Application of System Dynamics in Car-following Models

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ABSTRACT

Over the past 50 years, many different "car-following" models have been proposed to describe the driver behaviour in a traffic stream. A number of inherent assumptions about human constraints and preferences in existing car-following models hamper their validity for use in the design and evaluation of different ITS (Intelligent Transportation Systems) technologies and/or controls such as AVCSS (Advanced Vehicle Control and Safety Systems).

In this paper we introduce a new Systems Dynamic (SD) car-following model that addresses many of the shortcomings of existing car-following models and provides a more relevant platform for simulating driver behavior in all types of car-following situations subject to changing traffic conditions. The proposed SD model was developed and validated based on observed vehicle tracking data. Preliminary results suggest that the proposed model yields speed and spacing profiles for vehicles in "real time" that compare well with those observed empirically.

Keywords: Car-following, Driver behavior, Systems Dynamics, Microscopic traffic simulation

1.0 INTRODUCTION

Driver behavior involves two main responses: 1) speed and 2) steering. The primary objective of most car-following models is to predict following vehicle speed and spacing profiles based on lead vehicle stimuli (speeds) for a set of route/traffic conditions and driver characteristics. These models typically consider a string of vehicles traveling in a single lane. Lane changes are normally not considered within the scope of simple car-following algorithms. More complex driver responses considered within more extensive microscopic traffic simulations combine simple car-following models with models of other driver responses (i.e. lane changes, routing, etc.) to produce a more practical topology of driver behaviour in actual traffic situations.

Given the increasing demand for using new technologies and techniques in transportation sector, it is clear that a detailed understanding of driver behaviour under different transportation conditions is now becoming highly important. For example, the validity of car-following models appears to be especially important when evaluating different ITS technologies and/or controls such as, AVCSS or ACC (Adaptive Cruise Control). These technologies are expected to modify driver behavior in a complex interactive fashion. From the perspective of car-following, these technologies also seek to replicate driver behavior through partial control of the accelerator, while removing potential hazards that may occur through misperception of distance and other driver errors. Working prototypes are currently being investigated and will likely be available commercially within the next few years (Touran, 1999). To assess the impact of AVCSS or ACC on safety and traffic flow, it becomes necessary to utilize the results of car-following models and the insights they provide into how drivers perceive and react to variable speeds and separation distances in actual traffic situations.

The model introduced in this paper makes use of Systems Dynamics (SD) principles. Systems Dynamics provides the computational platform for describing and investigating the complex process that reflect driver behaviour in a traffic stream. The SD platform is characterized by many non-linear relationships (both heuristic and empirical) with numerous feedback loops. As such, the proposed SD car-following model introduced in this paper relaxes many of the limiting assumptions of existing car-following models, rendering the process more relevant for microscopic traffic simulation.

This paper has three basic objectives: 1) review existing car-following models and identify their behavioural shortcomings, 2) develop an SD car-following model that addresses many of these shortcomings, and 3) compare the SD model to observed vehicle tracking data and assess its ability to predict speed and spacing profiles over time.

2.0 REVIEW OF CAR-FOLLOWING MODELS

A comprehensive review of the historical development of car-following models is available in the literature (Brackstone and McDonald, 1999). In this paper we provide a summary of the important models, their formulation, and limitations.

Car-following models have been studied extensively since the early 1950s. The earliest work focused on the principle that vehicle separation is governed by safety considerations by which distance or time headway between vehicles is a function of relative vehicle speeds. Pipes (1953) developed a car-following model that assumes that drivers control their speed to maintain a desired spacing. This spacing is assumed to be linearly dependent on speed.

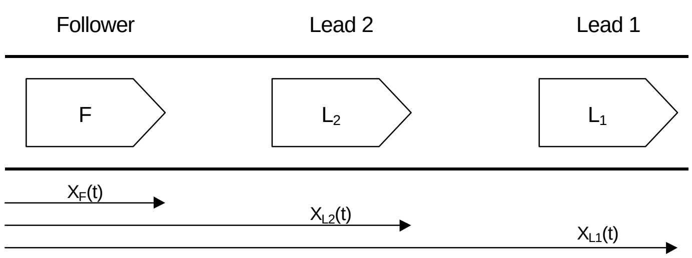
Forbes (1958) assumed that drivers control their speed to maintain a minimum time headway. This time headway is a linear function of the speed of the lead vehicle. Subsequent models (**Table 1**) have incorporated factors such as spacing between vehicles, speed differential, and driver sensitivity into car-following behavior. Car-following models developed by Chandler et al. (1958), Gazis et al. (1959, 1961), Edie (1961), Newell (1961), Herman and Rothery (1962), and Bierley (1963) all assume that following vehicle drivers respond solely to changes in speed and position of the lead vehicle (essentially the vehicle immediately in front). Fox and Lehman (1967), and Bexelius (1968) have suggested that instead of considering only the vehicle immediately in front, drivers should also take into account the speed and position of other “lead vehicles” (at least two downstream). This suggests a more reasonable perception of driver behaviour where following vehicle drivers take a longer range view of the traffic conditions downstream in setting their respective speed and spacing over time. A common feature of most of the car-following models in Table 1 is the assumption that the following vehicle driver’s responses are based on spacing and differential speed between the following and the lead vehicle(s). The underlying assumption for these models is that the following vehicle driver can accurately perceive spacing and differential speed between the following and the lead vehicle(s).

A larger number of studies have focused on calibration of parameters (á, *m*, and *l*) in the GHR model (the model developed by Gazis, Herman and Rothery, 1962) and it variants. Among these the most notable examples of are: May and Keller (1967), Heyes and Ashworth (1972), Treiterer and Myers (1974), Ceder et al. (1976), Aron (1988), Ozaki, (1993). According to (Brackstone and McDonald, 1999) not withstanding considerable work on calibration and validation the general level of agreement on parameter values has led to its general demise.

Another class of models, called psychophysical or action point models, also exists. These models have been developed in the basis that drivers perceive relative speed by detecting changes in the apparent size of the downstream vehicles. The threshold for this perception, which is well known, determines whether or not a driver can perceive a change in relative speed or spacing. Several existing microscopic traffic simulation programs including Paramics and Mission incorporated action point car-following models. The difficulty with these models is the lack of objective calibration of the individual parameters and thresholds, and consequently of the models as a whole.

Table 1: Selected car-following model algorithms.

