predicting the spacing and Gipps the speed. The uncongested conditions Pitt predicted a better spacing and MITSIM a more accurate speed.

Comparing the models by driver type, for conservative and aggressive drivers, Pitt predicted a better spacing and MITSIM a better speed. For average driver Gipps predicted more accurate results for both variables.

Summary of Findings

Calibration is needed for all the models to fit the data accurately. All the models performed better when the parameters where calibrated. MITSIM was the best to fit the field data, and this is caused by the number of parameters that the model has. The MITSIM model predicted the field data more accurately when it was calibrated by driver type. The Pitt model also performed best if the calibration was by driver type. On the other hand, the Modified Pitt model fit the data more accurately if the calibration was by condition. The Gipps model was the only model that performed accurately if calibrated by condition or by driver type. The highest values of RMSE for all the models were when calibrating them using all the data.

Three of the four conditions were better predicted if the calibration was done by traffic conditions. The congested condition was better predicted using Gipps and if calibrated by condition. Rain uncongested and rain congested conditions were better predicted by MITSIM using the calibration by condition. However the uncongested conditions were better predicted by Pitt (spacing) and MITSIM (speed) using the calibration by driver type.

For conservative drivers and aggressive drivers the calibration by driver type provided more accurate results. The models that predicted a better trajectory for the conservative and aggressive driver were Pitt for spacing and MITSIM for the follower speed.

For average drivers Gipps was the best model predicting their behavior when calibrating by driver and/or by condition. The values of RMSE for both calibrations (driver and condition) using the Gipps model were very similar therefore either one can be used.

The Pitt and Gipps models were more accurate when the calibration was done by driver type. The Modified Pitt was best if calibrated by condition. Only the Gipps model showed accurate results if it was calibrated by driver type or by condition. However when calibrating Gipps by condition the results for the speed variable were more accurate and when calibrated by driver type the results for the spacing variable were better. The differences between the calibrations for the Gipps model were very similar, so either calibration works for Gipps.

Overall the calibration by driver type using the MISTIM model was the best and the highest values of RMSE was for the calibration by model.

Table 6-1. Gipps car-following calibration parameters for uncongested conditions

Subject number	Calibration	Parameters a_n 2.00	b_n -3.00	$\hat{b}$ -3.50	RMSE values: Spacing, Initial analysis	Spacing, After calibration	Speed, Initial analysis	Speed, After calibration
52	Spacing	3.30	-5.00	-5.00	24.66	10.25	1.75	1.02
	Speed	3.30	-2.00	-2.00		10.73		1.00
72	Spacing	3.30	-3.31	-3.31	42.79	18.24	2.78	1.40
	Speed	3.30	-2.00	-2.00				
67	Spacing	3.30	-2.00	-2.00	16.42	5.04	1.45	1.22
	Speed	3.30	-5.00	-5.00		5.88		1.21
68	Spacing	2.00	-2.49	-2.49	8.29	2.62	1.17	0.80
	Speed	1.06	-3.62	-3.62		3.01		0.64
66	Spacing	3.30	-5.00	-5.03	13.55	3.98	1.69	1.38
	Speed	1.19	-5.00	-5.21		6.73		1.05
50	Spacing	3.30	-4.56	-4.56	45.92	18.69	6.42	5.94
	Speed	3.30	-4.56	-4.56				

Table 6-2. Gipps car-following calibration parameters for congested conditions

Subject number	Calibration	Parameters a_n 2.00	b_n -3.00	$\hat{b}$ -3.50	RMSE values: Spacing, Initial analysis	Spacing, After calibration	Speed, Initial analysis	Speed, After calibration
72	Spacing	2.97	-2.00	-2.00	2.20	1.34	1.19	1.05
	Speed	2.87	-2.00	-2.00		1.34		1.05
67	Spacing	3.30	-2.68	-8.00	2.88	1.93	0.72	0.55
	Speed	1.55	-1.58	-8.00				
68	Spacing	2.46	-2.72	-2.85	1.60	1.26	0.90	0.88
	Speed	1.69	-2.00	-2.00		1.34		0.84
66	Spacing	3.12	-2.00	-2.00	3.73	1.71	1.14	1.04
	Speed	0.83	-2.00	-2.00		2.99		0.78
50	Spacing	0.34	-1.50	-2.21	Not working for default values*	23.09	Not working for default values*	2.04
	Speed	0.33	-1.50	-3.92		6.62		0.92

*Using the default values the results were unrealistic.

Table 6-3. Gipps car-following calibration parameters for rain uncongested conditions

Subject number	Calibration	Parameters			RMSE values			
		a_n	b_n	$\hat{b}$	Spacing		Speed	
		2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	Spacing	3.30	-5.00	-5.00	20.60	10.34	2.17	1.77
	Speed	2.00	-1.50	-2.50		49.80		3.43
67	Spacing	1.30	-3.66	-3.66	5.49	3.67	2.69	2.97
	Speed	1.74	-4.46	-8.00		22.15		2.47
68	Spacing	2.80	-5.00	-5.03	11.80	2.64	1.54	1.16
	Speed	1.27	-5.00	-5.00		4.36		0.88
50	Spacing	3.30	-2.00	-2.00	20.81	8.58	1.71	4.94
	Speed	2.65	-2.00	-2.00		8.91		4.94

Table 6-4. Gipps car-following calibration parameters for rain congested conditions

Subject number	Calibration	Parameters			RMSE values			
		a_n	b_n	$\hat{b}$	Spacing		Speed	
		2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	Spacing	2.50	-2.00	-2.00	3.80	2.58	0.79	0.84
	Speed	0.33	-3.13	-3.13		3.59		0.48
67	Spacing	2.00	-1.94	-2.00	2.17	0.81	0.45	0.49
	Speed	2.00	-5.00	-5.71		1.32		0.40
68	Spacing	2.00	-5.00	-5.00	2.99	1.58	0.62	0.60
	Speed	2.00	-4.81	-5.20		2.01		0.59
50	Spacing	3.30	-2.00	-2.00	3.32	1.47	0.78	0.79
	Speed	2.20	-2.09	-2.33		2.99		0.75

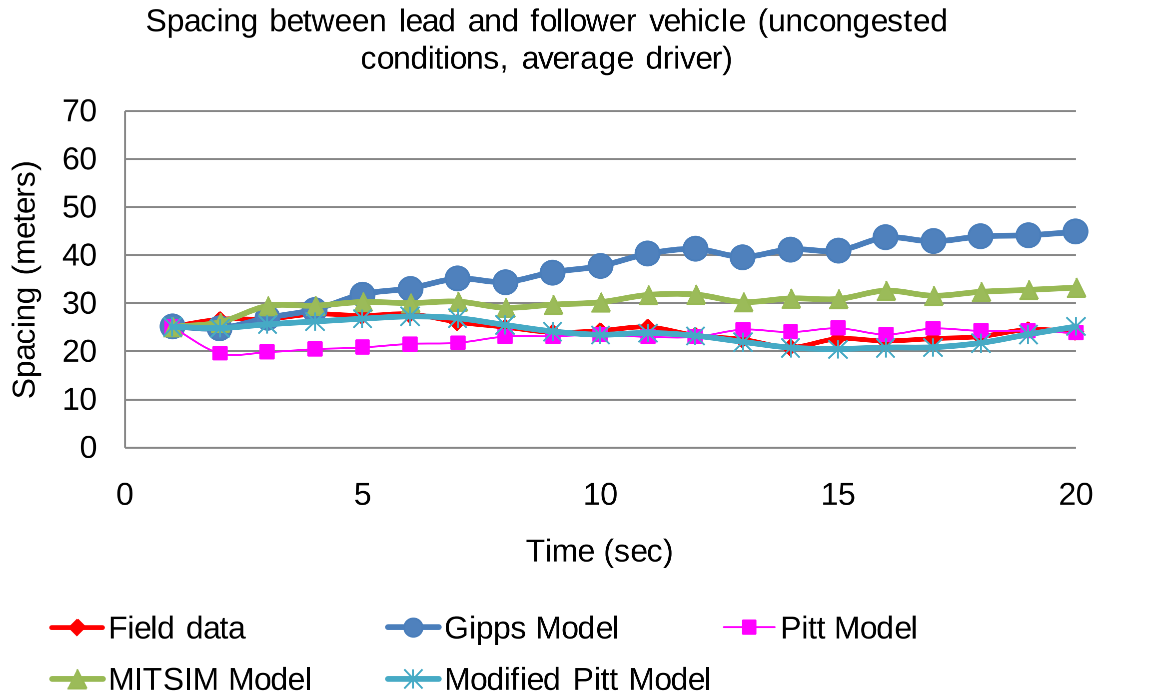

Figure 6-9. After spacing calibration - Spacing between lead and follower vehicle for each time interval (uncongested condition, subject 67)

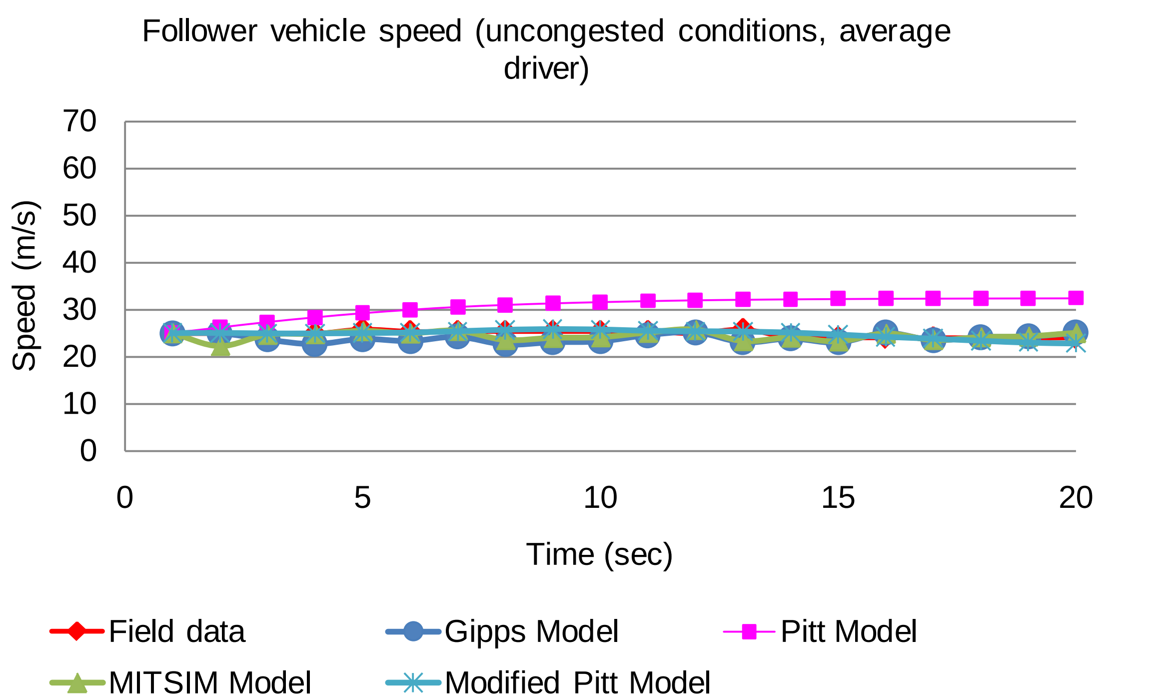

Figure 6-10. After spacing calibration - Follower vehicle speed for each time interval (uncongested condition, subject 67)

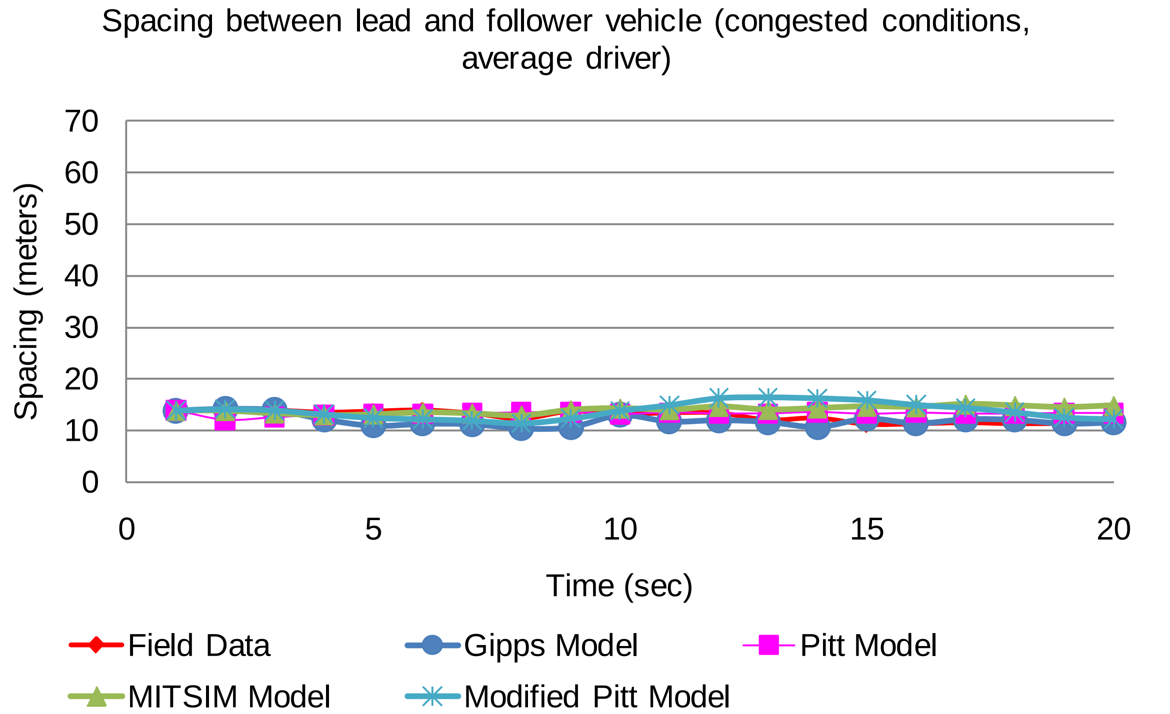

Figure 6-11. After spacing calibration - Spacing between lead and follower vehicle for each time interval (congested condition, subject 67)

