Review of Data Collection Methods for Microscopic Traffic Simulation

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Abstract

Research into developing more reliable microscopic traffic simulation models is seriously hampered by the availability of suitable microscopic data for calibration and validation purposes. This paper presents a review of several data collection technologies that the authors have been experimenting with. The methods include (i) video recording (ii) the use of differential GPS (DGPS) and (iii) an instrumented vehicle fitted with the S.M.S. Drive Recorder system. Examples of data collection with each method are briefly described, and some of the results presented to illustrate the capabilities of the methods. The last section of the paper summarises the advantages and limitations of each method and conclusions are drawn on their suitability for the required purpose. The experiments shows that each method can provide some useful results for microscopic simulation model development, but cannot provide continuous spacing-, speed- and acceleration profiles of large vehicle platoons moving through various traffic scenarios. Further research is required to develop more sophisticated data collection techniques and to investigate such aspects of driver behaviour as aggressiveness, and factors influencing lane selection.

Keywords: microsimulation, data collection, car following, lane changing

Topic area: Transport Modelling (Data Collection Methods)

1 Introduction

Microscopic simulation models are becoming increasingly important tools in modelling transport systems. They can be used to model complex transport networks and to evaluate various traffic management alternatives in order to determine the optimum solution for traffic problems that cannot be studied by traditional analytical methods. Several traffic simulation tools are widely used in many countries, including AIMSUN-2 (Barceló et al. 1999), MITSIM (Yang and Koutsopoulos, 1996), PARAMICS (Duncan 1995) and VISSIM (Fellendorf and Vortisch, 2001). A recent survey of such systems, however, reports several major problems including computational performance, the

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accuracy of models in representing the traffic flow, and the difficulty of integration with advanced traffic management and traffic information systems (Skabardonis and May 1998).

A topic of increasing concern is the validity of the microscopic sub-models, such as the car following and lane changing models. It is often claimed that the visualisation and animation capabilities of microsimulation models are more advanced than their ability to reproduce measured/observed traffic flow characteristics. Research into developing more reliable car following and lane changing models is ongoing, but these efforts are seriously hampered by the availability of suitable data for calibration and validation purposes. In the past car following and lane changing models were accepted as valid if they were able to reproduce traffic flow conditions at the aggregate level, in the form of speed-flow and density relationships and little, if any, microscopic comparisons were made. This, in turn, was due to the unavailability of time series data of individual vehicle movement characteristics over longer periods and in different traffic conditions. One notable exception is the data collected by the US Federal Highway Administration in 1982-85 for selected types of freeway bottleneck sections (FHWA 1985). These data sets were developed by digitising vehicle positions from time-lapse aerial photography at six freeway sites. The serious lack of suitable microscopic data is demonstrated by the fact that several recent research efforts are still based on this one twenty-year old source, eg. Toledo et al. (2003), Bham. and Benekohal (2004) and Cohen (2004). The US FHWA's Next Generation Simulation (NGSIM) program initiated in 2003 recognised the importance of this data shortage and set one of the core objectives of the project to provide suitable data sets for calibration and validation purposes (NGSIM 2003).

Many aspects of driver behaviour require further research at the level of detail appropriate for micro-simulation models, including

- vehicle acceleration-deceleration characteristics in typical driving conditions, for various vehicle types (passenger cars, motorcycles, trucks, buses)
- vehicle speed variation with respect to desired speed and legal speed limit,
- car following behaviour in typical urban and high speed driving situations,
- lane selection behaviour in typical urban driving situations,
- lane changing and merging behaviour in various flow conditions, especially during highly congested conditions.

The authors have been experimenting with several methods to collect data on the above vehicle/driver characteristics with varying levels of success. The aim of this paper is to review these data collection technologies and their use in developing car following and lane changing models for micro-simulation. The methods include (i) video recording (ii) the use of differential GPS (DGPS) and (iii) an instrumented vehicle fitted with the S.M.S. Drive Recorder system, and additionally, with a device to measure the acceleration directly. In the following sections examples of data collection with each method are briefly described, and some of the results presented to illustrate the capabilities of the methods. The last section of the paper summarises the advantages and limitations of each method and conclusions are drawn on their suitability for the required purpose.

2 Data Collection by video recording

Video cameras placed at high vantage points in Sydney were used to record the movement of vehicle platoons over several urban road sections between signalised intersections. Vehicle platoons were recorded cruising, decelerating and stopping at the intersection, then accelerating and departing, over a section of 160 to 200 metres. The distance between physical features on the road (eg, stop-lines, lane markings) was measured by a measuring wheel. The tapes were then replayed frame by frame, and the position of each vehicle was estimated at 0.2 second intervals by comparison with the identified features of the road. The vehicle positions were smoothed using a polynomial function to reduce the estimation error, and the speed and acceleration of each vehicle were estimated from the vehicle positions. This process produced relatively smooth trajectories with an estimated accuracy of 0.5 metres.

2.1 Study of car following behaviour

In one study the data were used to calibrate and validate a car following model developed for a microsimulation model (ARTEMiS, previously called SITRAS) using a 1 second simulation time update interval (Hidas, 1998). The car following model is based on the assumption that the follower vehicle has a desired spacing which is a linear function of the speed, including a random judgement error component. The desired spacing parameters were estimated separately for each individual vehicle from the video recordings. A total of eight platoons including 26 vehicles (all passenger cars) were studied in detail. Figure 1 shows the spacing vs. speed relationship of one platoon undergoing a speed disturbance (ie. deceleration followed by acceleration). It can be seen that while individual vehicles have a fairly consistent spacing behaviour with respect to their own speed, there are significant differences between individual drivers. Figure 1 also shows that each driver has different desired spacing in the deceleration and acceleration phases, creating a distinct hysteresis curve. This analysis confirmed that the desired spacing is an individual driver characteristic, and that distinct parameters represent the desired spacing in acceleration and deceleration. However, it should be taken into account that these relationships are based on relatively short time observations of the individual drivers and no information is collected on the consistency of drivers in maintaining their spacing behaviour.