Source:	**Corresponding Car-following Model**
Chandler et al. (1958)	$a_F(t+\Delta t) = a \left[V_{L2}(t) - V_F(t)\right]$
Gazis et al. (1959, 1961)	$a_F(t+\Delta t) = a \left[\dfrac{1}{X_{L2}(t) - X_F(t)}\right]\left[V_{L2}(t) - V_F(t)\right]$
Edie (1961)	$a_F(t+\Delta t) = a \left[\dfrac{V_F(t)}{[X_{L2}(t) - X_F(t)]^2}\right][V_{L2}(t) - V_F(t)]$
Newell (1961)	$a_F(t+\Delta t) = G_n \left[X_{L2}(t) - X_F(t)\right]$
Herman and Rothery, (1962)	$a_F(t+\Delta t) = a \left[\dfrac{[V_F(t)]^m}{[X_{L2}(t) - X_F(t)]^l}\right][V_{L2}(t) - V_F(t)]$
Bierley (1963)	$a_F(t+\Delta t) = a \left[V_{L2}(t) - V_F(t)\right] + b \left[X_{L2}(t) - X_F(t)\right]$
Fox and Lehman (1967)	$a_F(t+\Delta t) = a\, V_F(t) \left[\dfrac{W_1[V_{L2}(t) - V_F(t)]}{[X_{L2}(t) - X_F(t)]^2} + \dfrac{W_2[V_{L1}(t) - V_F(t)]}{[X_{L1}(t) - X_F(t)]^2}\right]$
Bexelius (1968)	$a_F(t+\Delta t) = a \left[V_{L2}(t) - V_F(t)\right] + b \left[V_{L1}(t) - V_F(t)\right]$
Rockwell et al. (1968)	$a_F(t+\Delta t) = a \left[V_{L2}(t) - V_F(t)\right] + b \; a_{L2}(t)$



Where:

a_F(t+Ät)	=	Acceleration rate of Following Vehicle driver at time t + Ät
a_{L2}(t)	=	Acceleration rate of Lead Vehicle 2 driver at time t
V_F(t), V_{L1}(t), V_{L2}(t)	=	Speed of Following, Lead Vehicle 1 and Lead Vehicle 2 at time t
X_F(t), X_{L1}(t), X_{L1}(t)	=	Position of Following, Lead Vehicle 1 and Lead Vehicle 2 at time t
t	=	Current simulation time (seconds)
Ät	=	Perception-reaction time (seconds) or simulation interval
G_n	=	Empirical relationship between velocity and headway for acceleration/deceleration
á,â,m,l,W_1,W_2	=	Model parameters

There are four basic assumptions inherent in many existing models that tend to restrict their ability to explain and predict driver behaviour in actual traffic situations:

1. The vast majority of car-following models assume that following vehicle drivers can accurately perceive relative speed of the lead and following vehicles, absolute speed and/or acceleration of lead vehicle at any point in time. These assumptions are unrealistic given the rectilinear nature of vehicles moving in a single lane, and problems of depth perception and differences driver reactions with factors such as, ageing, impairment, disability, etc (Boer, 1999).

2. Many existing car-following models assume that following vehicle drivers respond only to the lead vehicle immediately in front without observing other vehicles downstream. A number of researchers have observed that in actual traffic situations, drivers take a more extensive view of traffic conditions ahead (which may include several lead vehicles) in setting the following vehicle desired speeds and spacing (Fox and Lehman, 1967; Bexelius, 1968, Ozaki, 1993, and Toruran, 1999).

3. Many existing car-following models, particularly the GRH models, assume a mathematical expression that is empirically based but fails to explain actual behaviour in a mechanistic fashion (cause-effect). Best fit expressions fail to clarify or explain, why certain relationships are specified as they are (Winsum, 1999). These expressions have little, if any, basis on actual behaviour, and the model parameters have no obvious connection with identifiable driver and vehicle traits that explains behaviour (Gipps, 1981).

4. Many existing car-following models assume symmetrical driver responses to changing traffic stimuli involving lead vehicles. To illustrate, we consider two cases, one with a positive relative speed (i.e. lead vehicle is travelling faster) and the other with a negative relative speed (lead vehicle slower). For the same magnitude of speed difference, the following vehicle driver in the first instance will increase his or her speed without incurring higher collision risks. In the latter instance, the following vehicle driver will need to decelerate to avoid a potential collision, since both vehicles are moving closer to each other. From a safety perspective, we would expect the acceleration/deceleration rate in the first case to be less than the acceleration/deceleration rate in the second case. Many existing car-following models assume the magnitude of acceleration/deceleration to be the same. This situation is normally outside the scope of existing car-following models and is explained using separate collision avoidance algorithms (Leutzbach, 1988). When both the lead and following vehicle are traveling at the same speed, many existing

car-following models assume zero following vehicle deceleration/acceleration rates regardless of the spacing between vehicles. This assumption is clearly unrealistic (Chakroborty and Kikuchi, 1999).

3.0 PROPOSED SD CAR-FOLLOWING MODEL

The car-following situation considered in this paper assumes a string of three vehicles (two lead vehicles and one following vehicle) traveling along a single lane. It is assumed that all vehicles travel in the same lane and only adjustments in speed are permitted for all drivers involved. The profile of the first lead vehicle is determined exogenously based on predominant traffic conditions. The speed and spacing profiles for the second lead and the following vehicle are determined internally.

One of the basic differences between the proposed model and the existing car-following models is that in existing car-following models following vehicle drivers consider only one lead vehicle ahead, while in the proposed model following vehicle drivers consider all vehicles travelling ahead within their comfort zone. For example, in case of three vehicles situation considered in this paper the following vehicle driver would perceive information either from both lead vehicles (1^{st} and 2^{nd}) or from only second lead vehicle, depending on whether one or both lead vehicles are travelling within his/her comfort zone. The comfort zone of a driver is defined based on his/her current speed and perception of crash risk.

Unlike many existing car-following models, the proposed model assumes that in a rectilinear travel system with variable speeds and conditions, following vehicle drivers do not have the required depth perception to accurately ascertain spacing, differential speeds, and/or acceleration of lead vehicle at any point in time. In addition to his own speed and safe comfort zone, the following vehicle driver can only ascertain his or her spacing to the vehicle immediately in front (the second lead vehicle), and possibly the spacing between both lead vehicles if they are sufficiently close. We note that in the proposed model the speeds and/or acceleration of the lead vehicles are not required as inputs in setting the following vehicle acceleration/deceleration rates and spacing. This assumption differs from many existing car-following models and can be viewed as being more parsimonious than these models in estimating the following vehicle speed and position over time.