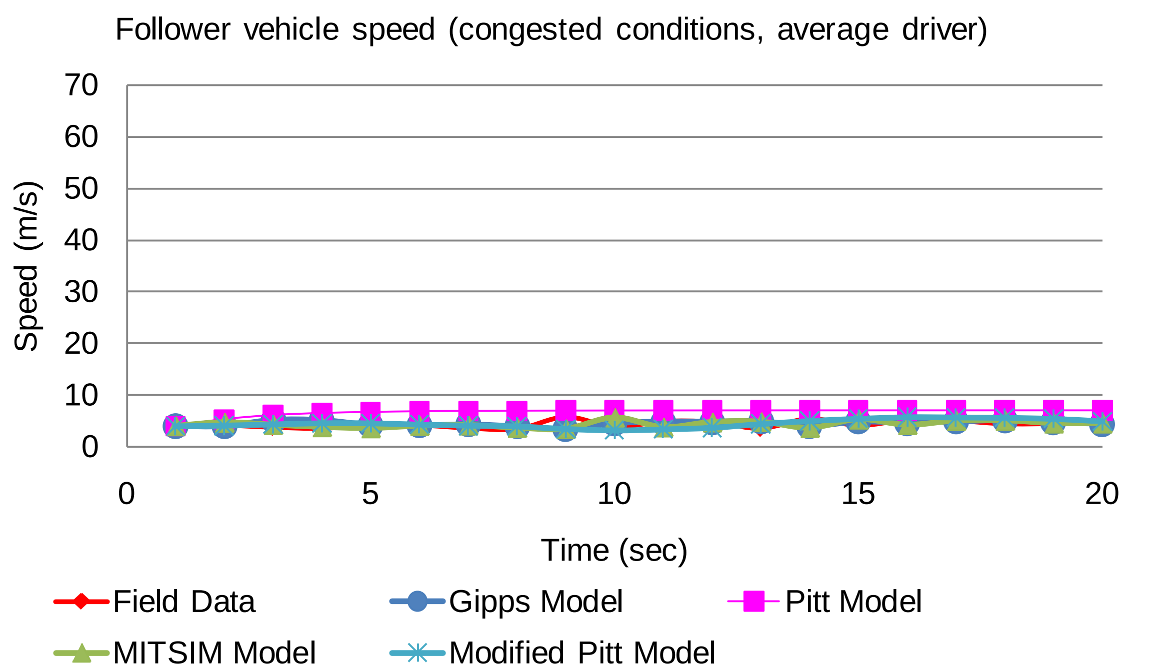

Figure 6-12. After spacing calibration - Follower vehicle speed for each time interval (congested condition, subject 67)

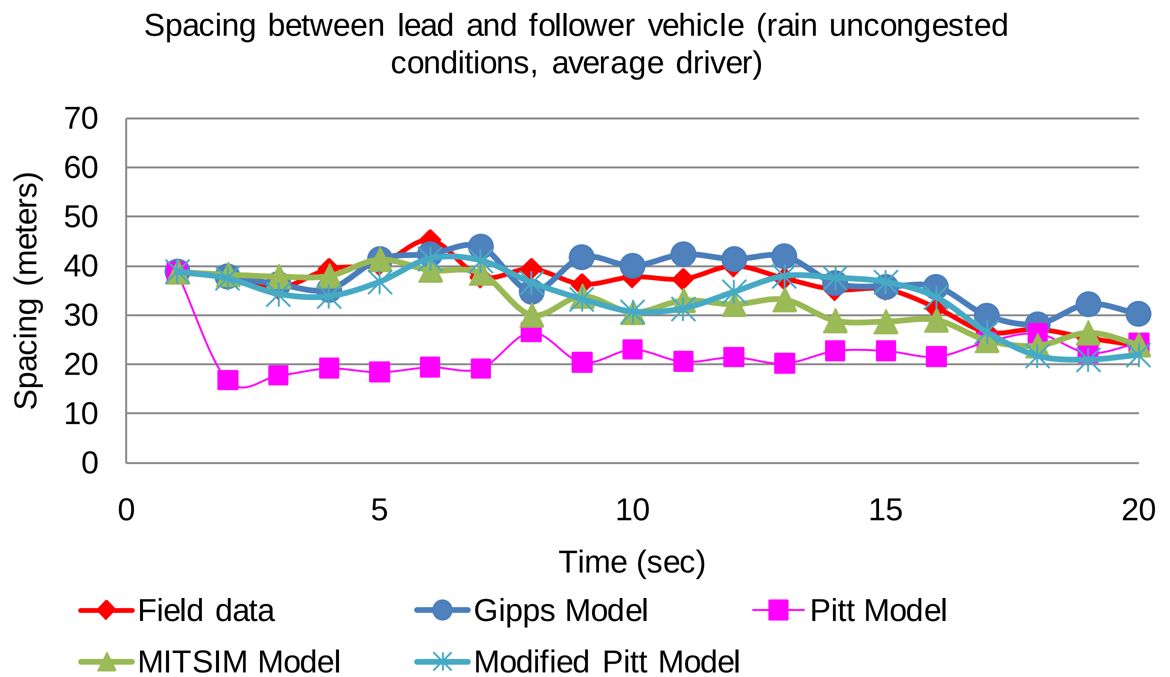

Figure 6-13. After spacing calibration - Spacing between lead and follower vehicle for each time interval (rain uncongested condition, subject 67)

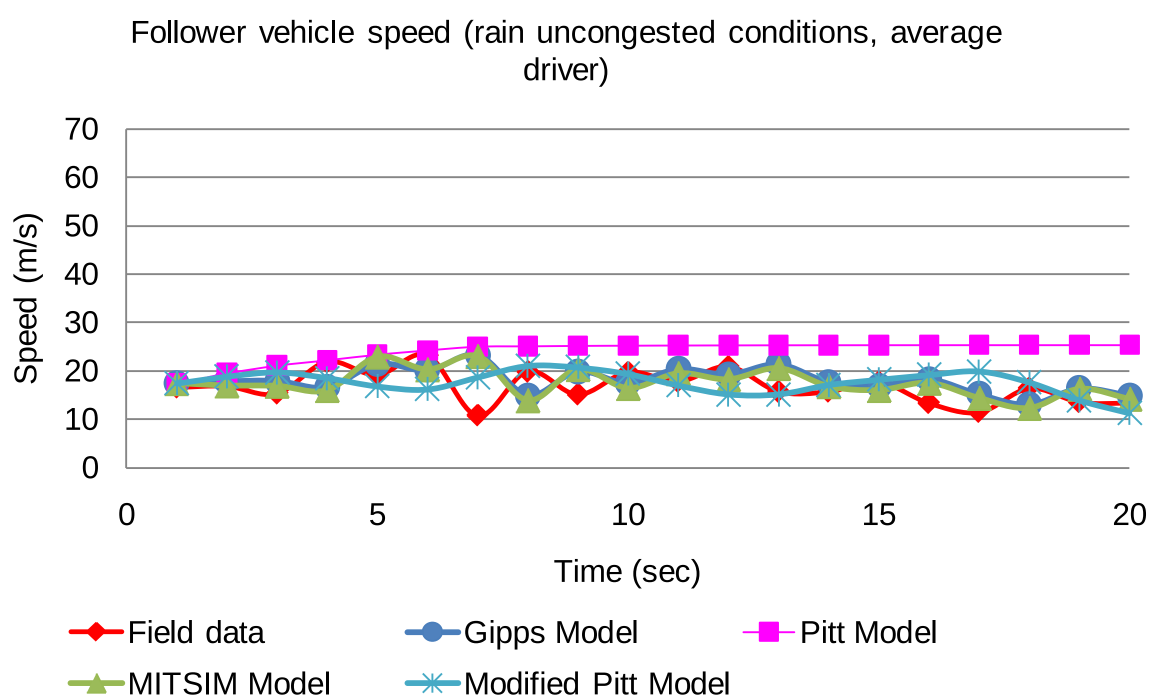

Figure 6-14. After spacing calibration - Follower vehicle speed for each time interval (rain uncongested condition, subject 67)

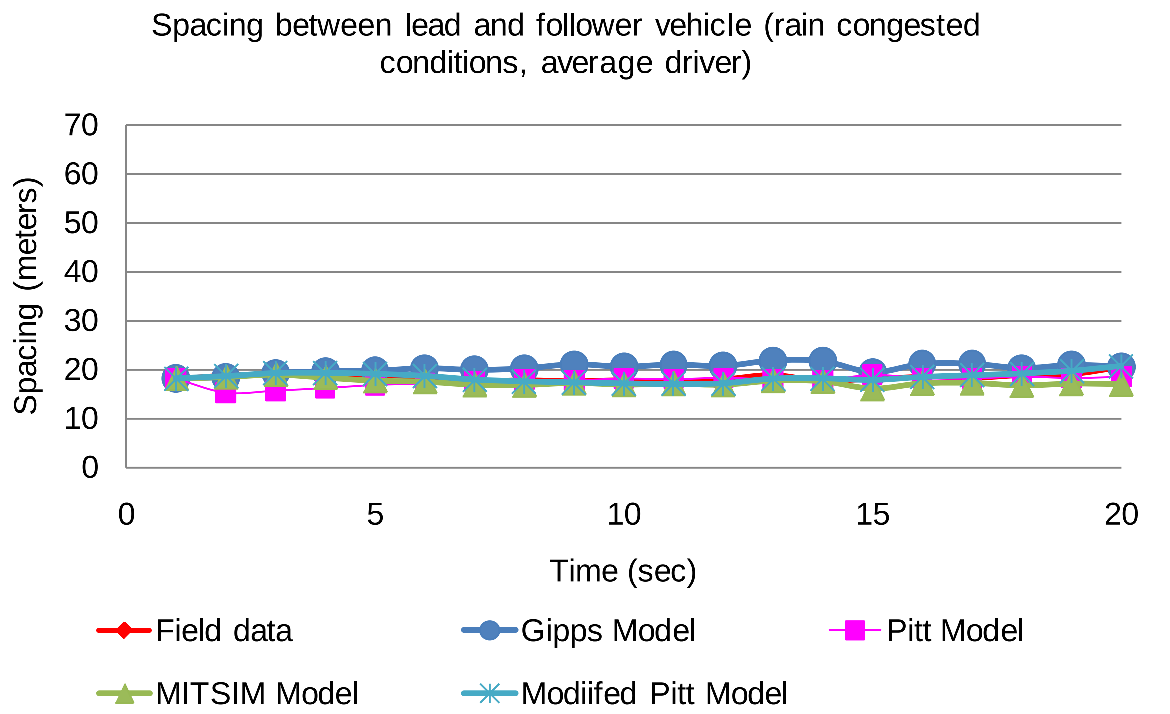

Figure 6-15. After spacing calibration - Spacing between lead and follower vehicle for each time interval (rain congested condition, subject 67)

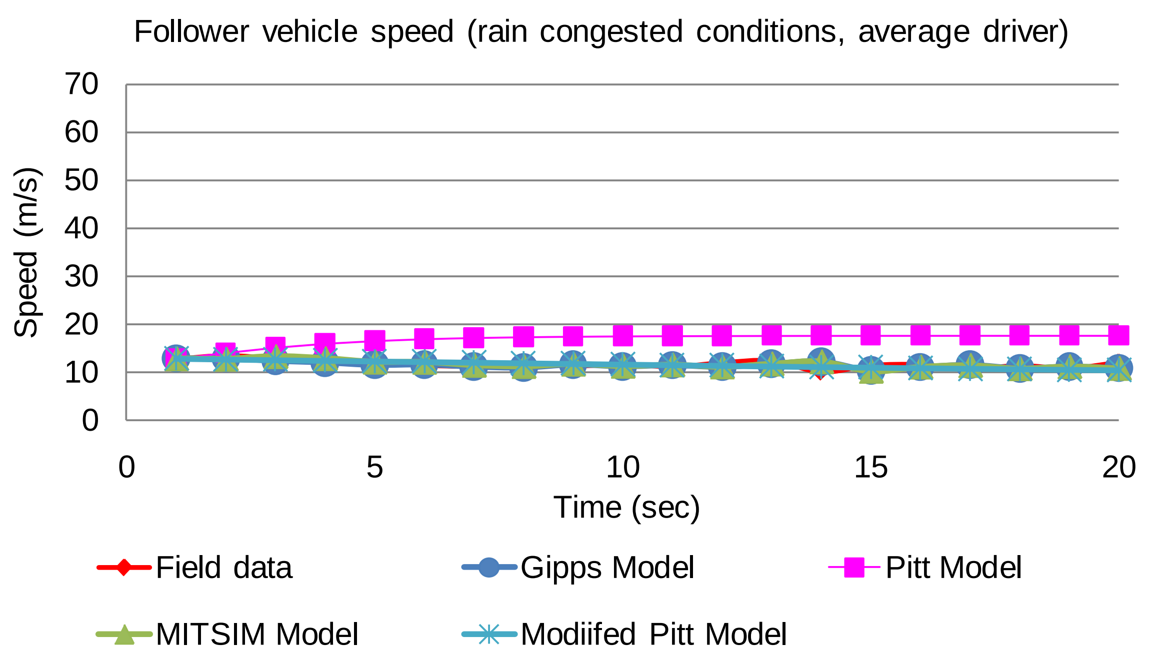

Figure 6-16. After spacing calibration - Follower vehicle speed for each time interval (rain congested condition, subject 67)