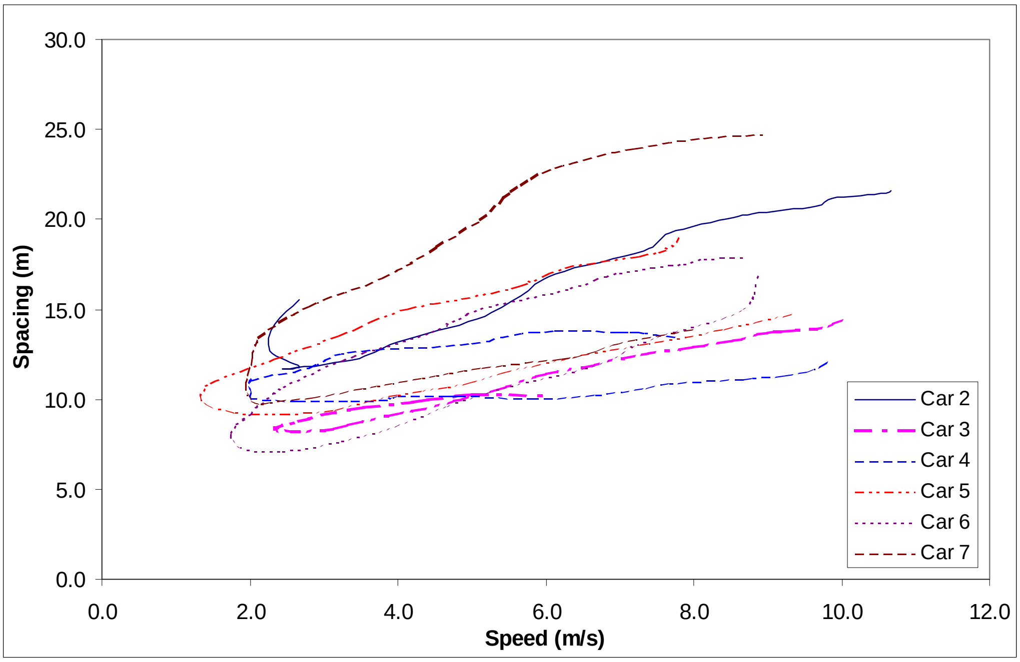

Figure 1 Spacing of individual vehicles in platoon

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Table 1 shows the average, minimum, maximum and the standard deviation of the desired spacing parameters. In order to define the variance of the judgement error parameter, the spacings measured from the video recordings were compared with the desired spacings calculated with the linear model parameters. It was found that the errors are normally distributed with a standard deviation = 0.124.

Table 1 Desired spacing parameters for individual vehicles (passenger cars)

	Deceleration		Acceleration		Combined	
	gradient	intercept	gradient	intercept	gradient	intercept
Mean	1.24	6.43	1.48	9.09	1.38	7.66
STD	0.51	1.53	0.59	2.25	0.47	1.76
Min	0.52	3.81	0.72	5.36	0.63	4.93
Max	2.42	9.63	2.90	13.67	2.59	11.42

The car-following model was implemented in the ARTEMiS simulation model and further tests were undertaken by simulating vehicle movement in typical urban interrupted flow conditions. In ARTEMiS individual vehicle characteristics, such as desired maximum speed, maximum acceleration and deceleration, and desired spacing parameters, are generated from normal distributions with user-defined mean and standard deviation, based on a 'driver aggressivity' parameter, which in turn is drawn from a uniform distribution; more aggressive drivers are assumed to have higher maximum speed and maximum acceleration/deceleration and shorter desired spacing.

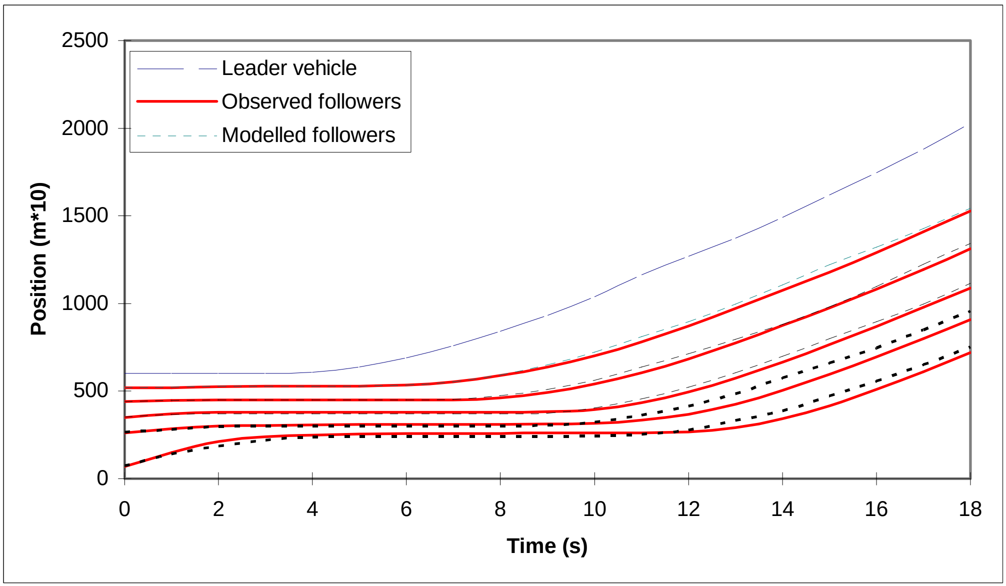

Figure 2 Comparison of measured and modelled trajectories (platoon 6)

The performance of the car following model was first checked by simulating the vehicle trajectories of the platoons recorded on video. Overall, the trajectories generated by the model were very close to the measured trajectories. Figure 2 shows an example of the measured and modelled trajectories. It can be seen that when the desired spacing characteristics are calibrated for each individual driver, the trajectories modelled by the car following model are very close to the observed trajectories. However, validation is

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required to be undertaken on data which were not used in the calibration of the model. Because the desired spacing is an individual driver characteristic, this validation can only be carried out at macroscopic level, by comparing the average characteristics of vehicle platoons.