Underlying assumptions

The proposed SD model differs from existing car-following models in several important aspects:

1. A simplified acceleration/deceleration rule is used for following drivers that includes only spacing and rate of change in spacing between the lead and the following vehicle.
2. The information from more than one vehicle ahead is used for decision-making process of following vehicle drivers.
3. The proposed model permits changes in perception/reaction time of following vehicle drivers to account for supplementary lead vehicle stimuli, such as, the status of lead vehicle(s) brake lights.
4. The concept of a comfort zone for the following vehicle driver is introduced to reflect his/her desired speed and spacing for different driving conditions.

Figure 1 illustrates the dynamic relationships inherent in the proposed SD car-following model. For every decision interval, a driver sets a unique "safe comfort zone". This comfort zone reflects speed and spacing status that the driver considers to be safe over time and changing traffic conditions. Here we assume that the desired speed is based on the current spacing and rate of change in spacing with respect to the lead vehicle immediately in front. If the current spacing is shorter than that dictated by the driver's comfort zone and is decreasing in length, the following vehicle driver will decelerate to achieve a desired comfort zone or separation distance. Conversely, if the current spacing exceeds that set by the driver’s comfort zone, and the vehicle is travelling at a speed below desired speed, the following vehicle driver will accelerate.

The proposed model assumes that the level of alertness of a driver affects the perception/reaction time component of the acceleration/deceleration rate. If a driver is alert, less time is needed to perceive and react to a given situation. In the proposed SD car-following model, the following vehicle driver will modify his or her personal perception/reaction time with respect to the status of the lead vehicle brake lights. In the proposed SD model, we assume that the following vehicle driver becomes more alert with reduced perception/reaction times when the lead vehicle brake lights are on and the lead vehicle is within the following vehicle driver comfort zone. The status of the brake lights can be ascertained internally. Ozaki (1993) suggests that brake light status can be determined as a function of vehicle deceleration rates, such that: if deceleration rate < -0.013 times the speed of the vehicle, then brake lights are assumed to be lit.

As indicated in Figure 1, the following vehicle driver considers both the first and second lead vehicle position in changing his/her speed. The question is how to balance the stimuli between the first and second lead vehicles in setting the following vehicle driver response. While both lead vehicles provide stimuli to the following vehicle driver, the importance that the following vehicle driver places on one lead as compared to the other depends on the spacing between the following vehicles and the lead vehicle immediately in front, driver comfort zone for prevailing speed, and the spacing between the two lead vehicles.

Model Formulation

The proposed car-following model consists of four sectors: 1) the first lead vehicle, 2) the second lead vehicle (vehicle immediately in front of following vehicle), 3) the following vehicle, and 4) the spacing sector. The stock flow diagram for the proposed model is given in **Figure 2 (a and b)**. Each sector performs certain functions to produce speed and spacing profiles for individual vehicles in the three-vehicle string. Functions in each sector interact with functions in the other sectors through feedback links. This reflects how the speed and spacing of one vehicle acts to affect the speed and spacing of another vehicle in the string. The first lead vehicle sector is specified exogenously and prescribes the lead vehicle target conditions for input into the second lead and following vehicle sectors. The acceleration/deceleration rate, speed and spacing of the second lead and following vehicles are determined within the model, subject to rules and assumptions pre-scribed in the following paragraphs. Road geometry, pavement conditions, and weather conditions are set exogenously.

The process describing the second lead vehicle sector is similar to that associated with the following vehicle sector. The only difference is that the following vehicle driver sets his or her spacing and rate of change in spacing on the basis of spacing between the first and second lead vehicle and between the second lead vehicle and itself. The second lead vehicle driver on the other hand considers only its spacing with the first lead vehicle in setting his/her spacing and speed. The assumption here is that we are dealing with a three vehicle string. This can be extended to include longer strings, with an appropriate number of lead vehicle sectors.

The acceleration/deceleration rate of the following vehicle depends on the driver’s perception reaction time, current and desired speed. The desired speed depends on two factors: 1) current spacing between the following vehicle and lead vehicle immediately in front, and 2) rate of change in spacing between the following vehicle and the lead vehicle immediately in front. In the SD model, the former factor is calibrated based on observed individual vehicle tracking data, while the latter is a non-linear function of rate of change in spacing between second lead and following vehicles. This relationship is based on a heuristic understanding of the situation as opposed to empirical results from observed field data. The boundary limits of this non-linear function are set so as to satisfy the extreme limits of a driver's perception reaction time as reported by Ozaki (1993). The product of factors (1) and (2) above yields the desired speed of the following vehicle.

The perception reaction time of the following vehicle driver depends upon his/her level of alertness. Alertness is defined in terms of driver's perception reaction time as modified by brake light status, as discussed above. When the value of alertness level is one, the perception reaction time is assumed to be 2.5 sec (Olson, 1986). The perception reaction time decreases as the vehicles get close to each other and the brake lights on the lead vehicle(s) are lit (Ozaki,1993).

In Figure 2b, a fourth sector is defined that reflects vehicle spacing (separation distance) profiles, between the first and second lead vehicles, and between the second lead and following vehicle. The factors such as pavement conditions, pavement friction, road geometry, and traffic conditions can affect the distance travelled by a vehicle at a particular speed. For this paper, we have assumed ideal weather and pavement conditions.

4.0 CALIBRATION AND VALIDATION USING SAVE DATA

The major component of the proposed car-following model (relationship between current spacing and desired speed) is calibrated based on observed individual vehicle tracking data obtained from the SAVME (System for Assessment of Vehicle Motion Environment) database (Ervin, 2001). The University of Michigan Transportation Research Institute (UMTRI) developed this SAVME database for the National Highway Traffic Safety Administration. This database provides a complete microscopic record of trajectories and distance headway observed for individual vehicles in a traffic stream over a period of time. The SAVME database contains 18 hours of vehicle trajectory data representing over 30,500 vehicles. All data were collected during daylight hours.

Trajectory data for a random sample of 132 vehicle pairs traveling in the shoulder lane were extracted from the SAVME database. For each pair of vehicles, the speed of the following vehicle and the spacing were extracted. For each observed speed, the mean distance headway from all vehicles observed to travel at this speed was computed. The results are illustrated in Figure 3 as the desired speed versus mean spacing. To ensure realistic behavior at the boundaries of relationship shown in Figure 3, constraints are incorporated such that the desired speed must be non-negative and not greater than the maximum assumed speed of 70 ft/sec (77 Km/h). The relationship illustrated in Figure 3 is consistent with the data obtained from a Newcastle University research team in the United Kingdom (May, 1990). Like SAVME database, the data collected by a research team at Newcastle University also tends to demonstrate a fairly aggressive car-following behaviour at short spacing and less aggressive car-following behaviour at longer spacing, as illustrated by Figure 3.