Table 6-5. Calibration using all data - Gipps car-following model for uncongested conditions

Subject number	Parameters			RMSE values			
	a_n	b_n	$\hat{b}$	Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	3.30	-3.40	-3.40	24.66	10.53	1.75	1.01
72	3.30	-3.40	-3.40	42.79	18.25	2.78	1.41
67	3.30	-3.40	-3.40	16.42	5.63	1.45	1.22
68	3.30	-3.40	-3.40	8.29	4.06	1.17	0.97
66	3.30	-3.40	-3.40	13.55	5.00	1.69	1.54
50	3.30	-3.40	-3.40	45.92	19.68	6.42	5.94
			Total Condition	151.63	63.15	15.25	12.09

Table 6-6. Calibration using all data - Gipps car-following model for congested conditions

Subject number	Parameters			RMSE values			
	a_n	b_n	$\hat{b}$	Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
72	3.30	-3.40	-3.40	2.20	1.43	1.19	1.10
67	3.30	-3.40	-3.40	2.88	3.33	0.72	0.83
68	3.30	-3.40	-3.40	1.60	1.32	0.90	0.89
66	3.30	-3.40	-3.40	3.73	2.08	1.14	1.22
50	3.30	-3.40	-3.40	Not working*		Not working*	
* Using the default values the results were not valid			Total condition	10.41	8.16	3.95	4.03

Table 6-7. Calibration using all data - Gipps car-following model for rain uncongested conditions

Subject number	Parameters			RMSE values			
	a_n	b_n	$\hat{b}$	Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	3.30	-3.40	-3.40	20.60	11.28	2.17	1.76
67	3.30	-3.40	-3.40	5.49	5.35	2.69	2.87
68	3.30	-3.40	-3.40	11.80	2.78	1.54	1.28
50	3.30	-3.40	-3.40	20.81	10.31	1.71	1.20
			Total condition	58.70	29.72	8.11	7.12

Table 6-8. Calibration using all data - Gipps car-following model for rain congested conditions

Subject number	Parameters			RMSE values			
	a_n	b_n	$\hat{b}$	Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	3.30	-3.40	-3.40	3.80	2.62	0.79	0.87
67	3.30	-3.40	-3.40	2.17	1.01	0.45	0.48
68	3.30	-3.40	-3.40	2.99	1.60	0.62	0.61
50	3.30	-3.40	-3.40	3.32	1.81	0.78	0.80
			Total condition	12.28	7.04	2.64	2.77

Table 6-9. Calibration using all data – Results by driver type Gipps car-following model

Driver type	RMSE values Spacing		Speed	
	Initial analysis	After calibration	Initial analysis	After calibration
Aggressive	94.05	44.11	8.67	6.15
Average	51.63	25.07	9.78	9.16
Conservative	87.34	38.88	11.74	10.70

Table 6-10. Calibration using all data – Total RMSE results for the Gipps car-following model

Overall RMSE			
RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
233.02	29.95	108.07	26.01

Table 6-11. Calibration using all data - Pitt car-following model for uncongested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.45	4.02	3.06	10.15	10.05
72	0.00	0.45	2.54	3.13	4.88	4.62
67	0.00	0.45	3.96	3.04	6.99	6.76
68	0.00	0.45	15.93	14.42	5.76	5.53
66	0.00	0.45	17.25	15.69	4.36	4.45
50	0.00	0.45	2.94	1.49	2.77	2.76
		Total condition	46.64	40.83	34.91	34.17

Table 6-12. Calibration using all data - Pitt car-following model for congested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
72	0.00	0.45	9.18	6.17	10.36	10.25
67	0.00	0.45	2.91	2.78	2.34	2.25
68	0.00	0.45	3.73	3.73	3.48	3.46
66	0.00	0.45	3.41	3.31	1.68	1.69
50	0.00	0.45	2.19	2.40	1.25	1.27
		Total condition	21.42	18.39	19.11	18.91

Table 6-13. Calibration using all data - Pitt car-following model for rain uncongested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.45	8.51	6.17	11.08	11.25
67	0.00	0.45	13.52	12.72	9.46	9.85
68	0.00	0.45	14.98	13.74	6.98	6.83
50	0.00	0.45	Not working*		Not working*	
		Total condition	37.01	32.62	27.52	27.92

* Using the default values the results were unrealistic

Table 6-14. Calibration using all data - Pitt car-following model for rain congested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.45	4.06	4.03	5.36	5.26
67	0.00	0.45	1.52	1.06	5.61	5.46
68	0.00	0.45	1.22	1.50	2.74	2.54
50	0.00	0.45	2.69	2.96	1.89	1.89
		Total condition	9.49	9.55	15.61	15.16

Table 6-15. Calibration using all data – Results by driver type Pitt car-following model

	RMSE values			
	Spacing		Speed	
Driver type	Initial analysis	After calibration	Initial analysis	After calibration
Aggressive	28.31	22.55	41.83	41.43
Average	57.78	52.98	43.36	42.68
Conservative	28.48	25.86	10.28	10.37

Table 6-16. Calibration using all data – Total RMSE results for the Pitt car-following model

Overall RMSE			
RMSE Total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
114.57	97.15	101.39	96.16

Table 6-17. Calibration using all data - MITSIM car-following model for uncongested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.50	-1.00	-1.00	1.25	1.00	1.00	9.17	9.17	1.05	1.05
72	0.50	-1.00	-1.00	1.25	1.00	1.00	12.21	12.21	1.20	1.20
67	0.50	-1.00	-1.00	1.25	1.00	1.00	6.83	6.83	1.09	1.09
68	0.50	-1.00	-1.00	1.25	1.00	1.00	6.18	6.18	1.88	1.88
66	0.50	-1.00	-1.00	1.25	1.00	1.00	6.44	6.44	2.10	2.10
50	0.50	-1.00	-1.00	1.25	1.00	1.00	14.66	14.66	1.51	1.51
						Total condition	55.50	55.50	8.84	8.84

Table 6-18. Calibration using all data - MITSIM car-following model for congested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
72	0.50	-1.00	-1.00	1.25	1.00	1.00	4.62	4.62	1.19	1.19
67	0.50	-1.00	-1.00	1.25	1.00	1.00	4.71	4.71	0.82	0.82
68	0.50	-1.00	-1.00	1.25	1.00	1.00	3.54	3.54	0.87	0.87
66	0.50	-1.00	-1.00	1.25	1.00	1.00	1.67	1.67	0.95	0.95
50	0.50	-1.00	-1.00	1.25	1.00	1.00	6.77	6.77	1.03	1.03
						Total condition	21.30	21.30	4.86	4.86

Table 6-19. Calibration using all data - MITSIM car-following model for rain uncongested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.50	-1.00	-1.00	1.25	1.00	1.00	10.47	10.47	1.61	1.61
67	0.50	-1.00	-1.00	1.25	1.00	1.00	4.98	4.98	2.83	2.83
68	0.50	-1.00	-1.00	1.25	1.00	1.00	4.62	4.62	1.79	1.79
50	0.50	-1.00	-1.00	1.25	1.00	1.00	7.14	7.14	1.09	1.09
						Total condition	27.21	27.21	7.32	7.32

Table 6-20. Calibration using all data - MITSIM car-following model for rain congested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.50	-1.00	-1.00	1.25	1.00	1.00	2.21	2.21	0.93	0.93
67	0.50	-1.00	-1.00	1.25	1.00	1.00	1.34	1.34	0.46	0.46
68	0.50	-1.00	-1.00	1.25	1.00	1.00	1.28	1.28	0.62	0.62
50	0.50	-1.00	-1.00	1.25	1.00	1.00	2.85	2.85	0.83	0.83
						Total condition	7.70	7.70	2.83	2.83

Table 6-21. Calibration using all data – Results by driver type MITSIM car-following model

Driver type	RMSE values Spacing Initial analysis	 After calibration	 Speed Initial analysis	 After calibration
Aggressive	38.69	38.69	5.98	5.98
Average	33.49	33.49	10.35	10.35
Conservative	39.53	39.53	6.56	6.56

Table 6-22. Calibration using all data – Total RMSE results for the MITSIM car-following model

Overall RMSE RMSE total initial		 RMSE total after calibration	
Spacing	Speed	Spacing	Speed
111.71	23.85	111.71	23.85

Table 6-23. Calibration using all data – Modified Pitt car-following model for uncongested conditions

Subject number	Parameters K 0.35	 h 1.50	 L_l 32.00	RMSE values Spacing Initial analysis	 After calibration	 Speed Initial analysis	 After calibration
52	0.12	0.86	22.00	32.80	6.13	8.25	1.28
72	0.12	0.86	22.00	43.15	21.17	10.56	6.39
67	0.12	0.86	22.00	26.62	4.82	6.66	1.28
68	0.12	0.86	22.00	26.78	8.81	7.38	2.12
66	0.12	0.86	22.00	20.84	21.07	7.73	3.34
50	0.12	0.86	22.00	23.95	8.57	7.08	2.47
	Total condition			174.14	70.57	47.66	16.89

Table 6-24. Calibration using all data – Modified Pitt car-following model for congested conditions

Subject number	Parameters			RMSE values			
	K	h	L_l	Spacing		Speed	
	0.35	1.50	32.00	Initial analysis	After calibration	Initial analysis	After calibration
72	0.12	0.86	22.00	6.34	25.48	3.61	11.66
67	0.12	0.86	22.00	2.04	7.01	0.53	2.54
68	0.12	0.86	22.00	5.17	19.14	1.85	9.16
66	0.12	0.86	22.00	10.41	9.76	5.54	2.98
50	0.12	0.86	22.00	4.35	9.37	1.43	3.49
	Total condition			28.31	70.76	12.96	29.83

Table 6-25. Calibration using all data – Modified Pitt car-following model for rain uncongested conditions

Subject number	Parameters			RMSE values			
	K	h	L_l	Spacing		Speed	
	0.35	1.50	32.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.12	0.86	22.00	29.49	15.61	8.84	3.74
67	0.12	0.86	22.00	8.13	19.85	3.81	5.63
68	0.12	0.86	22.00	16.81	12.26	5.58	1.82
50	0.12	0.86	22.00	36.23	10.90	9.00	2.33
	Total condition			90.66	58.62	27.23	13.51

Table 6-26. Calibration using all data – Modified Pitt car-following model for rain congested conditions

Subject number	Parameters			RMSE values			
	K	h	L_l	Spacing		Speed	
	0.35	1.50	32.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.12	0.86	22.00	10.06	2.94	2.36	0.75
67	0.12	0.86	22.00	9.44	4.29	2.44	1.04
68	0.12	0.86	22.00	10.24	1.86	2.74	0.55
50	0.12	0.86	22.00	13.41	3.10	3.58	0.89
	Total condition			43.15	12.20	11.12	3.23

Table 6-27. Calibration using all data – Results by driver type Modified Pitt car-following model

Driver type	RMSE values			
	Spacing		Speed	
	Initial analysis	After calibration	Initial analysis	After calibration
Aggressive	121.84	71.34	33.62	23.82
Average	105.23	78.04	30.99	24.13
Conservative	109.19	62.77	28.82	12.52

Table 6-28. Calibration using all data – Total RMSE results for the Modified Pitt car-following model

Overall RMSE			
RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
336.26	98.97	212.15	63.46

Table 6-29. Calibration by condition – Gipps car-following model for uncongested conditions

Subject number	Parameters a_n 2.00	b_n -3.00	$\hat{b}$ -3.50	RMSE Values Spacing Initial Analysis	After Calibration	Speed Initial Analysis	After Calibration
52	3.30	-4.56	-4.56	24.66	10.32	1.75	1.02
72	3.30	-4.56	-4.56	42.79	18.47	2.78	1.45
67	3.30	-4.56	-4.56	16.42	5.84	1.45	1.22
68	3.30	-4.56	-4.56	8.29	4.51	1.17	0.94
66	3.30	-4.56	-4.56	13.55	4.14	1.69	1.41
50	3.30	-4.56	-4.56	45.92	18.69	6.42	5.94
			Total Condition	151.63	61.98	15.25	11.98

Table 6-30. Calibration by condition – Gipps car-following model for congested conditions