A regression analysis was conducted on the spacing-vs-speed data obtained from the simulation and the results were compared with those of two recorded platoons not used in the calibration process. It was found that the regression parameters of the simulated data are very close to those of the observed data and that the 95 percent confidence intervals are almost completely overlapping. This indicates that there is a strong agreement between the simulation and the real-world results. A statistical test confirmed that the two regression lines are not significantly different at 0.05 level of significance, therefore it can be concluded that the model can satisfactorily reproduce the observed overall car-following behaviour.

2.2 Study of Lane Changing behaviour

In order to study the conditions during lane changing under congested conditions, the Transport Management Centre of the NSW Roads and Traffic Authority (RTA) provided video recording of 4 selected sites in the Sydney CBD from its traffic surveillance CCTV cameras. A total of about 20 hours of recording was collected from reasonably high vantage points allowing a view of about 80-100 m section of road where a large number of lane changing or merging manoeuvres were expected. However, only about 4 hours of data were analysed in detail so far, due to funding limits. First, a number of lane changing manoeuvres were identified from the tapes. Then, each manoeuvre was analysed in detail, and the position and speed of each vehicle involved in the manoeuvre were identified at 0.2 second intervals using frame-by-frame analysis.

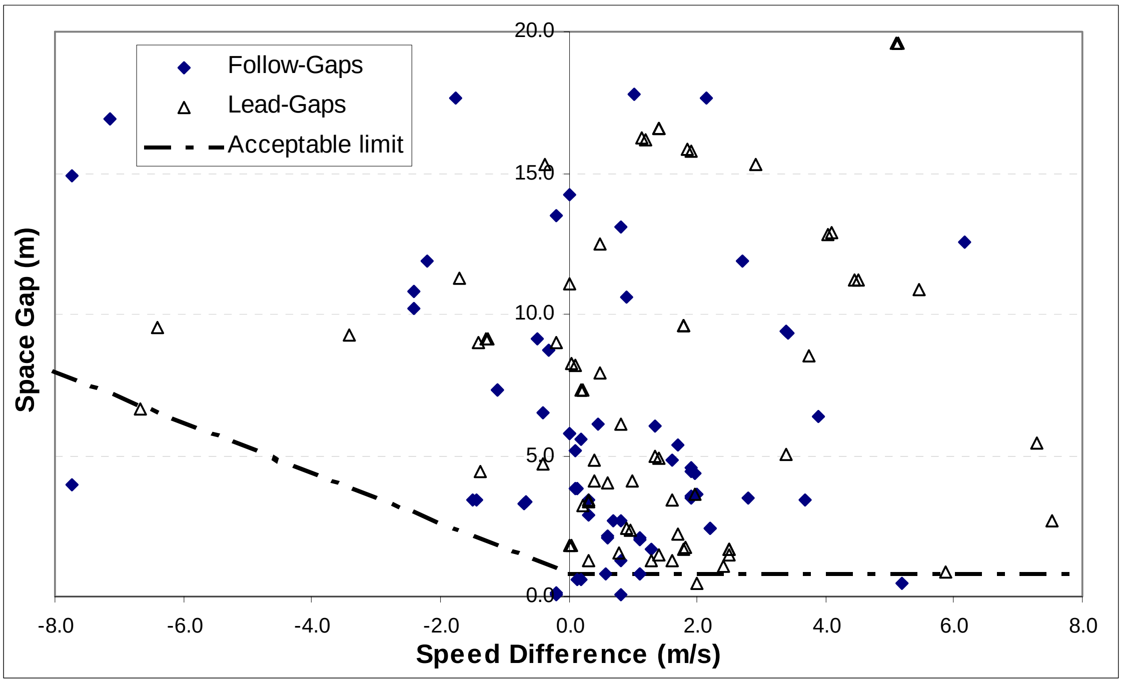

Figure 3 Observed space gaps as a function of speed difference

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A total of 73 lane change manoeuvres were analysed in detail. The analysis has confirmed the field observations that under congested conditions lane changes occur at very short space gaps. The accepted space gaps are closely related to the relative speed difference between the leader-follower vehicles and no correlation was found between the absolute speed of the subject vehicle and the space gap, as opposed to a car following situation. Figure 3 shows the space gaps (at the moment when the subject vehicle crosses the lane marking) as a function of the speed difference between the leader and follower vehicles. It shows that as long as the leader vehicle is faster than the follower, the minimum accepted gap remains constant, and its value is about 1.0 meter. However, when the leader is slower than the follower, the minimum accepted gap increases with the speed difference in a quasi-linear fashion. Figure 3 also shows that there is no observable difference between the accepted lead-gaps and follow-gaps. This relationship can be used to define the minimum acceptance gap criteria in the lane changing models.

A detailed analysis of the space gaps during the lane change process (before and after the time of entry to the target lane) reveals interesting differences in driver behaviour among different lane change manoeuvres. Figures 4 to 6 show three separate lane change manoeuvres. The thin lines represent the raw position data as estimated from the video frames. The data is smoothed using a third-degree polynomial curve, and these are taken as the calculated vehicle positions, represented by the thick lines. The calculated relative position of the Subject Vehicle is represented by the X-axis. The distance between the thick lines and the X-axis shows the space gap between the Leader and Subject, and the Subject and Follower vehicles during the lane changing manoeuvre (excluding the length of the Subject vehicle). The position of the Y-axis represents the point in time when the Subject vehicle started to move into the target lane. This representation allows the inspection of the interactions between the vehicles involved in the manoeuvre in a microscopic scale. It can be seen that there are important changes occurring over several seconds before and after the moment the subject vehicle crosses the lane marking. The nature of these changes indicates very different types of lane change manoeuvres. Based on the relative gaps between the Leader and Follower, lane changes can be classified into 3 distinct types:

1. Free Lane Change – in this case, there is no noticeable change in the relative gap between the Leader and Follower during the whole process, indicating that there was no interference between the Subject and the Follower vehicle (Figure 4).

2. Forced Lane Change – this type of lane change is indicated by a distinct change in the gaps before and after the entry point: the gap between Leader and Follower was either constant or narrowing before the entry point, and it starts to widen after the Subject vehicle enters, indicating that the Subject vehicle has "forced" the Follower to slow down (Figure 5).