Observations in SAVME suggest that desired speed for a given spacing differs between drivers. This is likely due to individual driver differences of age, gender, risk taking propensity, skills, vehicle size and performance characteristics. Moreover, the situational factors such as time of day, day of week, road geometry, traffic conditions, weather and road conditions also influence the desired speed of a driver for a given spacing. As an initial step, we have assumed ideal roadway conditions and individual driver differences and situational factors are not explicitly considered into the proposed car-following model in this paper.

5.0 EVALUATION OF PROPOSED SD CAR-FOLLOWING MODEL

The microscopic evaluation of the proposed model is conducted by comparing model estimates of speed and spacing for the second lead and the following vehicle to those observed in the SAVME database. The trajectories of first lead vehicles were randomly selected from the SAVME database. The trajectories of the two vehicles following the selected lead vehicle (second lead and following) were also extracted from the SAVME database and were used to compare to the model outputs.

The trajectory of the first lead vehicle, the initial speed and position of the second lead and following vehicles were provided as inputs to the proposed car-following model. The model was then used to estimate the behavior of the second lead and following vehicle in response to the known behavior of the first lead vehicle.

Figure 4 illustrates the observed and model predicted results for the first data set extracted from the SAVME database. Figure 4a illustrates observed and predicted speed and spacing associated with the second lead vehicle. Figure 4b illustrates the same for the following vehicle. As indicated by the results illustrated in Figure 4 (a and b), the speed and spacing profiles predicted by the proposed car-following model closely follow those in the observed field data.

Twenty samples of three-vehicle strings were extracted from SAVME database. For each sample the root-mean-squared (RMS) error associated with the prediction of speeds and spacing of second and following vehicle was estimated as given in **Table 2**. The average RMS error associated with the prediction of second lead and following vehicle speed for the twenty samples was found to be 3.68 Km/h and 4.7 Km/h respectively. The RMS error associated with the prediction of second lead and following vehicle spacing was 2.56 m and 2.87 m respectively.

Table 2: RMS error associated with twenty sample applications

Sample	Observed Average Speed (Km/h)		Observed Average Spacing (m)		Root-Mean-Squared-Error Speed (Km/h)		Root-Mean-Squared-Error Spacing (m)	
	V2	Vf	S2	Sf	V2	Vf	S2	Sf
1	53.31	66.11	24.98	62.17	5.16	1.46	1.65	1.24
2	55.72	59.96	24.02	18.57	1.06	6.15	0.28	5.63
3	55.66	59.54	30.58	29.67	3.39	4.33	2.34	0.89
4	67.17	65.27	18.66	18.13	0.78	3.05	0.19	2.10
5	52.20	58.87	16.00	30.85	5.23	5.07	5.94	3.82
6	55.78	52.71	21.39	25.15	2.99	6.42	3.23	4.01
7	58.67	61.43	29.69	27.40	1.61	1.24	0.76	0.80
8	41.99	48.70	23.18	42.42	5.51	8.44	2.54	1.15
9	44.03	43.97	16.47	20.02	2.24	2.59	1.40	1.13
10	62.35	62.87	25.38	51.91	3.15	3.68	0.95	2.57
11	67.95	60.04	45.81	61.42	3.24	6.30	1.05	0.79
12	52.34	52.43	51.06	16.13	5.80	7.02	3.90	8.45
13	44.63	44.47	15.15	20.82	3.61	2.77	3.61	2.01
14	47.01	48.72	20.68	19.52	3.09	5.48	5.66	3.48
15	59.99	63.47	29.16	32.43	1.57	2.63	1.15	1.00
16	50.88	48.51	29.18	19.36	4.09	3.26	3.82	5.62
17	54.93	55.25	40.68	48.83	8.88	9.73	3.45	0.17
18	47.49	50.80	17.40	17.21	4.66	5.34	2.53	3.20
19	35.45	36.67	21.22	12.00	2.94	5.04	4.88	5.56
20	60.05	60.52	32.89	20.37	4.55	4.04	1.84	3.75
Average	**53.38**	**55.01**	**26.68**	**29.72**	**3.68**	**4.70**	**2.56**	**2.87**

V2 = Second lead vehicle speed

Vf = Following vehicle speed

S2 = Spacing between first and second lead Vehicle

Sf = Spacing between second lead and following Vehicle

A one-way ANOVA was carried out to assess the statistical significance of the RMS error with respect to the following vehicle speed and spacing. The results of ANOVA are given in **Table 3**. For this analysis the variation in observed mean speed of following vehicle was grouped into three classes (< 50Km/h, 50 - 60 Km/h, and > 60 Km/h).

Table 3: ANOVA results, RMS error versus following vehicle speed and spacing.

Variable	P-value	Remarks
Vf	0.024	Significant
Sf	0.206	Not significant

As indicated in Table 3, the ANOVA suggests that the mean speed of following vehicle (Vf) has a statistically significant effect on the RMS error of following vehicle speed. The P-value for the following vehicle spacing (Sf) shows the variation in observed mean speed of following vehicle speed lacks statistical significance at the 5% level. To further investigate the performance of the proposed model in predicting the speed of following vehicle, the RMS error of following vehicle speed is plotted against observed mean speed of following vehicle (**Figure 5**). As shown in Figure 5, the RMS error of following vehicle speed at higher observed mean speed is less than the RMS error at lower observed mean speed. At this point we cannot speculate on the reason for this relationship.

A regression analysis of predicted and observed speed and spacing of following vehicle was carried out for the sample application. The results are shown in **Figures 6 and 7**. Figure 6 shows the plot of predicted versus observed speed of the following vehicle. Figure 7 shows the plot of predicted versus observed spacing of the following vehicle. The results indicate significant agreement between the predicted output from the model and the observed field data. While these results are based on a limited comparison between the proposed SD car-following estimates and observed SAVME data, they suggest that the proposed model can closely reflect observed speed and spacing profiles for selected three-vehicle strings, where following vehicle drivers consider both two lead vehicle stimuli in setting speeds and spacing over time.