Subject number	Parameters a_n 2.00	b_n -3.00	$\hat{b}$ -3.50	RMSE values Spacing Initial analysis	After calibration	Speed Initial analysis	After calibration
72	2.94	-2.00	-2.00	2.20	1.34	1.19	1.05
67	2.94	-2.00	-2.00	2.88	3.26	0.72	0.78
68	2.94	-2.00	-2.00	1.60	1.30	0.90	0.86
66	2.94	-2.00	-2.00	3.73	1.71	1.14	1.04
50				Not working*		Not working*	
* Using the default values the results were unrealistic			Total condition	10.41	7.61	3.95	3.72

Table 6-31. Calibration by condition – Gipps car-following model for rain uncongested conditions

Subject number	Parameters a_n 2.00	b_n -3.00	$\hat{b}$ -3.50	RMSE values Spacing Initial analysis	After calibration	Speed Initial analysis	After calibration
52	3.30	-2.33	-2.33	20.60	12.46	2.17	1.77
67	3.30	-2.33	-2.33	5.49	4.13	2.69	2.88
68	3.30	-2.33	-2.33	11.80	3.22	1.54	1.35
50	3.30	-2.33	-2.33	20.81	9.12	1.71	1.12
			Total condition	58.70	28.93	8.11	7.12

Table 6-32. Calibration by condition – Gipps car-following model for rain congested conditions

Subject number	Parameters a_n	b_n	$\hat{b}$	RMSE values Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	3.30	-2.00	-2.00	3.80	2.58	0.79	0.84
67	3.30	-2.00	-2.00	2.17	1.06	0.45	0.51
68	3.30	-2.00	-2.00	2.99	1.60	0.62	0.64
50	3.30	-2.00	-2.00	3.32	1.47	0.78	0.79
			Total condition	12.28	6.71	2.64	2.78

Table 6-33. Calibration by condition – Results by driver type Gipps car-following model

Driver type	RMSE values Spacing Initial analysis	After calibration	Speed Initial analysis	After calibration
Aggressive	94.05	45.18	8.67	6.13
Average	51.63	24.92	9.78	9.18
Conservative	87.34	35.13	11.74	10.29

Table 6-34. Calibration by condition – Total RMSE results for the Gipps car-following model

Overall RMSE RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
233.02	29.95	105.23	25.60

Table 6-35. Calibration by condition – Pitt car-following model for uncongested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.46	4.02	3.27	10.15	10.00
72	0.00	0.46	2.54	3.39	4.88	4.59
67	0.00	0.46	3.96	2.97	6.99	6.72
68	0.00	0.46	15.93	14.17	5.76	5.50
66	0.00	0.46	17.25	15.42	4.36	4.45
50	0.00	0.46	2.94	1.55	2.77	2.75
		Total condition	46.64	40.77	34.91	34.01

Table 6-36. Calibration by condition – Pitt car-following model for congested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
72	0.00	0.13	9.18	2.80	10.36	10.93
67	0.00	0.13	2.91	3.61	2.34	2.78
68	0.00	0.13	3.73	2.53	3.48	3.60
66	0.00	0.13	3.41	4.32	1.68	1.68
50	0.00	0.13	2.19	1.69	1.25	1.22
		Total condition	21.42	14.95	19.11	20.22

Table 6-37. Calibration by condition – Pitt car-following model for rain uncongested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.75	8.51	13.75	11.08	9.79
67	0.00	0.75	13.52	10.21	9.46	9.04
68	0.00	0.75	14.98	5.29	6.98	5.68
50			Not working*		Not working*	
		Total condition	37.01	29.24	27.52	24.52

* Using the default values the results were unrealistic

Table 6-38. Calibration by condition – Pitt car-following model for rain congested conditions

Subject number	Parameters		RMSE Values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.38	4.06	3.45	5.36	5.48
67	0.00	0.38	1.52	1.67	5.61	5.63
68	0.00	0.38	1.22	1.17	2.74	2.71
50	0.00	0.38	2.69	2.73	1.89	1.89
		Total condition	9.49	9.03	15.61	15.71

Table 6-39. Calibration by condition – Results by driver type Pitt car-following model

	RMSE values			
	Spacing		Speed	
Driver type	Initial analysis	After calibration	Initial analysis	After calibration
Aggressive	28.31	26.66	41.83	40.79
Average	57.78	41.61	43.36	41.67
Conservative	28.48	25.71	10.28	10.32

Table 6-40. Calibration by condition – Total RMSE results for the Pitt car-following model

Overall RMSE			
RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
114.57	97.15	93.99	94.45

Table 6-41. Calibration by condition – MITSIM car-following model for uncongested conditions

Subject number	Parameters						RMSE Values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.96	-0.90	-0.88	0.55	0.00	-0.26	9.17	6.64	1.05	1.37
72	0.96	-0.90	-0.88	0.55	0.00	-0.26	12.21	7.95	1.20	1.31
67	0.96	-0.90	-0.88	0.55	0.00	-0.26	6.83	4.57	1.09	1.77
68	0.96	-0.90	-0.88	0.55	0.00	-0.26	6.18	10.14	1.88	3.50
66	0.96	-0.90	-0.88	0.55	0.00	-0.26	6.44	6.48	2.10	6.45
50	0.96	-0.90	-0.88	0.55	0.00	-0.26	14.66	11.36	1.51	2.01
						Total condition	55.50	47.15	8.84	16.42

Table 6-42. Calibration by condition – MITSIM car-following model for congested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
72	0.50	-1.00	-1.00	1.25	1.00	1.00	4.62	4.62	1.19	1.19
67	0.50	-1.00	-1.00	1.25	1.00	1.00	4.71	4.71	0.82	0.82
68	0.50	-1.00	-1.00	1.25	1.00	1.00	3.54	3.54	0.87	0.87
66	0.50	-1.00	-1.00	1.25	1.00	1.00	1.67	1.67	0.95	0.95
50	0.50	-1.00	-1.00	1.25	1.00	1.00	6.77	6.77	1.03	1.03
						Total condition	21.30	21.30	4.86	4.86

Table 6-43. Calibration by condition – MITSIM car-following model for rain uncongested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	4.00	1.00	2.16	0.58	2.00	2.31	10.47	4.32	1.61	1.05
67	4.00	1.00	2.16	0.58	2.00	2.31	4.98	5.76	2.83	2.56
68	4.00	1.00	2.16	0.58	2.00	2.31	4.62	3.29	1.79	0.38
50	4.00	1.00	2.16	0.58	2.00	2.31	7.14	2.98	1.09	1.01
						Total condition	27.21	16.35	7.32	4.99

Table 6-44. Calibration by condition – MITSIM car-following model for rain congested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.67	-1.00	-1.00	1.31	1.15	1.00	2.21	2.50	0.93	1.26
67	0.67	-1.00	-1.00	1.31	1.15	1.00	1.34	0.78	0.46	0.70
68	0.67	-1.00	-1.00	1.31	1.15	1.00	1.28	1.28	0.62	0.73
50	0.67	-1.00	-1.00	1.31	1.15	1.00	2.85	2.14	0.83	0.97
						Total condition	7.70	6.70	2.83	3.66

Table 6-45. Calibration by condition – Results by driver type MITSIM car-following model

Driver type	RMSE values Spacing Initial analysis	 After calibration	 Speed Initial analysis	 After calibration
Aggressive	38.69	26.03	5.98	6.18
Average	33.49	34.07	10.35	11.34
Conservative	39.53	31.39	6.56	11.47

Table 6-46. Calibration by condition – Total RMSE results for the MITSIM car-following model

Overall RMSE RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
111.71	23.85	91.50	29.94

Table 6-47. Calibration by condition – Modified Pitt car-following model for uncongested conditions

Subject number	Parameters K 0.35	 h 1.50	 L_l 32.00	RMSE values Spacing Initial analysis	 After calibration	 Speed Initial analysis	 After calibration
52	0.16	0.72	22.00	32.80	5.15	8.25	1.98
72	0.16	0.72	22.00	43.15	22.06	10.56	6.17
67	0.16	0.72	22.00	26.62	2.80	6.66	1.02
68	0.16	0.72	22.00	26.78	4.46	7.38	1.69
66	0.16	0.72	22.00	20.84	20.97	7.73	4.01
50	0.16	0.72	22.00	23.95	3.54	7.08	1.32
	Total condition			174.14	58.97	47.66	16.20

Table 6-48. Calibration by condition – Modified Pitt car-following model for congested conditions

Subject number	Parameters K 0.35	 h 1.50	 L_l 32.00	RMSE values Spacing Initial analysis	 After calibration	 Speed Initial analysis	 After calibration
72	0.45	1.91	22.00	6.34	5.20	3.61	3.73
67	0.45	1.91	22.00	2.04	2.21	0.53	0.89
68	0.45	1.91	22.00	5.17	3.83	1.85	1.73
66	0.45	1.91	22.00	10.41	6.42	5.54	2.42
50	0.45	1.91	22.00	4.35	3.23	1.43	2.30
	Total condition			28.31	20.88	12.96	11.07

Table 6-49. Calibration by condition – Modified Pitt car-following model for rain uncongested conditions

Subject number	Parameters			RMSE values			
	K	h	L_l	Spacing		Speed	
	0.35	1.50	32.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.07	1.10	22.00	29.49	9.11	8.84	2.10
67	0.07	1.10	22.00	8.13	18.20	3.81	3.55
68	0.07	1.10	22.00	16.81	4.12	5.58	1.00
50	0.07	1.10	22.00	36.23	18.40	9.00	1.25
	Total Condition			90.66	49.83	27.23	7.90

Table 6-50. Calibration by condition – Modified Pitt car-following model for rain congested conditions

Subject number	Parameters			RMSE values			
	K	h	L_l	Spacing		Speed	
	0.35	1.50	32.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.18	0.93	22.00	10.06	2.04	2.36	0.72
67	0.18	0.93	22.00	9.44	2.62	2.44	0.85
68	0.18	0.93	22.00	10.24	1.85	2.74	0.60
50	0.18	0.93	22.00	13.41	2.64	3.58	0.58
	Total Condition			43.15	9.16	11.12	2.76

Table 6-51. Calibration by condition – Results by driver type Modified Pitt car-following model

Driver type	RMSE values			
	Spacing		Speed	
	Initial analysis	After calibration	Initial analysis	After calibration
Aggressive	121.84	43.57	33.62	14.71
Average	105.23	40.08	30.99	11.34
Conservative	109.19	55.20	28.82	9.47

Table 6-52. Calibration by condition – Total RMSE results for the Modified Pitt car-following model

Overall RMSE			
RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
336.26	98.97	138.85	37.93

Table 6-53. Calibration by driver type – Gipps car-following model for uncongested conditions

Subject number	Parameters			RMSE values			
	a_n	b_n	$\hat{b}$	Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	3.30	-5.00	-5.00	24.66	10.25	1.75	1.02
72	3.30	-5.00	-5.00	42.79	18.51	2.78	1.47
67	3.11	-2.19	-2.19	16.42	5.23	1.45	1.23
68	3.11	-2.19	-2.19	8.29	3.37	1.17	1.00
66	3.30	-4.44	-4.44	13.55	4.20	1.69	1.42
50	3.30	-4.44	-4.44	45.92	18.77	6.42	5.94
			Total condition	151.63	60.33	15.25	12.08

Table 6-54. Calibration by driver type – Gipps car-following model for congested conditions

Subject number	Parameters			RMSE values			
	a_n	b_n	$\hat{b}$	Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
72	3.30	-5.00	-5.00	2.20	1.51	1.19	1.15
67	3.11	-2.19	-2.19	2.88	3.27	0.72	0.79
68	3.11	-2.19	-2.19	1.60	1.30	0.90	0.86
66	3.30	-4.44	-4.44	3.73	2.32	1.14	1.33
50				Not working*		Not working*	
			Total condition	10.41	8.40	3.95	4.13

Table 6-55. Calibration by driver type – Gipps car-following model for rain uncongested conditions

Subject number	Parameters			RMSE values			
	a_n	b_n	$\hat{b}$	Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	3.30	-5.00	-5.00	20.60	10.34	2.17	1.77
67	3.11	-2.19	-2.19	5.49	4.03	2.69	2.88
68	3.11	-2.19	-2.19	11.80	3.53	1.54	1.36
50	3.30	-4.44	-4.44	20.81	10.98	1.71	1.28
			Total condition	58.70	28.88	8.11	7.30

Table 6-56. Calibration by driver type – Gipps car-following model for rain congested conditions

Subject number	Parameters			RMSE values			
	a_n	b_n	$\hat{b}$	Spacing		Speed	
	2.00	-3.00	-3.50	Initial analysis	After calibration	Initial analysis	After calibration
52	3.30	-5.00	-5.00	3.80	2.68	0.79	0.93
67	3.11	-2.19	-2.19	2.17	1.05	0.45	0.50
68	3.11	-2.19	-2.19	2.99	1.60	0.62	0.63
50	3.30	-4.44	-4.44	3.32	2.01	0.78	0.85
			Total condition	12.28	7.34	2.64	2.91

Table 6-57. Calibration by driver type – Results by driver type Gipps car-following model

Driver type	RMSE values			
	Spacing		Speed	
	Initial analysis	After calibration	Initial analysis	After calibration
Aggressive	94.05	43.28	8.67	6.34
Average	51.63	23.39	9.78	9.26
Conservative	87.34	38.28	11.74	10.82