3. Cooperative Lane Change – this type is characterised by an opposite change in the gaps before and after the entry point: the gap between the Leader and Follower is increasing before the entry point, and it starts to decrease afterwards, indicating that the Follower slowed down to allow the Subject vehicle to enter (Figure 6).

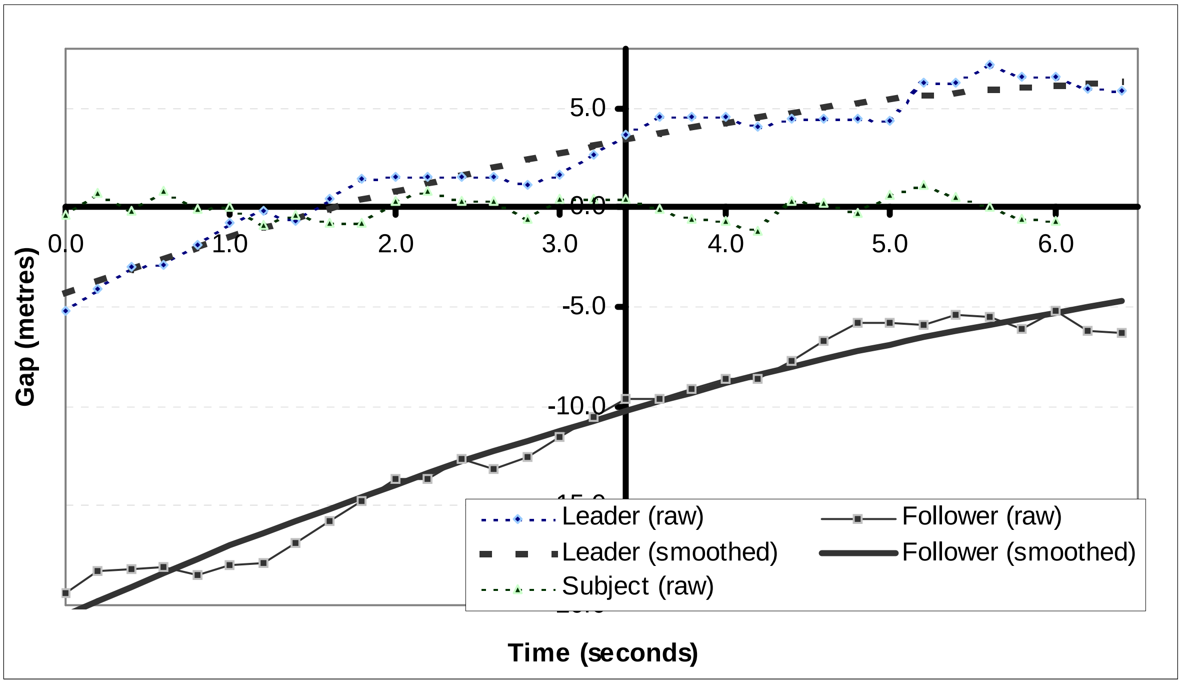

Figure 4 Free lane change (observed)

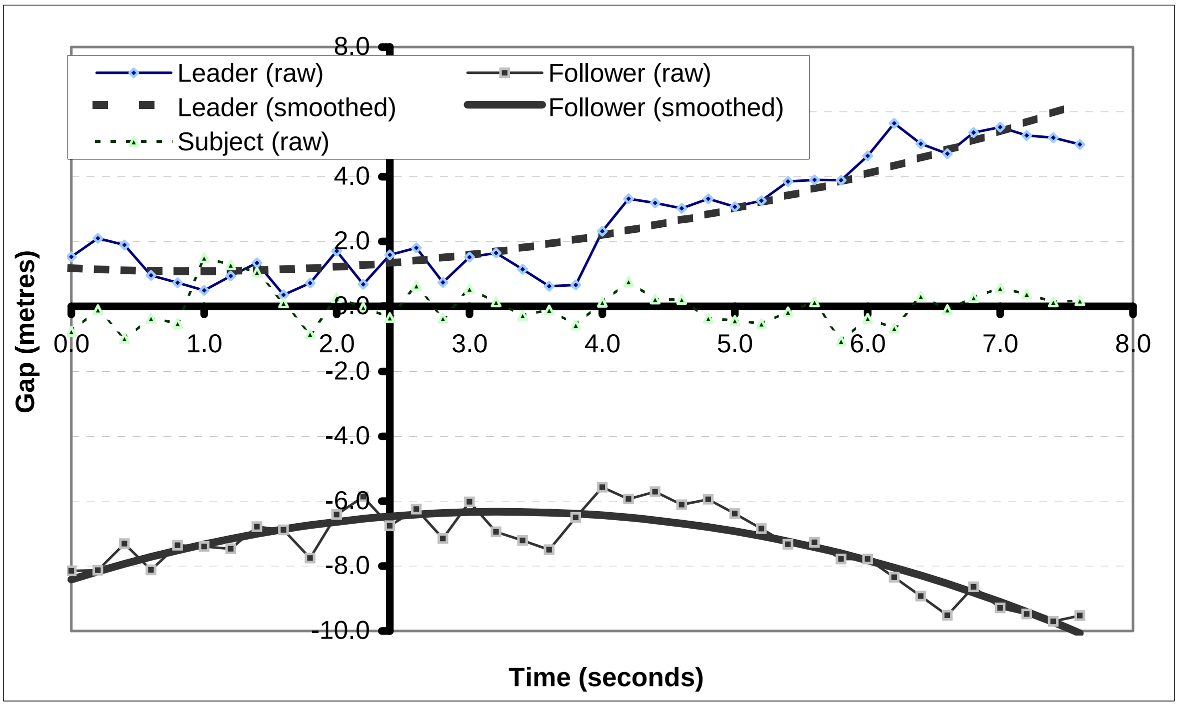

Figure 5 Forced lane change (observed)