6.0 CONCLUSIONS

In this paper we have discussed a number of existing car-following models and have identified several common shortcomings. We have presented a revised car-following model based on System Dynamics principles, which attempts to address many of these shortcomings. The proposed model assumes that drivers adjust their speed based on the current spacing and rate of change in current spacing to next downstream vehicle. The model also takes into account the driver's desired speed and distance headway in relation to increased risk of collisions.

The proposed model assumes that drivers are capable of estimating the spacing between their own vehicle and the next downstream vehicle. The model, unlike many existing car-following models, does not make unrealistic assumptions about drivers' ability to estimate the speed of downstream vehicles.

In this paper we have compared the model estimates of speed and spacing profiles for the following and second lead vehicle to the speed and spacing profiles of observed vehicles. These comparisons suggest that the proposed car-following model yields realistic results in replicating the behavior of the following vehicle driver from an observed vehicle tracking database. In the proposed model drivers seek to maintain the speed and spacing that is consistent with their understanding of the risks involved for any traffic situation.

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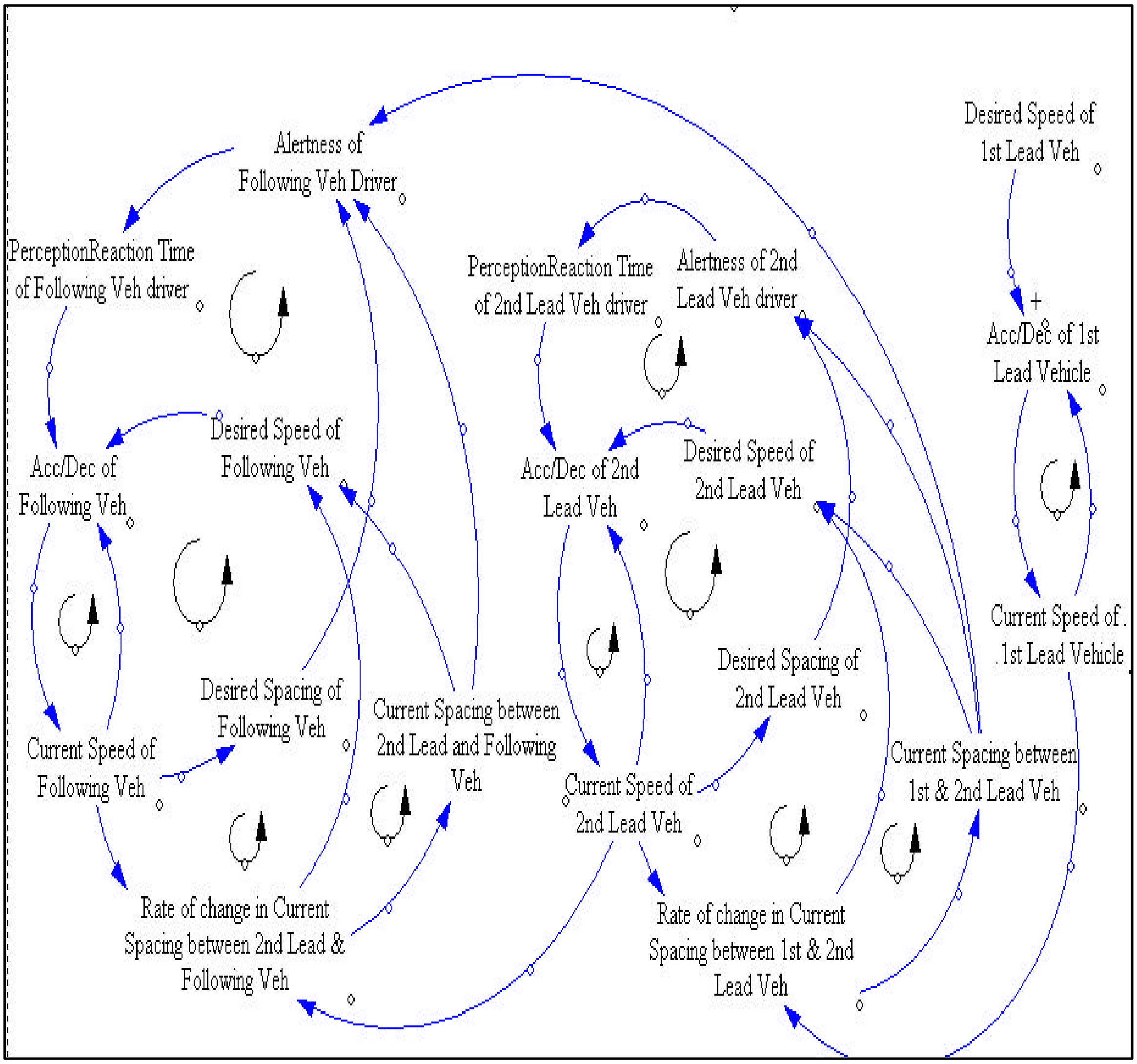