Table 6-58. Calibration by driver type – Total RMSE results for the Gipps car-following model

Overall RMSE			
RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
233.02	29.95	104.95	26.42

Table 6-59. Calibration by driver type – Pitt car-following model for uncongested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.36	4.02	2.84	10.15	10.52
72	0.00	0.36	2.54	2.15	4.88	4.92
67	0.00	0.70	3.96	6.78	6.99	5.79
68	0.00	0.70	15.93	8.28	5.76	4.63
66	0.10	0.47	17.25	13.68	4.36	4.30
50	0.10	0.47	2.94	1.99	2.77	2.67
		Total condition	46.64	35.72	34.91	32.83

Table 6-60. Calibration by driver type – Pitt car-following model for congested conditions

Subject number	Parameters		RMSE Values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
72	0.00	0.36	9.18	5.07	10.36	10.44
67	0.00	0.70	2.91	2.99	2.34	1.87
68	0.00	0.70	3.73	4.63	3.48	3.38
66	0.10	0.47	3.41	3.35	1.68	1.69
50	0.10	0.47	2.19	2.51	1.25	1.26
		Total condition	21.42	18.55	19.11	18.65

Table 6-61. Calibration by driver type – Pitt car-following model for rain uncongested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.36	8.51	4.77	11.08	11.67
67	0.00	0.70	13.52	10.36	9.46	9.18
68	0.00	0.70	14.98	6.65	6.98	5.89
50	0.10	0.47	Not working*		Not working*	
		Total condition	37.01	21.78	27.52	26.74

* Using the default values the results were unrealistic

Table 6-62. Calibration by driver type – Pitt car-following model for rain congested conditions

Subject number	Parameters		RMSE values			
	b	k	Spacing		Speed	
	0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	0.00	0.36	4.06	3.29	5.36	5.55
67	0.00	0.70	1.52	3.53	5.61	4.79
68	0.00	0.70	1.22	3.66	2.74	1.91
50	0.10	0.47	2.69	3.16	1.89	1.89
		Total condition	9.49	13.64	15.61	14.14

Table 6-63. Calibration by driver type – Results by driver type Pitt car-following model

Driver type	RMSE values			
	Spacing		Speed	
	Initial analysis	After calibration	Initial analysis	After calibration
Aggressive	28.31	18.12	41.83	43.10
Average	57.78	46.88	43.36	37.44
Conservative	28.48	24.69	10.28	10.13

Table 6-64. Calibration by driver type – Total RMSE results for the Pitt car-following model

Overall RMSE			
RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
114.57	97.15	89.69	92.35

Table 6-65. Calibration by driver type – MITSIM car-following model for uncongested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.50	-0.81	-0.84	1.20	0.69	1.13	9.17	3.34	1.05	0.52
72	0.50	-0.81	-0.84	1.20	0.69	1.13	12.21	4.30	1.20	0.75
67	0.50	-1.55	-1.00	2.00	0.00	0.65	6.83	4.71	1.09	0.61
68	0.50	-1.55	-1.00	2.00	0.00	0.65	6.18	2.33	1.88	0.38
66	0.50	-0.85	-0.93	1.19	0.13	0.30	6.44	10.95	2.10	2.27
50	0.50	-0.85	-0.93	1.19	0.13	0.30	14.66	7.26	1.51	1.12
						Total condition	55.50	32.88	8.84	5.65

Table 6-66. Calibration by driver type - MITSIM car-following model for congested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
72	0.50	-0.81	-0.84	1.20	0.69	1.13	4.62	6.26	1.19	1.40
67	0.50	-1.55	-1.00	2.00	0.00	0.65	4.71	2.66	0.82	0.55
68	0.50	-1.55	-1.00	2.00	0.00	0.65	3.54	3.01	0.87	0.98
66	0.50	-0.85	-0.93	1.19	0.13	0.30	1.67	1.96	0.95	0.94
50	0.50	-0.85	-0.93	1.19	0.13	0.30	6.77	4.27	1.03	1.01
						Total condition	21.30	18.16	4.86	4.88

Table 6-67. Calibration by driver type - MITSIM car-following model for rain uncongested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.50	-0.81	-0.84	1.20	0.69	1.13	10.47	4.61	1.61	1.10
67	0.50	-1.55	-1.00	2.00	0.00	0.65	4.98	3.31	2.83	2.41
68	0.50	-1.55	-1.00	2.00	0.00	0.65	4.62	3.54	1.79	0.41
50	0.50	-0.85	-0.93	1.19	0.13	0.30	7.14	2.16	1.09	0.89
						Total condition	27.21	13.63	7.32	4.81

Table 6-68. Calibration by driver type - MITSIM car-following model for rain congested conditions

Subject number	Parameters						RMSE values			
	α+	β+	γ+	α-	β-	γ-	Spacing		Speed	
	0.50	-1.00	-1.00	1.25	1.00	1.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.50	-0.81	-0.84	1.20	0.69	1.13	2.21	4.76	0.93	0.84
67	0.50	-1.55	-1.00	2.00	0.00	0.65	1.34	3.11	0.46	0.35
68	0.50	-1.55	-1.00	2.00	0.00	0.65	1.28	2.82	0.62	0.58
50	0.50	-0.85	-0.93	1.19	0.13	0.30	2.85	4.73	0.83	0.86
						Total condition	7.70	15.42	2.83	2.62

Table 6-69. Calibration by driver type – Results by driver type MITSIM car-following model

Driver type	RMSE values Spacing Initial analysis	After calibration	Speed Initial analysis	After calibration
Aggressive	38.69	23.25	5.98	4.60
Average	33.49	25.49	10.35	6.27
Conservative	39.53	31.34	6.56	6.15

Table 6-70. Calibration by driver type – Total RMSE results for the MITSIM car-following model

Overall RMSE			
RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
111.71	23.85	80.08	17.96

Table 6-71. Calibration by driver type – Modified Pitt car-following model for uncongested conditions

Subject number	Parameters K 0.35	h 1.50	L_l 32.00	RMSE values Spacing Initial analysis	After calibration	Speed Initial analysis	After calibration
52	0.12	0.78	25.61	32.80	5.37	8.25	1.22
72	0.12	0.78	25.61	43.15	20.88	10.56	6.47
67	0.21	0.89	32.00	26.62	13.02	6.66	4.50
68	0.21	0.89	32.00	26.78	12.57	7.38	4.05
66	0.16	0.67	24.07	20.84	21.48	7.73	4.16
50	0.16	0.67	24.07	23.95	3.49	7.08	1.25
	Total condition			174.14	76.79	47.66	21.66

Table 6-72. Calibration by driver type – Modified Pitt car-following model for congested conditions

Subject number	Parameters K 0.35	h 1.50	L_l 32.00	RMSE values Spacing Initial analysis	After calibration	Speed Initial analysis	After calibration
72	0.12	0.78	25.61	6.34	25.81	3.61	12.47
67	0.21	0.89	32.00	2.04	4.21	0.53	2.20
68	0.21	0.89	32.00	5.17	14.09	1.85	8.40
66	0.16	0.67	24.07	10.41	8.23	5.54	4.07
50	0.16	0.67	24.07	4.35	9.11	1.43	6.11
	Total condition			28.31	61.46	12.96	33.24

Table 6-73. Calibration by driver type – Modified Pitt car-following model for rain uncongested conditions

Subject number	Parameters			RMSE values			
	K	h	L_l	Spacing		Speed	
	0.35	1.50	32.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.12	0.78	25.61	29.49	16.09	8.84	4.15
67	0.21	0.89	32.00	8.13	15.73	3.81	4.93
68	0.21	0.89	32.00	16.81	8.80	5.58	2.62
50	0.16	0.67	24.07	36.23	12.40	9.00	3.34
	Total condition			90.66	53.02	27.23	15.05

Table 6-74. Calibration by driver type – Modified Pitt car-following model for rain congested conditions

Subject number	Parameters			RMSE values			
	K	h	L_l	Spacing		Speed	
	0.35	1.50	32.00	Initial analysis	After calibration	Initial analysis	After calibration
52	0.12	0.78	25.61	10.06	2.68	2.36	0.69
67	0.21	0.89	32.00	9.44	1.49	2.44	0.36
68	0.21	0.89	32.00	10.24	5.19	2.74	1.87
50	0.16	0.67	24.07	13.41	2.73	3.58	0.85
	Total condition			43.15	12.09	11.12	3.76

Table 6-75. Calibration by driver type – Results by driver type Modified Pitt car-following model

Driver type	RMSE values			
	Spacing		Speed	
	Initial analysis	After calibration	Initial analysis	After calibration
Aggressive	121.84	70.82	33.62	25.00
Average	105.23	75.09	30.99	28.92
Conservative	109.19	57.45	28.82	15.71

Table 6-76. Calibration by driver type – Total RMSE results for the Modified Pitt car-following model

Overall RMSE			
RMSE total initial		RMSE total after calibration	
Spacing	Speed	Spacing	Speed
336.26	98.97	203.37	73.71

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

The accuracy of computer simulation programs used to develop transportation systems depends on the quality of the traffic-flow models from which they are derived. The three main components of this traffic-flow models are car-following, lane changing and gap acceptance models. This study evaluates car-following. Four models were selected based on their application in existing simulation programs and in the differences between them. Field data were obtained from a database consisting of data collected in Jacksonville, Florida. The data were collected by an instrumented vehicle recording speed, time, and distances between the subject vehicle and its leader. The data captured critical factors such as human characteristics, different conditions (congested and uncongested) for different times of day and different environmental conditions (rain). The investigation methodology used is described in Chapter 3. The car-following behavior for each model was compared to field data using a number of error tests. The error test root mean square error (RMSE) was used on spacing and speed as a key performance indicator.

Results show:

- The variable predicted best by the models was the speed of the following vehicle. The RMSE for speed was lower than the spacing for all the conditions for all the drivers for all the analysis. This is consistent with previous studies, which explained that in comparison to the spacing, the speed does not increase or decrease accumulatively. Error in predicting it does not accumulate every second.

- The calibration results show that the best variable to calibrate is the spacing. This is consistent with previous studies that explained that if calibrating on speed, the values of RMSE calculated for spacing are going to be higher and more sensitive than the optimum ones, there will be higher values of error obtained than calibrating the model by spacing.

- Results of the MITSIM model present the lowest values of RMSE for the initial analysis using the default values. MITSIM is capable of reproducing the field data better than the other models. However, this performance can be due to the large number of parameters and degrees of freedom that may tend to over fit the data.

- Congested scenarios were the conditions most accurate predicted by all the models.

- Results in some cases are mixed. The model that predicted more precisely the congested conditions was Gipps for the initial analysis and MITSIM for the calibration analysis. On the other hand uncongested scenarios were better predicted by MITSIM for the initial analysis and for the calibration analysis.

- For the initial analysis, the performance of average drivers was better predicted by all models. The models that predicted average driver behavior the best were MITSIM and Gipps, before and after calibration.

- Conservative and aggressive drivers were the highest values of RMSE in the initial analysis. However the Pitt model predicted their spacing and MITSIM their speed more accurately. After calibration Pitt predicted better the conservative behavior and MITSIM the aggressive.

- The calibration analysis shows that the congested conditions are better predicted when the parameters are calibrated by condition. Uncongested conditions were better predicted when the parameters are calibrated by driver type.

- The calibration analysis shows that for conservative and aggressive drivers' behavior is better predicted when calibrated by driver type. Average drivers' behavior is better predicted when the parameters were calibrated by driver or condition depending on its condition. The average driver from the initial analysis was predicted accurately. Therefore it does not need to be calibrated. It already works for all the models.

- It is recommended to use the following parameter ranges for the car-following models if conservative and aggressive driver behaviors are to be analyzed.

  Gipps model:

  - Aggressive driver, a_n = 3.3 m/s^2 (7.38 mi/hr-s) , b_n = -5.0 m/s^2 (-11.18 mi/hr-s), $\hat{b}$ = -5.0 m/s^2 (-11.18 mi/hr-s)

  - Average driver, a_n = 3.11 m/s^2 (6.96 mi/hr-s), b_n = -2.19 m/s^2 (-4.9 mi/hr-s) , $\hat{b}$ = -2.19 m/s^2 (-4.9 mi/hr-s)

  - Conservative driver, a_n = 3.3 m/s^2 (7.38 mi/hr-s), b_n = -4.44 m/s^2 (-9.93 mi/hr-s), $\hat{b}$ = -4.44 m/s^2 (-9.93 mi/hr-s)

Pitt model:

- Aggressive b = 0.0 and k = 0.36
- Average driver, b = 0.0 and k = 0.70
- Conservative driver, b = 0.10 and k = 0.47

MITSIM model:

- Aggressive α^+ = 0.5, β^+ =- 0.81, γ^+ =- 0.84, α^-= 1.20, β^-= 0.69, and γ^- = 1.13

- Average driver α^+ = 0.5, β^+ = -1.55, γ^+ = -1.0, α^-= 2.0, β^-= 0.0, and γ^- = 0.65

- Conservative driver α^+ = 0.5, β^+ = -0.85, γ^+ = -0.93, α^-= 1.19, β^-= 0.13, and γ^- = 0.3

Modified Pitt model:

- Aggressive driver K = 0.12, h = 0.78, L_l= 25.61 ft (7.81 m)
- Average driver, K = 0.21, h = 0.89, L_l= 32 ft (9.76 m)
- Conservative driver, K = 0.16, h = 0.67, L_l= 24.07 ft (7.34 m)

- The lowest values of RMSE were when the parameters of Gipps were calibrated by condition and driver type. It is recommended to use or either the above mentioned parameters or the following parameters ranges for the car-following models. Modified Pitt has the lowest RMSE when the parameters were by condition. Therefore the following parameters are recommended.