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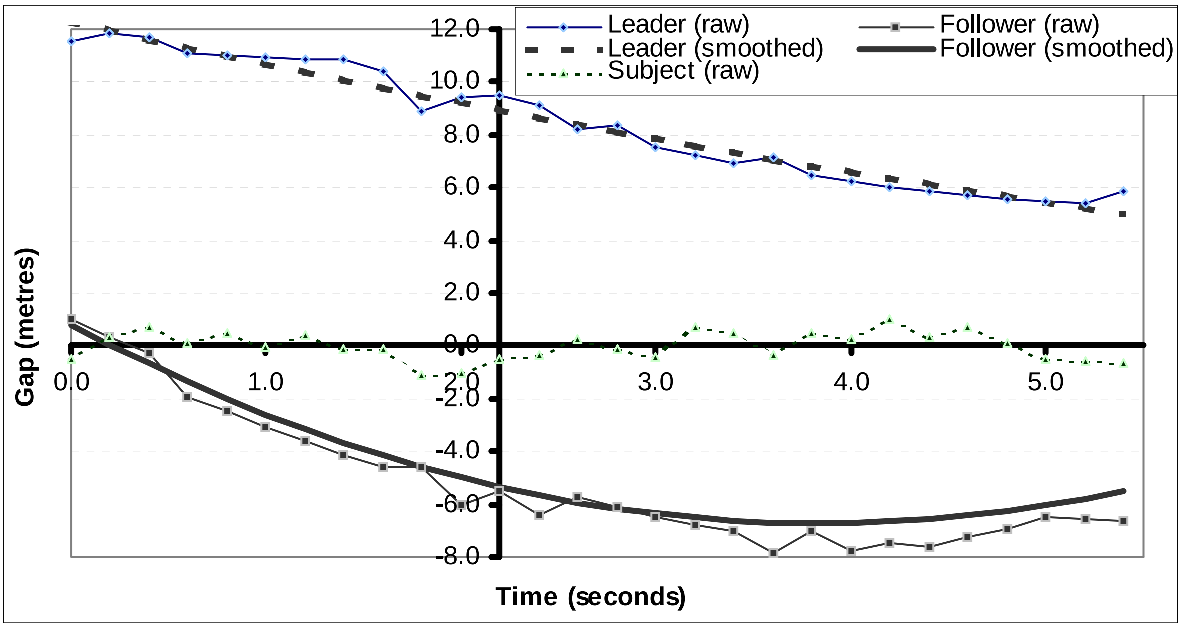

Figure 6 Cooperative lane change (observed)

The main difference between the above 3 cases is in the nature of interaction between the Subject and Follower vehicles (the Leader vehicle is usually a passive player in the lane change process, representing a constraint for the Subject and Follower vehicles). In a free lane change manoeuvre there is no interaction at all. In a forced lane change, the interaction is such that the Subject vehicle plays the active role by initiating the interaction and the Follower reacts by slowing down. While in a cooperative lane change the interaction has 3 components:

(a) first, the subject vehicle indicates that it wants to move into the target lane

(b) then, the follower vehicle recognises this situation, decides to cooperate and slows down, creating a longer space gap in front,

(c) finally, the subject vehicle realises that the follower vehicle gave way and when the gap is long enough for a safe lane change, it executes the manoeuvre.

This process may take several seconds during which the vehicles continuously coordinate their actions. Note that the distinction between forced and cooperative lane changing may be ambiguous. In a real traffic situation it may happen that the subject vehicle starts moving closer to the target lane when the follower vehicle is too close for a safe manoeuvre, and it starts to slow down to avoid a collision before the subject vehicle is actually entering the target lane. This case, in terms of a logical chain of actions-reactions, should be characterised as a forced lane changing. In theory, the distinction between a forced and cooperative lane change would depend on the order of decisions made by the two drivers. However, in a simulation model where the lateral position of vehicles within the lane is not represented, this will be equivalent to a cooperative lane change, because the follower vehicle starts to slow down before the subject vehicle is moving into the target lane.

It is also important to recognise that when modelling forced and cooperative lane changes, the car following model has an important role to play. In such situations, the vehicle moving in from another lane causes a distinct reduction of the spacing between its leader and follower vehicles. If the spacing before the lane change was close to the desired spacing at the given speed, it will be significantly less than the desired spacing, and as a

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result, the "normal" car following model would calculate an emergency deceleration, which in turn, would generate a shock-wave slowing down all the vehicles upstream in the lane. However, the recorded lane changes did not cause emergency braking even at very short space gaps. It seems that while drivers do have a given desired spacing, they are also willing to tolerate much shorter spacing when they can clearly see the situation and can *anticipate* the actions of the other drivers. In the lane changing situation usually only a moderate/minimal deceleration is used to restore gradually the desired spacing over a period of about 5 to 10 seconds after the subject vehicle moved into the target lane. This process must be handled by a special relaxation procedure in the car following models.

Based on the observations described above a new lane change model was developed and the car following model revised and implemented in the ATREMiS simulation model (which was previously called SITRAS). The model details are described in a forthcoming paper (Hidas 2004). Several hypothetical test studies were conducted to demonstrate the capabilities of the new model. The results showed that the model is able to reproduce the observed behaviour of individual vehicles in terms of speed-, gap acceptance and conflict-resolution in all three types of lane change manoeuvres, and hence, it is able to simulate highly congested flow conditions in a realistic manner.

3 Data Collection by Differential GPS (DGPS) systems

In this experiment, two passenger cars were fitted with DGPS and driven around an urban road cycle in Sydney following each other. The mountable Leica GPS receiver sets were fixed onto roof racks on both the lead and follow cars. The data recorders enabled us to start and stop recording on demand, check the number of satellites currently engaged during the survey. The DGPS provided the location of each vehicle at 0.5 second intervals to an accuracy of less than 0.5 m. The speed, acceleration and the distance (spacing) between the 2 vehicles were estimated from the vehicle locations. The distance was measured from the location of the GPS receivers on the roof of each car, to their front and rear ends to correct the spacing between the front and end bumpers of the two vehicles.

The essential element of a differential GPS operation is to have a fixed base station receiver of known location that has been tracked for a number of months. The bias errors of the moving receivers are corrected with the measured bias errors at the known position of the reference (base) station. If both the moving receiver and the base station are in connection with at least 4 GPS satellites for the entire duration of the half-second interval over which its location is calculated then the accuracy of the positioning data is ensured to a centimetre level.