Figure 1: Dynamics hypothesis of proposed car-following model

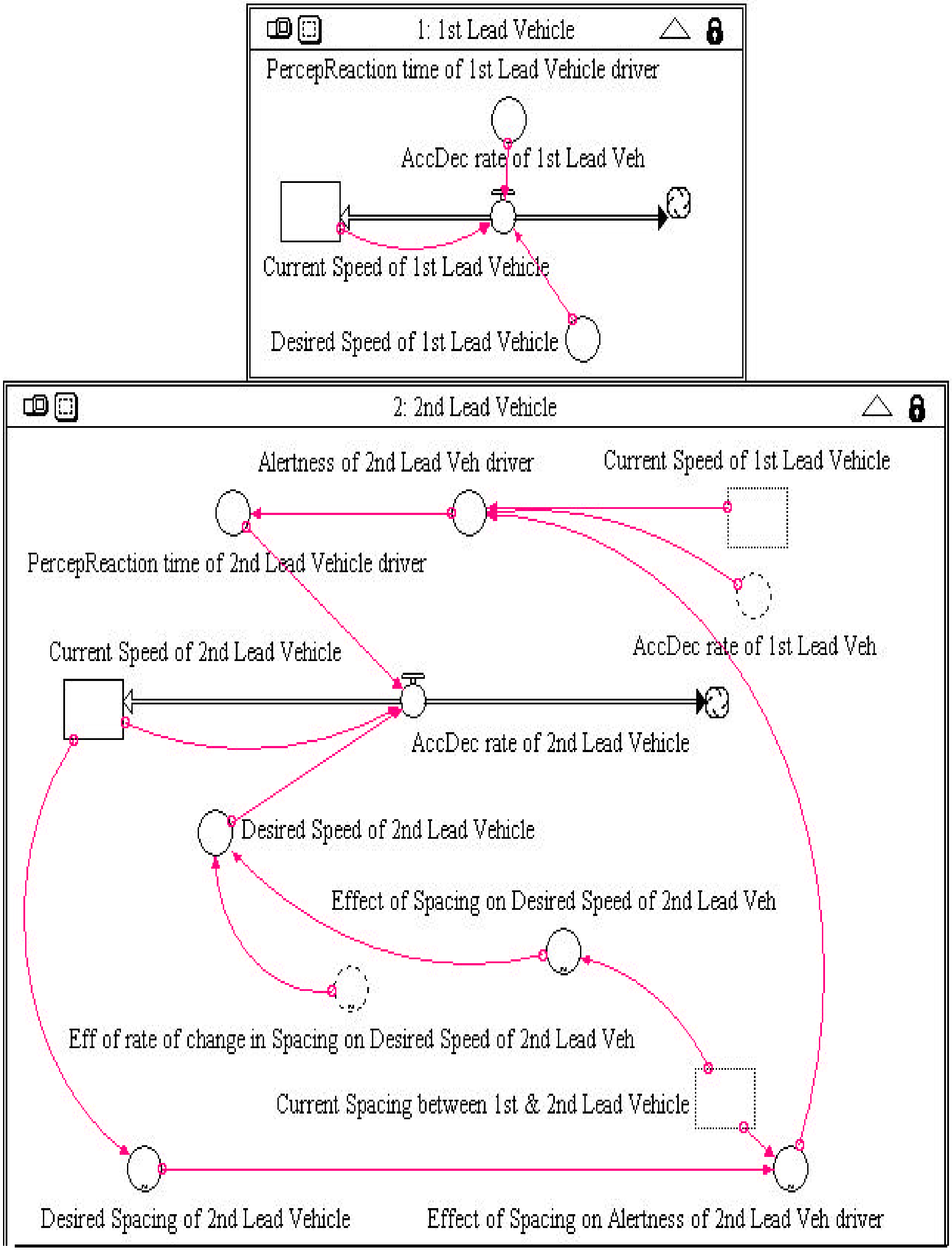


Figure 2a: Stock-flow diagram of 1st and 2nd lead vehicle sector

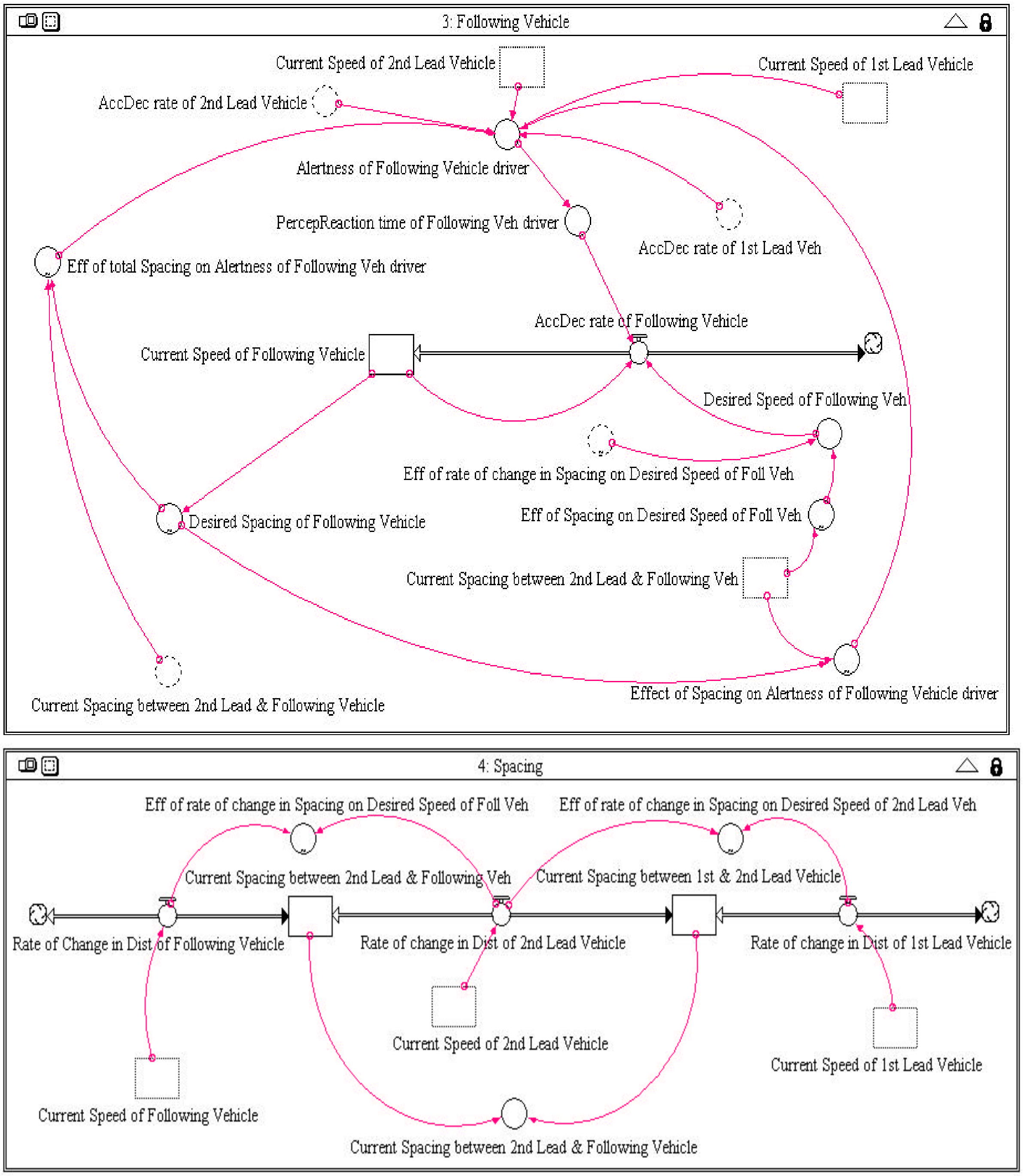


Figure 2b: Stock-flow diagram of following vehicle and spacing sector