  Gipps model:

  - Uncongested conditions a_n = 3.3 m/s^2 (7.38 mi/hr-s), b_n = -4.56 m/s^2 (-9.95 mi/hr-s), $\hat{b}$ = -4.56 m/s^2 (-9.95 mi/hr-s).

  - Congested conditions a_n = 2.94 m/s^2 (6.58 mi/hr-s), b_n = -2.0 m/s^2 (-4.47 mi/hr-s) , $\hat{b}$ = -2.0 m/s^2 (-4.47 mi/hr-s)

  - Rain uncongested conditions a_n = 3.3 m/s^2 (7.38 mi/hr-s), b_n = -2.33 m/s^2 (-5.21 mi/hr-s) , $\hat{b}$ = -2.33 m/s^2 (-5.21 mi/hr-s)

  - Rain congested conditions a_n = 3.3 m/s^2 (7.38 mi/hr-s), b_n = -2.0 m/s^2 (-4.47 mi/hr-s), $\hat{b}$ = -2.0m/s^2 (-4.47 mi/hr-s)

  Modified Pitt model:

  - Uncongested conditions K = 0.16, h = 0.72, L_l= 22 ft (6.71 m)
  - Congested conditions, K = 0.45, h = 1.91, L_l= 22 ft (6.71 m)
  - Rain uncongested conditions, K = 0.07, h = 1.10, L_l= 22 ft (6.71 m)

    - Rain congested conditions, K = 0.18, h = 0.93, L_l= 22 ft (6.71 m)

- The lowest values of RMSE for Pitt and MITSIM were when the parameters were calibrated by driver type.

- However, the values of RMSE overall were lowest when calibrating the parameter values by driver type using the MITSIM model. MITSIM was the best model in incorporating all the different conditions and drivers.

In conclusion, this thesis recommends performed calibration using spacing and to conduct calibration by driver type. It is recommended to use the parameter ranges for calibration by driver type for each car-following model.

Modifications to various simulation programs allowing more flexibility in setting car-following parameters related to different traffic conditions, and drivers' types is recommended. This study shows that different drivers' types affect the performance of the car-following models. Therefore different drivers have to be considered in the car-following models of simulation programs. Research on the implementation of these findings in the micro-simulations software has to be undertaken. This study only considered car-following behavior. In future studies, other important factors such as lane changing behavior and gap acceptance should be considered. The distances between vehicles (subject/follower and the lead) are estimated for each consecutive frame using the method applied for measuring distances from still images explained by Psarianos et al. (2001). An instrumented vehicle with infrared sensor will provide more accurately measures of distances. This thesis is based on Jacksonville, Florida field data; therefore additional data collection in various locations is needed to confirm and refine the findings.

APPENDIX A
PROCEDURE USED TO OBTAINED SPEED AND LENGHT MEASUREMENTS

The method used to obtained measurements of length and speed from the cameras is described in this section. Is necessary to understand the trajectories and record the different speed of the subjects for comparisons with the outputs of the equations models. Procedures use on Psarianos et al. (2001) research paper was implemented to extract the data from the cameras installed on the Pilot car. For this thesis the front camera is the only that will be evaluated.

The basic geometry of lane width measurement is shown in Figure A-1, in which O denotes the perspective center and M is the image center. The X axis in object space and the x image coordinate axis are normal to the plane of the Figure.

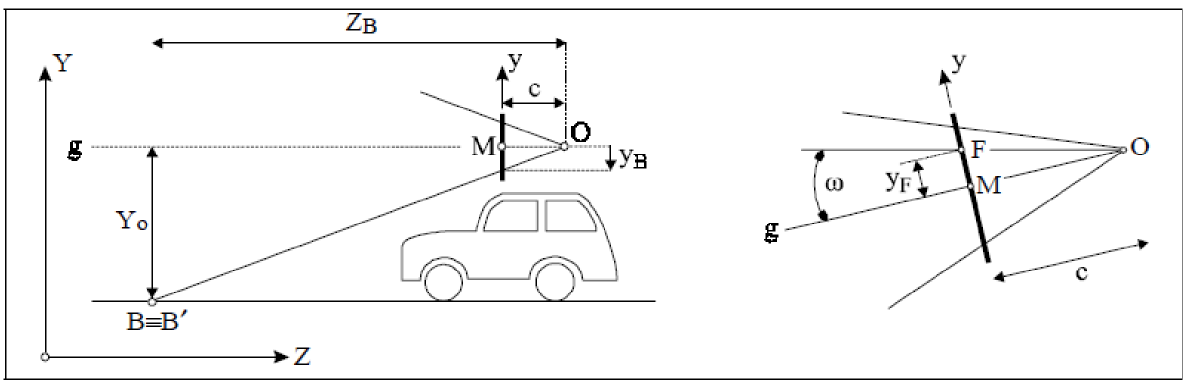

Figure A-1. Image acquisition geometry with camera axis horizontal (left) and tilted (right) (Psarianos et al. 2001)

On the left, the situation is illustrated when the camera axis is horizontal. The camera constant is denoted by c, while y_B is the y image coordinates of points B and′B on the road surface defining lane width. If Y_0 is the camera height above ground level, then image scale at the distance Z_B is expressed as follows:

$$\frac{c}{Z_B} = -\frac{y_B}{Y_0} = \frac{\Delta x_B}{\Delta X_B} \qquad \text{(A-1)}$$

Where:

ΔX_B is the lane width BB',

Δx_B is the corresponding length measured on the image.

The method to estimate the values is by using the vanishing point of the Z direction of depth, found graphically on the frame. One can define the vanishing point F of a straight road segment by exploiting road delineation on the video snapshots, as shown in Figure A-2.

Figure A-2. Graphical determination of vanishing points

The formula used to connect a lane width ΔX measured on the image (at a certain y image coordinate) through the vanishing point F of the road direction with the corresponding actual lane width Δ correspond to Equation A-2.

$$\Delta X = \frac{\Delta x_B}{y - y_B} \times Y_0 \tag{A-2}$$

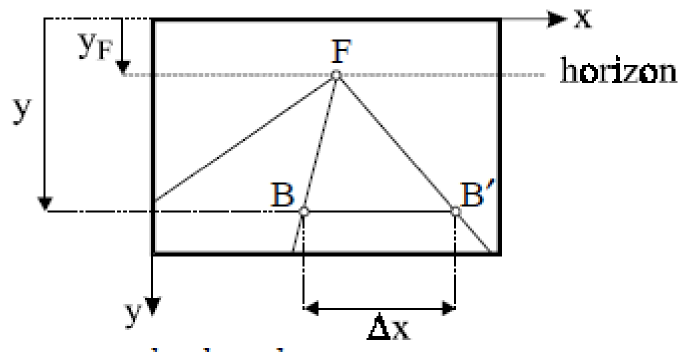

Figure A-3. Measurements on the digital camera Psarianos et all (2001)

In addition, the lane widths ΔX shown on these frames had been measured with a tape and were later used to estimate camera height Y_0. This value of Y_0 does not represent the actual camera height but is affected by image affinity.

Figure A-4. Images of the process for estimating the Y_0 and ΔX

Before employing the described approach on a routine basis, its accuracy was evaluated. To this end, 4 frames were first used to estimate a camera height Y_0 from known widths. Here, the lane widths had been measured by tape to serve for checking purposes. On each of these 30 frames, 5 different Δx measurements were taken at different y levels on the image plane, as illustrated in Figure A-4, and corresponding ground lane widths ΔX were computed. All five ΔX measurements from each frame were averaged to produce the absolute mean difference from the known ΔX value. The standard deviation (σ) of the five measurements was also found. Finally, their difference (s) from the known width was also computed. The final result is the c calibration parameter that will be used to compute the distances between the follower vehicle and his lead.

APPENDIX B
RESULTS OF INITIAL ANALYSIS

This section provides tables with detail results of each driver in each condition by model. Each model is subdivided by condition and by driver. The tables provided the maximum differences between the results of the models and the field data in terms of distances, speed and RMSE.

Table B-1. Gipps results for each driver in uncongested and congested conditions

Subject number	Uncongested condition				Congested condition			
	RMSE values		Max difference		RMSE values		Max difference	
	Spacing	Speed	Spacing	Speed	Spacing	Speed	Spacing	Speed
	Initial analysis				Initial analysis			
52	24.66	1.75	33.53 m (109.98 ft)	3.99 m/s (8.92 mi/hr)	**	**	**	**
72	42.79	2.78	58.13 m (190.66 ft)	4.53 m/s (10.13mi/hr)	2.20	1.19	5.67 m (18.60 ft)	2.62 m/s (5.85mi/hr)
67	16.42	1.45	21.58 m (70.78 ft)	2.82 m/s (6.30 mi/hr)	2.88	0.72	9.96 m (32.67 ft)	2.27 m/s (5.07mi/hr)
68	8.29	1.17	14.32 m (49.97 ft)	2.73 m/s (6.11 mi/hr)	1.60	0.90	3.32 m (10.89 ft)	2.17 m/s (4.85mi/hr)
66	13.55	1.69	24.93 m (81.77 ft)	3.86 m/s (8.63 mi/hr)	3.73	1.14	6.68 m (21.91 ft)	3.76 m/s (8.40mi/hr)
50	45.92	6.42	63.38 m (207.88 ft)	5.61 m/s (12.55mi/hr)	*	*	*	*

* Using default values results were unrealistic
** Subject did not drive in that traffic condition

Table B-2. Gipps results for each driver in rainy uncongested and congested conditions

Subject number	Rain uncongested condition				Rain congested condition			
	RMSE values		Max difference		RMSE values		Max difference	
	Spacing	Speed	Spacing	Speed	Spacing	Speed	Spacing	Speed
	Initial analysis				Initial analysis			
52	20.60	2.17	27.24 m (90.98 ft)	5.83 m/s (13.04mi/hr)	3.80	0.79	7.41 m (24.30 ft)	1.74 m/s (3.89mi/hr)
72	**	**	**	**	**	**	**	**
67	5.49	2.69	18.57 m (60.91 ft)	4.97 m/s (11.11mi/hr)	2.17	0.45	3.92 m (12.86 ft)	1.16 m/s (2.59mi/hr)
68	11.80	1.54	21.53 m (70.62 ft)	3.20 m/s (7.16 mi/hr)	2.99	0.62	4.98 m (16.33 ft)	1.68 m/s (3.76mi/hr)
66	**	**	**	**	**	**	**	**
50	20.81	1.71	27.65 m (90.69 ft)	5.13 m/s (11.47mi/hr)	3.32	0.78	5.36 m (17.58 ft)	2.47 m/s (5.52mi/hr)

* Using default values results were unrealistic
** Subject did not drive in that traffic condition

Table B-3. Pitt results for each driver in uncongested and congested conditions

Subject number	Uncongested condition				Congested condition			
	RMSE values		Max difference		RMSE values		Max difference	
	Spacing	Speed			Spacing	Speed		
	Initial analysis		Spacing	Speed	Initial analysis		Spacing	Speed
52	4.02	10.15	7.8 m (25.5 ft)	12.07m/s (27mi/hr)	**	**	**	**
72	2.54	4.88	4.4m (14.4 ft)	7.5m/s (16.7mi/hr)	9.18	10.36	15.1 m (49.54 ft)	14.62 m/s (32.7 mi/hr)
67	3.96	6.99	8.4 m (28 ft)	9.28 m/s (21 mi/hr)	2.91	2.34	10.3 m (33.8 ft)	2.88 m/s (6.44mi/hr)
68	15.93	5.76	24.33 m (79.8 ft)	7.35m/s (16.44mi/hr)	3.73	3.48	7.9 m (25.91 ft)	6.21 m/s (13.89 mi/hr)
66	17.25	4.36	25.88 m (85 ft)	6.57 m/s (15 mi/hr)	3.41	1.68	6.91 m (22.7 ft)	3.47 m/s (7.76mi/hr)
50	2.94	1.97	6.73 m (22ft)	4.35 m/s (9.7mi/hr)	2.19	1.25	3.57 m(11.7 ft)	3.26 m/s (7.29 mi/hr)

* Using default values results were unrealistic
** Subject did not drive in that traffic condition

Table B-4. Pitt results for each driver in rainy uncongested and congested conditions

Subject number	Rain uncongested condition RMSE values Spacing (Initial analysis)	Speed	Max difference Spacing	Speed	Rain congested condition RMSE values Spacing (Initial analysis)	Speed	Max difference Spacing	Speed
52	8.51	11.08	15.5 m (50.85 ft)	14.11m/s (31.6mi/hr)	4.06	5.36	8.4 m (26.8 ft)	6.56 m/s (14.7 mi/hr)
72	**	**	**	**	**	**	**	**
67	13.52	9.46	25.8 m (84.64 ft)	10.61m/s (23.7mi/hr)	1.52	5.61	3.7m (13.02 ft)	7.03m/s (15.73mi/hr)
68	14.98	6.98	20.2 m (66 ft)	8.56m/s (19.15mi/hr)	1.22	2.74	2.2 m (7.22 ft)	3.43 m/s (7.67 mi/hr)
66	**	**	**	**	**	**	**	**
50	*	*	*	*	2.69	1.89	5.09 m (17 ft)	3.13m/s (7mi/hr)