The study route was selected to include higher and lower speed environment sections in the range between 50 and 80 km/h speed limit with frequent stopping at signalised intersections. The circuit length was approximately 19 km within a 15 km radius of the fixed reference station to ensure maximum accuracy of the position data.

The test was planned to run for about 3 hours, allowing each car (with its driver) to run 2 laps as leader and follower. However, heavy rain began to fall roughly half way through the third lap, providing an unexpected opportunity to study the effect of the rain on car following behaviour. This was at a stage when Car A has completed 2 laps as leader and Car B was leading for the first time. Therefore, Car A was set to lead in lap 4, thereby providing some data for both cars leading in both wet and dry conditions. Thus, the final data included 2 laps with Car A leading in dry conditions, ½ lap each with Car B leading in dry and wet conditions, and 1 lap with Car A leading in wet conditions.

Satellite connection was monitored throughout the survey from Car B, as displayed on its GPS receiver unit. It was generally observed that at least 4 satellites were available most of the time, although brief periods of lost or insufficient connection occurred regularly.

The data output consisted about 19,000 rows showing the coordinates of each receiver station (2 mobile plus the base station) in 3 dimensions for each half-second interval recorded, together with a weighted error reading that incorporates the number of satellites engaged by all three receivers at that time, hence indicating the accuracy of each data point. The error reading code was represented by the numbers 0,1 and 3 for coordinates with centimetre accuracy, 4 for standard DGPS solutions of 1-4 metre accuracy, and 9 for unusable data.

Data manipulation included filtering out less than centimetre accurate data records and calculating the speed, acceleration, relative spacing and relative speed parameters from the vehicle coordinates at 0.5 second intervals. A summary of the number of useful data points that were incorporated in these plots is given in Table 2.

Table 2 Number of Useful data Points (at half second intervals)

Follow Car	Car A	Car B	TOTAL
Dry Conditions	1270	3144	4414
Wet Conditions	1290	2538	3828
TOTAL	**2560**	**5682**	**8242**

3.1 Car following behaviour

The volume of data available for each driver allowed a more detailed analysis of individual car following behaviour. Figure 7 shows the speed vs. spacing relationships for both cars, in dry and wet weather conditions. The figure also includes the linear trendlines and their parameters. It can be seen that there is a strong linear correlation for all cases.

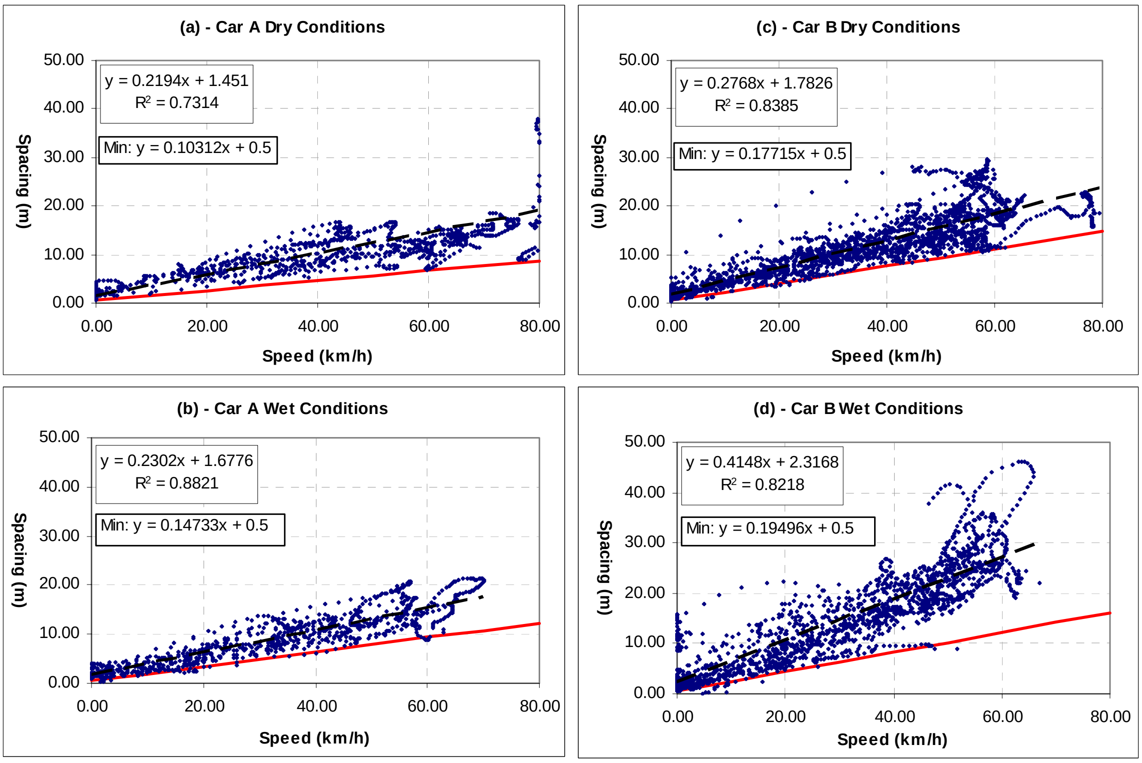

Figure 7 Speed vs spacing relationships

Figure 7 also shows and an attempt to represent a minimum envelope line for the spacing relationships, because this minimum line is the strongest indication of the car following behaviour: the minimum spacing at any speed that the follower driver is willing to accept. Table 3 shows a comparison of the minimum spacing gradients and the percentile difference that is evident between the 2 cars for wet and dry conditions.

Table 3 Gradient Analysis of Minimum spacing

Follow Car	Car A	Car B	**Diff**
Dry Conditions	0.10	0.18	**72%**
Wet Conditions	0.15	0.19	**32%**
Increase	**43%**	**10%**	

There is a clear difference between the individual driver tolerances during wet and dry conditions. Although the spacing range remained tight for car A in both conditions, the gradient of its minimum speed spacing envelope increased by 43% during heavy rain. The gradient of the minimum spacing envelope for car B only increased by 10% during heavy rain, however, the gradients of car B are significantly higher than those of car A.