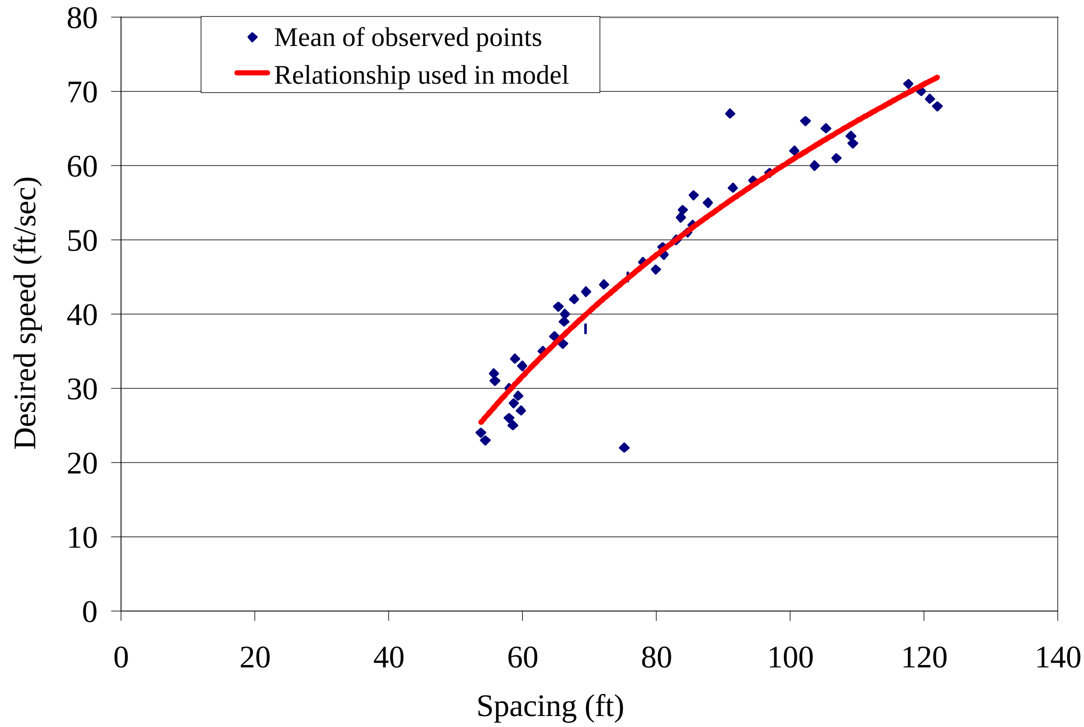
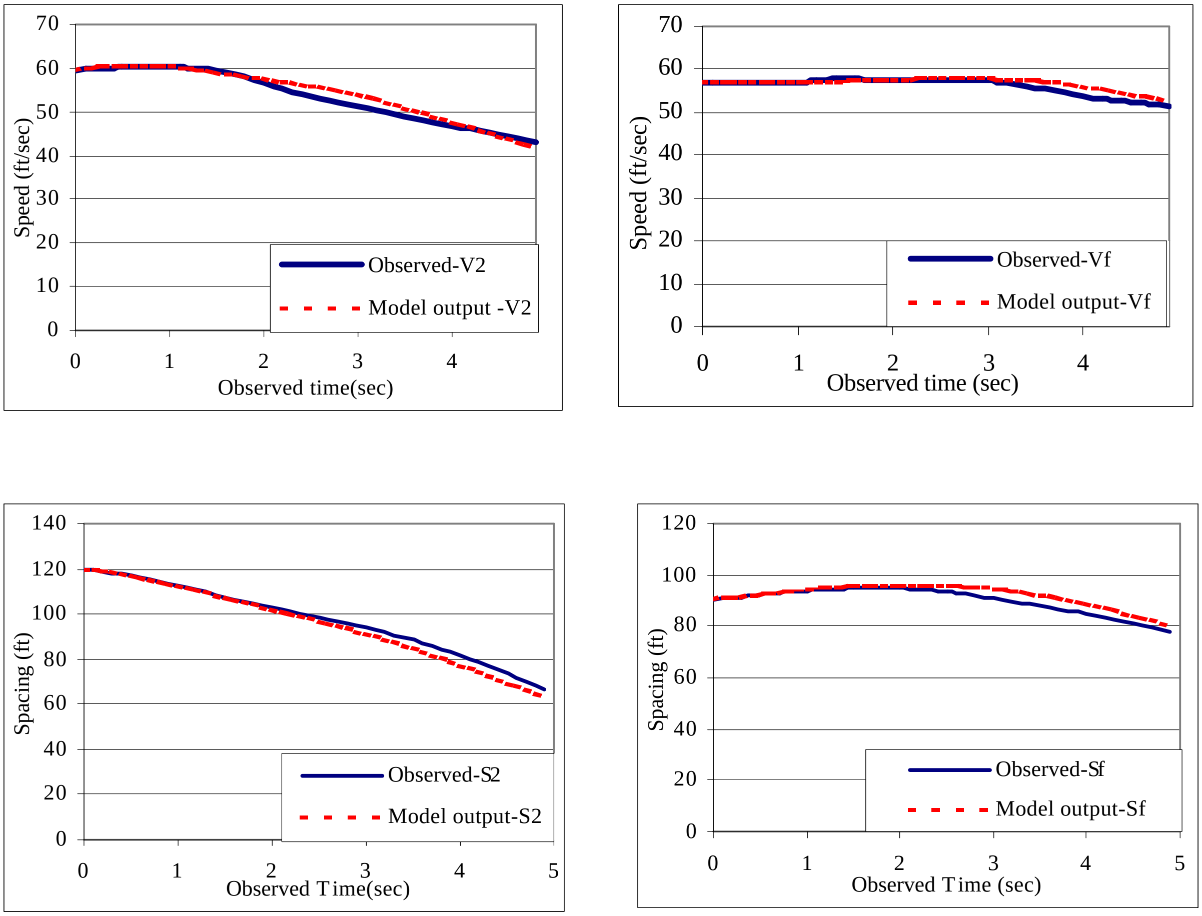


Figure 3: Calibrated relationship between spacing and desired speed



(a) second Lead Vehicle

(b) Following Vehicle

Figure 4: Comparison of Predicted and Observed vehicle speeds and spacing (Data Set 1)