* Using default values results were unrealistic
** Subject did not drive in that traffic condition

Table B-5. MITSIM results for each driver in uncongested and congested conditions

Subject number	Uncongested condition RMSE values Spacing (Initial analysis)	Speed	Max difference Spacing	Speed	Congested condition RMSE values Spacing (Initial analysis)	Speed	Max difference Spacing	Speed
52	9.17	1.05	13.2 m (43 ft)	2.34m/s (5.23mi/hr)	**	**	**	**
72	12.21	1.20	18.8m (62 ft)	2.5m/s (6mi/hr)	4.62	1.19	7.4 m (24.3 ft)	2.42 m/s (5.41 mi/hr)
67	6.83	1.09	10.4 m (30.12ft)	2.7 m/s (6.04 mi/hr)	4.71	0.82	13.3 m (43.6 ft)	2.47 m/s (5.52mi/hr)
68	6.18	1.88	11.9 m (39.04ft)	3.98m/s (9mi/hr)	3.54	0.87	5.1 m (16.7 ft)	1.91 m/s (4.3 mi/hr)
66	6.44	2.10	13.1 m (43 ft)	4.71 m/s (10.5 mi/hr)	1.67	0.95	4.5m (14.7 ft)	2.23 m/s (5mi/hr)
50	14.66	1.51	19.9 m (65ft)	4.46 m/s (10mi/hr)	6.77	1.03	10.7 m (35.1 ft)	3.02 m/s (6.8 mi/hr)

* Using default values results were unrealistic
** Subject did not drive in that traffic condition

Table B-6. MITSIM results for each driver in rainy uncongested and congested conditions

	Rain uncongested condition				Rain congested condition			
	RMSE values		Max difference		RMSE values		Max difference	
Subject number	Spacing	Speed	Spacing	Speed	Spacing	Speed	Spacing	Speed
	Initial analysis				Initial analysis			
52	10.47	1.61	15.7 m (51.5 ft)	4.63m/s (10.4mi/hr)	2.21	0.93	4.3m (14.10 ft)	3.05 m/s (6.82 mi/hr)
72	**	**	**	**	**	**	**	**
67	4.98	2.83	9.4m (30.8 ft)	4.70m/s (10.5mi/hr)	1.34	0.46	3.5m (11.4 ft)	1.15m/s (2.57mi/hr)
68	4.62	1.79	9.1m (30ft)	4.32m/s (9.7mi/hr)	1.28	0.62	2.7m (8.9ft)	1.6 m/s (3.6 mi/hr)
66	**	**	**	**	**	**	**	**
50	7.14	1.09	11.3 m (37 ft)	3.38 m/s (7.6 mi/hr)	2.85	0.83	5.9 m (19.4 ft)	2.32m/s (5.2mi/hr)

* Using default values results were unrealistic
** Subject did not drive in that traffic condition

Table B-7. Modified Pitt results for each driver in uncongested and congested conditions

	Uncongested condition				Congested condition			
	RMSE values		Max difference		RMSE values		Max difference	
Subject number	Spacing	Speed			Spacing	Speed		
	Initial analysis		Spacing	Speed	Initial analysis		Spacing	Speed
52	32.80	8.25	57.06 m (187.2ft)	12.9m/s (28.85mi/hr)	**	**	**	**
72	43.15	10.56	70.54m (231.4ft)	14.98m/s (33.5mi/hr)	6.34	3.61	20.48m (67.17ft)	6.80 m/s (15.21mi//hr)
67	24.53	6.83	44.35m (145.5ft)	10.34m/s (23 mi/hr)	2.04	0.53	5.84 m (19.15ft)	0.87 m/s (1.95mi/hr)
68	26.78	7.38	51.37 m (168.5ft)	11.48 m/s (25.67mi/hr)	5.17	1.85	12.53m (41.10 ft)	2.43 m/s (5.43 mi/hr)
66	20.84	7.73	38.38 m (125.9ft)	12.27m/s (27.44mi/hr)	10.41	5.54	17.98 m (58.97ft)	3.74 m/s (7.67 mi/hr)
50	23.95	7.08	42.58 m (139.7ft)	12.52 m/s (27.99mi/hr)	4.35	1.43	14.53 m (47.66 ft)	2.43 m/s (5.43 mi/hr)

* Using default values results were unrealistic
** Subject did not drive in that traffic condition

Table B-8. Modified Pitt results for each driver in rainy uncongested and congested conditions

Subject number	Rain uncongested condition: RMSE values, Spacing (Initial analysis)	Speed	Max difference: Spacing	Speed	Rain congested condition: RMSE values, Spacing (Initial analysis)	Speed	Max difference: Spacing	Speed
52	29.49	8.84	56.46 m (134.5 ft)	15.38 m/s (34.39mi/hr)	10.06	2.36	17.49 m (57.36 ft)	4.42 m/s (9.88 mi/hr)
72	**	**	**	**	**	**	**	**
67	8.13	3.81	17.83 m (58.48 ft)	4.0m/s (8.94 mi/hr)	9.44	2.44	17.05 m (55.92 ft)	3.90 m/s (9.88 mi/hr)
68	16.81	5.58	33.31 m (109.2 ft)	8.19m/s (18.32mi/hr)	10.24	2.74	17.78 m (58.32 ft)	4.19 m/s (9.37 mi/hr)
66	**	**	**	**	**	**	**	**
50	36.23	9.00	59.78 m (196.1 ft)	13.35 m/s (29.9 mi/hr)	13.41	3.58	23.95 m (78.56 ft)	5.27 m/s (11.8 mi/hr)

* Using default values results were unrealistic
** Subject did not drive in that traffic condition

APPENDIX C
PARAMETERS VALUES AFTER CALIBRATION

Car-following models calibration parameters for each driver by each condition are presented in this section.

Table C-1. Pitt car-following calibration parameters for uncongested conditions

Subject number	Calibration	Parameters		RMSE values			
		b	k	Spacing		Speed	
		0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
52	Spacing	0.00	0.40	4.02	2.48	10.15	10.32
	Speed	0.10	1.70		32.49		0.56
72	Spacing	0.00	0.38	2.54	2.03	4.88	4.85
	Speed	0.10	1.27		27.50		2.21
67	Spacing	0.00	0.48	3.96	2.90	6.99	6.64
	Speed	0.10	1.55		23.39		0.62
68	Spacing	0.10	0.93	15.93	4.02	5.76	3.61
	Speed	0.10	1.57		12.52		0.35
66	Spacing	0.03	0.96	17.25	3.72	4.36	4.26
	Speed	0.10	2.00		33.44		3.56
50	Spacing	0.00	0.44	2.94	1.49	2.77	2.76
	Speed	0.10	2.00		47.19		1.63

Table C-2. Pitt car-following calibration parameters for congested conditions

Subject number	Calibration	Parameters		RMSE values			
		b	k	Spacing		Speed	
		0.10	0.35	Initial analysis	After calibration	Initial analysis	After calibration
72	Spacing	0.00	0.07	9.18	2.64	10.36	11.06
	Speed	0.00	2.00		16.66		4.36
67	Spacing	0.00	0.49	2.91	2.77	2.34	2.18
	Speed	0.10	1.81		5.57		0.35
68	Spacing	0.10	0.00	3.73	2.11	3.48	3.68
	Speed	0.10	0.85		5.60		3.36
66	Spacing	0.00	0.44	3.41	3.31	1.68	1.69
	Speed	0.10	0.00		5.15		1.68
50	Spacing	0.10	0.00	2.19	1.51	1.25	1.21
	Speed	0.10	0.00				

Table C-3. Pitt car-following calibration parameters for rain uncongested conditions

Subject number	Calibration	Parameters b 0.10	k 0.35	RMSE values Spacing Initial analysis	Spacing After calibration	Speed Initial analysis	Speed After calibration
52	Spacing	0.00	0.31	8.51	4.52	11.08	11.91
	Speed	0.10	1.87		28.97		1.34
67	Spacing	0.00	0.79	13.52	10.18	9.46	8.95
	Speed	0.10	2.00		22.15		3.75
68	Spacing	0.04	0.89	14.98	2.51	6.98	5.05
	Speed	0.00	1.77		18.09		0.24
50	Spacing			Not working for default Values	Can't calibrate	Not working for default Values	Can't calibrate
	Speed						

Table C-4. Pitt car-following calibration parameters for rain congested conditions

Subject number	Calibration	Parameters b 0.10	k 0.35	RMSE values Spacing Initial analysis	Spacing After calibration	Speed Initial analysis	Speed After calibration
52	Spacing	0.00	0.22	4.06	2.70	5.36	6.03
	Speed	0.10	1.85		13.45		0.57
67	Spacing	0.00	0.47	1.52	1.01	5.61	5.40
	Speed	0.10	1.72		12.36		0.20
68	Spacing	0.00	0.36	1.22	1.15	2.74	2.76
	Speed	0.10	1.22		7.13		0.38
50	Spacing	0.10	0.33	2.69	2.68	1.89	1.89
	Speed	0.10	0.35		2.69		1.89

Table C-5. MITSIM car-following calibration parameters for uncongested conditions

Subject number	Calibration	Parameters α+	β+	γ+	α-	β-	γ-	RMSE values Spacing Initial analysis	Spacing After calibration	Speed Initial analysis	Speed After calibration
		0.50	-1.00	-1.00	1.25	1.00	1.00				
52	Spacing	1.79	-0.09	-0.11	1.58	0.00	-0.05	9.17	0.77	1.05	6.94
	Speed	0.50	-2.00	1.15	0.00	0.00	-0.91		3.24		0.34
72	Spacing	0.59	-0.75	-1.00	1.25	0.92	1.10	12.21	0.99	1.20	1.04
	Speed	4.00	-1.36	-1.00	1.74	2.00	3.00		5.14		0.53
67	Spacing	0.50	-1.12	-1.00	2.00	2.00	2.52	6.83	2.21	1.09	0.53
	Speed	0.50	-1.16	-1.00	2.00	2.00	2.76		3.61		0.47
68	Spacing	0.53	-0.99	-1.00	1.26	1.11	0.94	6.18	2.06	1.88	4.03
	Speed	2.94	1.04	2.03	0.33	0.00	2.91		3.62		0.25
66	Spacing	0.50	-1.00	-0.21	1.01	0.96	1.24	6.44	3.35	2.10	0.45
	Speed	0.50	-2.00	3.00	0.54	0.35	0.77		3.44		0.34
50	Spacing	0.60	-0.85	-1.00	1.21	0.81	1.15	14.66	2.60	1.51	0.84
	Speed	4.00	-1.49	-1.00	0.36	2.00	3.00		6.48		0.48

Table C-6. MITSIM car-following calibration parameters for congested conditions

Subject number	Calibration	Parameters α+	β+	γ+	α-	β-	γ-	RMSE values Spacing Initial analysis	Spacing After calibration	Speed Initial analysis	Speed After calibration
		0.50	-1.00	-1.00	1.25	1.00	1.00				
72	Spacing	0.50	0.26	-0.25	2.00	0.03	0.11	4.62	0.72	1.19	1.21
	Speed	4.00	0.32	0.79	2.00	0.25	0.46		3.75		1.08
67	Spacing	4.00	-2.00	-0.24	0.00	2.00	-1.00	4.71	1.73	0.82	0.43
	Speed	4.00	-2.00	3.00	-5.00	0.00	1.30		1.77		0.33
68	Spacing	0.50	0.06	-0.17	2.00	0.00	0.45	3.54	1.33	0.87	0.86
	Speed	0.88	-0.96	-0.82	1.68	0.00	0.56		4.61		0.81
66	Spacing	0.50	1.00	0.72	2.00	0.00	0.25	1.67	1.54	0.95	0.99
	Speed	1.26	1.00	1.37	0.14	0.00	3.00		6.20		0.86
50	Spacing	0.50	-1.02	-0.99	2.00	2.00	0.99	6.77	3.76	1.03	1.15
	Speed	0.60	-2.00	-1.00	2.00	2.00	0.60		4.39		1.07

Table C-7. MITSIM car-following calibration parameters for rain uncongested conditions

Subject number	Calibration	Parameters α+ 0.50	β+ -1.00	γ+ -1.00	α- 1.25	β- 1.00	γ- 1.00	RMSE values Spacing Initial analysis	Spacing After calibration	Speed Initial analysis	Speed After calibration
52	Spacing	2.01	0.63	0.55	2.00	0.78	0.92	10.47	1.05	1.61	6.22
	Speed	0.60	-0.52	-0.10	0.09	0.00	-0.28		4.03		0.94
67	Spacing	1.44	-1.28	-0.57	0.25	0.00	0.02	4.98	3.03	2.83	2.47
	Speed	1.03	1.00	2.00	0.09	1.62	2.00		8.12		1.88
68	Spacing	0.68	-1.00	-1.00	1.45	1.30	1.15	4.62	2.07	1.79	5.64
	Speed	0.50	-2.00	3.00	0.00	0.00	-1.00		2.99		0.22
50	Spacing	0.50	-0.78	-1.00	2.00	2.00	2.52	7.14	1.81	1.09	0.87
	Speed	1.55	-0.24	0.03	1.89	2.00	2.89		4.93		0.81