3.2 Driver Consistency

The long time series data available for each driver enabled a more detailed analysis of driver consistency in the spacing vs speed relationships. The data sets were broken up into speed groups of 5 km/h and the maximum, minimum, average and standard deviation values of the spacing measurements were calculated for each speed group. Figure

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8 shows the variance of the spacing characteristics for the two drivers in dry and wet conditions.

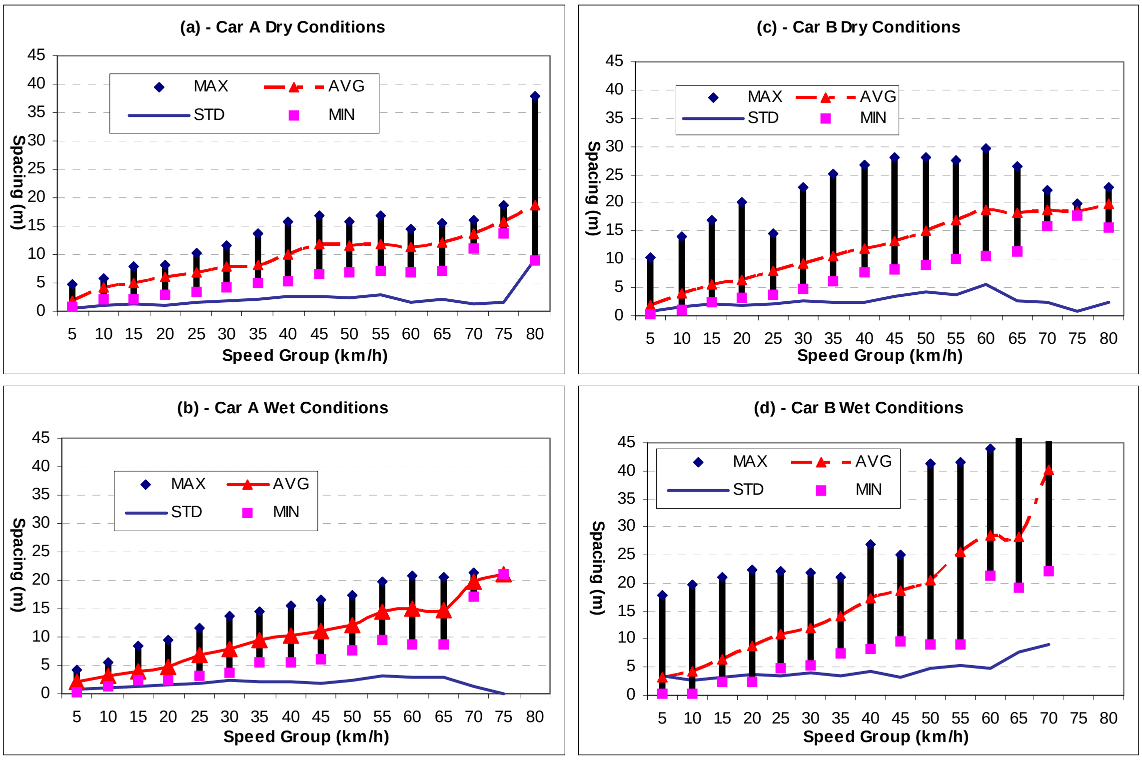

Figure 8 Variance in measured spacing characteristics

It is evident from Figure 8 that the variance of the measured spacing increases with speed in all four data sets, as noted in previous studies (Hidas, 1998). A roughly linear correlation can be observed between the speed and the standard deviation of the spacing (STD) in the 0 to 60 km/h speed range, but the standard deviation appears to be constant or decreasing in the 60 to 80 km/h speed range. However, it is important to note that there are much fewer data points available in the above-60 speed range, making this part of the relationship less reliable. These findings can be used to calibrate the judgement error parameter in the proposed car following model (Hidas, 1998).

3.3 Speed and Acceleration characteristics

The data were also used to study the typical speed and acceleration characteristics of passenger cars in interrupted urban flow conditions. While the maximum acceleration and deceleration capabilities of vehicles are well known, there is little information available on the typical acceleration and deceleration values actually used by drivers, and what is available, it is not in a format suitable for microsimulation models. The aim of this analysis is to collect information for the development of acceleration-deceleration models as a function of the instantaneous speed of the vehicle because the speed is the only relevant parameter available in the microsimulation model.

Acceleration sections from standing to cruising speed were identified. Figure 9 shows the acceleration vs. speed data for both vehicles. No significant difference was found between the dry and wet weather conditions. Although the data points have a large

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spread, there is a definite pattern in the data. Some of the continuous acceleration series are highlighted in Figure 9 to demonstrate the typical pattern. It shows that acceleration from standing to cruising speed follows a skewed parabolic shape. The maximum acceleration values used at any given speed are easily identifiable from the data; they can be represented by a triangular function. The actual acceleration used as a function of the speed is more difficult to model; it appears that beside the instantaneous speed, the initial and target speeds have an important effect on the instantaneous acceleration used by the driver.