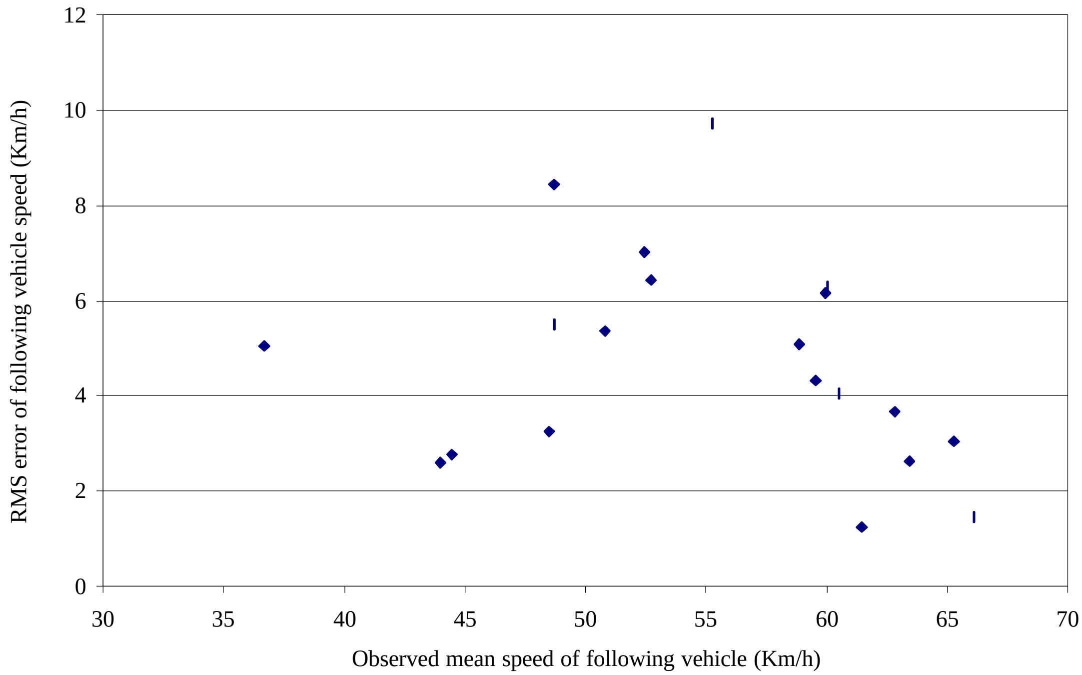


Figure 5: RMS error Vs Observed mean speed of following vehicle (Km/h)

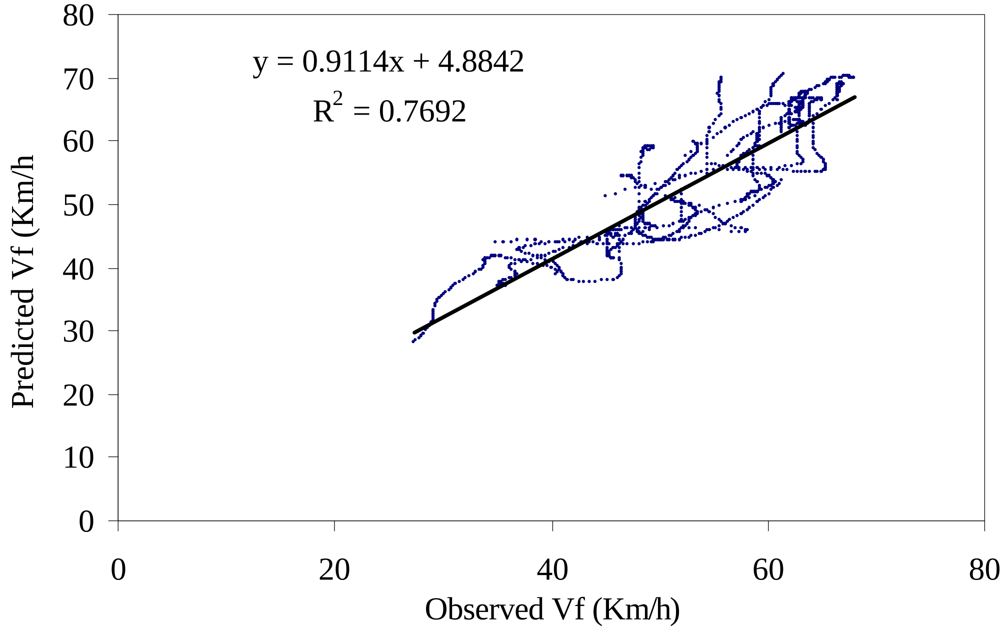


Figure 6: Predicated Vs Observed speed of following vehicle for twenty samples (n = 1055)

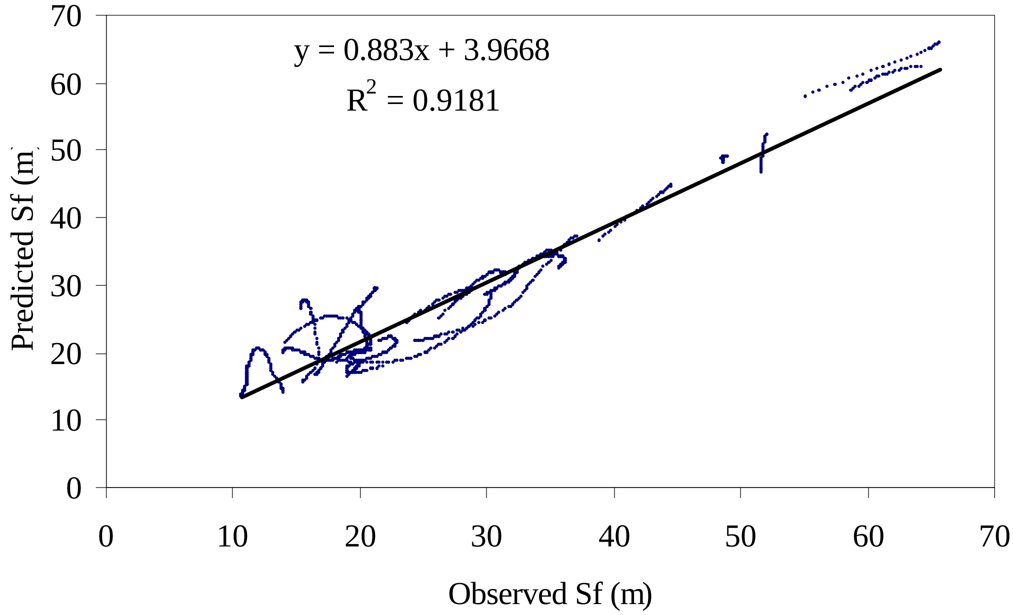


Figure 7: Predicated Vs Observed spacing of following vehicle for twenty samples (n = 1055)

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