Table C-8. MITSIM car-following calibration parameters for rain congested conditions

Subject number	Calibration	Parameters α+ 0.50	β+ -1.00	γ+ -1.00	α- 1.25	β- 1.00	γ- 1.00	RMSE values Spacing Initial analysis	Spacing After calibration	Speed Initial analysis	Speed After calibration
52	Spacing	3.17	1.00	2.07	0.55	0.46	2.99	2.21	1.32	0.93	0.58
	Speed	4.00	1.00	1.92	1.98	2.00	3.00		2.24		0.41
67	Spacing	1.75	0.21	0.20	2.00	0.00	0.01	1.34	0.49	0.46	1.17
	Speed	0.50	-2.00	1.23	0.00	2.00	-1.00		1.30		0.23
68	Spacing	1.19	1.00	1.26	0.35	0.00	3.00	1.28	1.13	0.62	0.45
	Speed	0.65	0.18	0.31	0.53	0.00	3.00		1.21		0.45
50	Spacing	4.00	0.40	0.98	2.00	2.00	1.80	2.85	1.21	0.83	1.08
	Speed	0.50	-0.36	-0.26	2.00	2.00	2.27		3.17		0.69

Table C-9. Modified Pitt car-following calibration parameters for uncongested conditions

Subject number	Calibration	Parameters K	h	L_l	RMSE values Spacing Initial analysis		Speed Initial analysis	
		0.35	1.50	32 ft	Initial analysis	After calibration	Initial analysis	After calibration
52	Spacing	0.15	0.76	22.00	32.80	4.46	8.25	1.42
	Speed	0.00	2.00	32.00		5.08		0.34
72	Spacing	0.41	1.16	22.00	43.15	32.53	10.56	14.57
	Speed	0.00	1.92	32.00		65.58		4.38
67	Spacing	0.13	0.73	22.00	24.53	1.11	6.83	0.56
	Speed	0.00	2.00	32.00		2.76		0.61
68	Spacing	0.02	0.50	22.00	26.78	2.77	7.38	1.38
	Speed	0.03	0.90	22.00		11.39		0.80
66	Spacing	0.40	0.85	22.00	20.84	13.47	7.73	6.52
	Speed	0.00	1.52	32.00		9.25		0.88
50	Spacing	0.16	0.70	22.00	23.95	3.34	7.08	1.12
	Speed	0.16	0.51	32.00		4.57		0.69

Table C-10. Modified Pitt car-following calibration parameters for congested conditions

Subject number	Calibration	Parameters K	h	L_l	RMSE values Spacing		Speed	
		0.35	1.50	32 ft	Initial analysis	After calibration	Initial analysis	After calibration
72	Spacing	0.35	1.42	22.00	9.47	7.40	3.53	3.49
	Speed	0.23	1.68	32.00		12.66		2.49
67	Spacing	0.46	1.57	22.00	3.83	1.95	0.41	0.69
	Speed	0.42	1.56	28.75		3.09		0.35
68	Spacing	0.53	1.24	22.00	7.71	3.00	0.99	1.02
	Speed	0.39	1.13	30.85		4.99		0.50
66	Spacing	0.20	0.61	22.00	12.13	3.31	2.14	1.35
	Speed	0.27	1.34	22.00		7.77		1.09
50	Spacing	0.55	2.00	22.00	6.05	4.63	1.69	1.67
	Speed	0.48	2.00	23.43		4.84		1.62

Table C-11. Modified Pitt car-following calibration parameters for rain uncongested conditions

Subject number	Calibration	Parameters K	h	L_l	RMSE values Spacing Initial analysis	Spacing After calibration	Speed Initial analysis	Speed After calibration
		0.35	1.50	32 ft				
52	Spacing	0.28	0.61	28.92	24.49	4.10	8.84	1.43
	Speed	0.01	2.00	32.00		6.18		1.03
67	Spacing	0.71	1.63	22.00	8.13	6.51	3.81	3.93
	Speed	0.07	1.68	22.00		8.37		2.57
68	Spacing	0.27	1.07	22.00	16.81	8.02	5.58	2.82
	Speed	0.20	1.05	22.00		8.38		2.07
50	Spacing	0.39	1.03	22.00	36.23	25.81	9.00	12.35
	Speed	0.09	0.75	22.00		8.50		0.82

Table C-12. Modified Pitt car-following calibration parameters for rain congested conditions

Subject number	Calibration	Parameters K	h	L_l	RMSE values Spacing Initial analysis	Spacing After calibration	Speed Initial analysis	Speed After calibration
		0.35	1.50	32 ft				
52	Spacing	0.01	0.50	22.00	10.06	2.32	2.36	0.59
	Speed	0.20	1.04	22.00		2.22		0.62
67	Spacing	0.02	2.00	32.00	9.44	0.46	2.44	0.19
	Speed	0.02	2.00	32.00		0.51		0.19
68	Spacing	0.18	0.79	22.00	10.24	0.51	2.74	0.37
	Speed	0.12	0.69	22.00		0.95		0.26
50	Spacing	0.14	0.51	32.00	13.41	1.81	3.58	0.52
	Speed	0.14	0.53	32.00		1.87		0.50

LIST OF REFERENCES

Ahn, S., Cassidy, M. J., and Laval, J. (2004). "Verification of a simplified car-following theory." *Transportation Research Part B: Methodological*, 38(5), 431-440.

Bham, G. H., and Benekohal, R. F. (2004). "A high fidelity traffic simulation model based on cellular automata and car-following concepts." *Transportation Research Part C: Emerging Technologies*, 12(1), 1-32.

Brackstone, M., and McDonald, M. (1999). "Car-following: A historical review." *Transportation Research Part F: Traffic Psychology and Behavior*, 2(4), 181-196.

Chakroborty, P., and Kikuchi, S. (1999). "Evaluation of the General Motors based car-following models and a proposed fuzzy inference model." *Transportation Research Part C: Emerging Technologies*, 7(4), 209-235.

Chandler, R. E., Herman, R., and Montroll, E. W. (1958). "Traffic dynamics: Studies in car-following." *Operations Research*, 6(2), 165-184.

Chundury, S., and Wolshon, B. (2000). "Evaluation of CORSIM car-Following model by using Global Positioning System field data." *Transportation Research Record: Journal of the Transportation Research Board*, 1710(-1), 114-121.

Cohen, S. (2002). "Application of car-following systems in microscopic time-scan simulation models." *Transportation Research Record: Journal of the Transportation Research Board*, 1802(-1), 239-247.

Edie, L. C. (1961). "Car-following and steady-state theory for noncongested traffic." *Operations Research*, 9(1), 66-76.

Fritzsche, H. T. (1994). "A model for traffic simulation." *Traffic Engineering Control*, 35, 317–321.

Gazis, D. C., Herman, R., and Potts, R. B. (1959). "Car-following theory of steady-state traffic flow." *Operations Research*, 7(4), 499-505.

Gazis, D. C., Herman, R., and Rothery, R. W. (1961). "Nonlinear follow-the-leader models of traffic flow." *Operations Research*, 9(4), 545-567.

Gipps, P. (1981). "A behavioral car-following model for computer simulation." *Transportation Research Part B: Methodological*, Transportation Research Part B: Methodological, 15(2), 105-111.

Herman, R., Montroll, E. W., Potts, R. B., and Rothery, R. W. (1959). "Traffic dynamics: analysis of stability in car-following." *Operations Research*, 7(1), 86-106.

Khoury, J. E., and Hobeika, A. (2006). "Simulation of an ITS - Crash prevention technology at a no-passing zone site." *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, 10(2), 75.

Kim, T., Lovell, D., and Park, Y. (2007). "Empirical analysis of underlying mechanisms and variability in car-following behavior." *Transportation Research Record: Journal of the Transportation Research Board*, 1999(-1), 170-179.

Kondyli, A. (2009). *Breakdown probability model at freeway-ramp merges based on driver behavior*. University of Florida, Gainesville, Fla.

Lownes, N. E., and Machemehl, R. B. (2006). "VISSIM: a multi-parameter sensitivity analysis." *Proceedings of the 38th conference on Winter simulation*, Winter Simulation Conference, Monterey, California, 1406-1413.

May, A. D. (1990). *Traffic flow fundamentals*. Prentice Hall.

May, A. D., and Keller, H. E. (1967). "Non-integer car-following models." *Highway Research Board*, 19–32.

Newell, G. F. (1961). "Nonlinear effects in the dynamics of car-following." *Operations Research*, 9(2), 209-229.

Olstam, J., and Tapani, A. (2004). *Comparison of car-following models*. Department of Science and Technology (ITN), Campus Norrk\öping, Link\öping University [Institutionen f\ör teknik och naturvetenskap (ITN), Campus Norrk\öping, Link\öpings universitet].

Ozaki, H. (1993). "Reaction and anticipation in the car-following behavior." *Proceedings of the 13th International Symposium on Traffic and Transportation Theory*, 366.

Panwai, S., and Dia, H. (2005). "Comparative evaluation of microscopic car-following behavior." *IEEE Transactions on Intelligent Transportation Systems*, 6(3), 314–325.

Pindyck, R. S., and Rubinfeld, D. L. (n.d.). *Econometric models and economic forecasts. 1998*. McGraw-Hill Book Co., New York, NY.

Psarianos, B., Paradissis, D., Nakos, B., and Karras, G. E. (2001). "A cost-effective road surveying method for the assessment of road alignments." *IV International Symposium Turkish-German Joint Geodetic Days*, 3–6.

Punzo, V., and Simonelli, F. (2005). "Analysis and comparison of microscopic traffic flow models with real traffic microscopic data." *Transportation Research Record: Journal of the Transportation Research Board*, 1934(-1), 53-63.

Rakha, H., Eng, P., and Gao, Y. (2010). "Calibration of steady-state car-following models using macroscopic loop detector data." *TRB 2010 Annual Meeting CD-ROM*.

Rakha, H., Pecker, C., and Cybis, H. (2007). “Calibration procedure for Gipps car-following model.” *Transportation Research Record: Journal of the Transportation Research Board*, 1999(-1), 115-127.

Ranjitkar, P., Nakatsuji, T., and Kawamura, A. (2005). “Experimental analysis of car-following dynamics and traffic stability.” *Transportation Research Record: Journal of the Transportation Research Board*, 1934(-1), 22-32.

Treiterer, J., and MYERS, J. A. (1974). “The hysteresis phenomenon in traffic flow.” *Transportation and Traffic Theory: Proceedings of the Sixth International Symposium on Transportation and Traffic Theory, University of New South Wales, Sydney, Australia, 26-28 August 1974*, 13.

Wiedemann, R., and Reiter, U. (1992). “Microscopic traffic simulation, the simulation system—mission.” *Background and Actual State, CEC Project ICARUS (V1052) Final Report*.

Wilson, R. E. (2001). “An analysis of Gipps's car-following model of highway traffic.” *IMA J Appl Math*, 66(5), 509-537.

Wraith, J. M., and Or, D. (1998). “Nonlinear parameter estimation using spreadsheet software.” *Journal of Natural Resources and Life Sciences Education*, 27, 13–19.

Yang, Q., and Koutsopoulos, H. N. (1996). “A microscopic traffic simulator for evaluation of dynamic traffic management systems.” *Transportation Research Part C: Emerging Technologies*, 4(3), 113-129.

Zhang, H. M., and Kim, T. (2005). “A car-following theory for multiphase vehicular traffic flow.” *Transportation Research Part B*, 39(5), 385–399.

BIOGRAPHICAL SKETCH

Irene Soria was born in 1985 in San Juan, Puerto Rico. The oldest daughter, she grew up mostly in Bayamon, Puerto Rico, graduating from Academia Santa Teresita in 2002. She earned her B.S. in civil engineering from the University of Puerto Rico (Mayaguez Campus) in 2008. In the fall of 2007, she participated in an undergraduate research program called UPR/PURP/ATI, researching in the collective transport of Puerto Rico. In addition, she was a teacher assistant for the introductory course of transportation and traffic engineering to 113 civil engineering students. Irene succesfully completed the Fundamentals of Engineering (FE) examination in 2008.

Irene received her Master of Engineering in civil engineering from the University of Florida in the spring of 2010. She was enrolled in the transportation engineering program. Her specific research interest is in traffic flow theory, driver behavior and geometric design. She centered her research and thesis on the enhancement of car-following models. She also served as a graduate research and teacher assistant at the University of Florida.

Irene has knowledge in different simulations programs like AIMSUN, CORSIM, Synchro, Passer, and Transyt 7-F. As well, she knows programs such as AutoCad, EPANET, Eagle Point, SAP, SPSS, SAS and Nlogit. She has been a recipient of the Dwight Eisenhower Fellowship where she had the opportunity to accomplish an intership at the University of Rhode Island. She is a member of Tau Beta Pi , a honor society for engineers, Institute of Transportation Engineers and the American Society of Civil Engineers.

Upon completion of her master’s program, she plans to seek a position in a civil engineering firm or government agency.