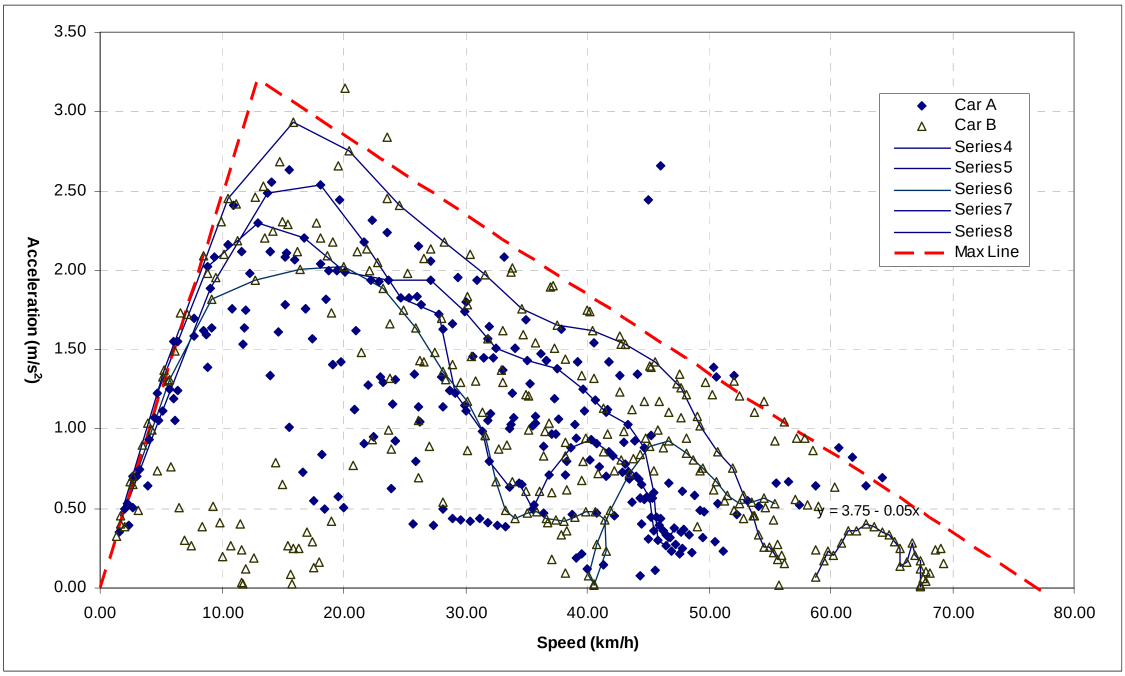

Figure 9 Acceleration vs. Speed

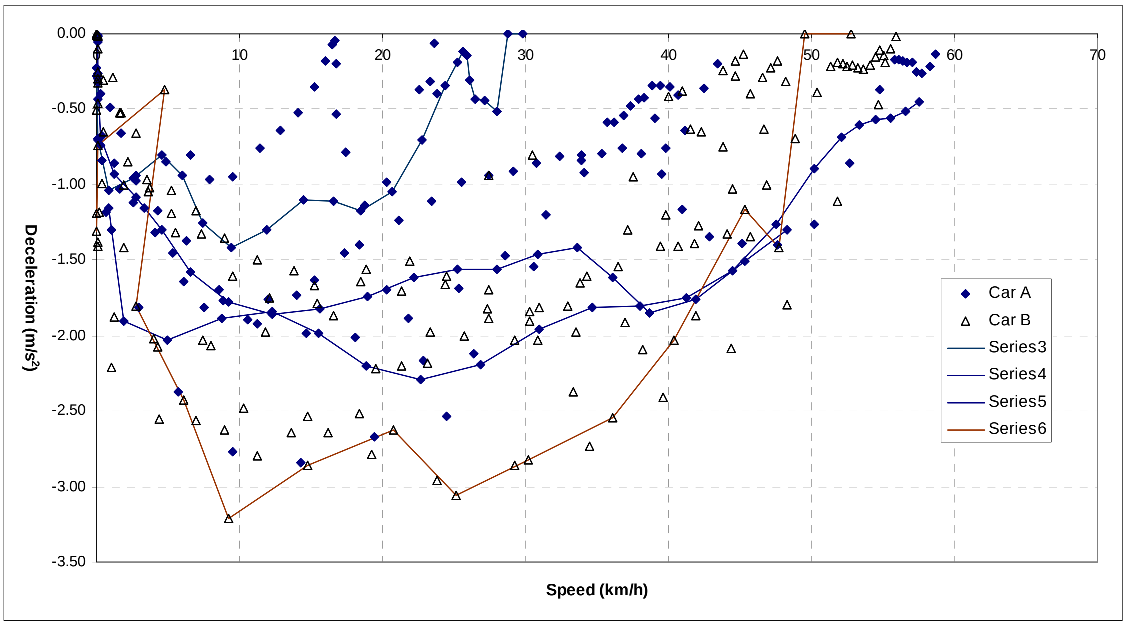

Figure 10 Deceleration vs. Speed

A similar analysis was conducted with the deceleration sections from cruising speed to stopping. Figure 10 shows the deceleration as a function of the speed for both

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vehicles. Again, some of the continuous deceleration sections are highlighted to demonstrate the typical pattern. It can be seen that the relationships are similar to the inverse of the acceleration functions shown in Figure 9, however, the peak of the maximum decelerations is less pronounced than in the case of acceleration.

These data can be used to develop more realistic acceleration and deceleration models for microscopic simulations, however, more data from several drivers need to be collected for the calibration and validation of such models.

4 Data collection by instrumented car

The vehicle is fitted with a DGPS, the S.M.S. Drive Recorder system using 4 radar sensors, and 2 video cameras recording the view in front of and behind the vehicle. The DGPS provides the vehicle location, a separate system records the vehicle speed, acceleration and distance covered, while the radar sensors record the relative position and speed of every object in front of and behind the vehicle in a distance range of about 2 to 150 metres. Two different radar systems are used, a short-range radar (distance up to 40 m) that has a wide viewing angle (about 30°) and a long-range radar (distance up to 150 m) with a small viewing angle (about 5°). The recorded data is synchronised with the video recording so that the objects picked up by the S.M.S. system can be identified from the VCR pictures.

Experiments with the S.M.S. Drive Recorder system are promising to provide larger data sets in various driving situations, but the difficulties of data analysis are significant. This is due to the fact that the radar sensors record any object which produced a radar echo, without making any attempt to discern between roadside objects and moving cars ahead and behind the instrumented vehicle. Furthermore, the two radar systems run on a different time-basis, i.e., provide data at different instants of time. The time-increment is about 33 ms. For this reason, and because of a different bias between the two radar systems, the data of the long-range and the short-range radar have been kept separate. First results have been obtained, despite such difficulties.

To transform the raw data into something usable for a more refined analysis, the following algorithm has been implemented to produce trajectories of the surrounding cars. Any (raw) data-point provided by the radar sensors consists of the distance in x and in y-direction and of the difference speeds Δv_x and Δv_y, respectively. Additional information about the quality of the echo is provided, too, but so far it is not being used. By keeping at any time of the data analysis a list of unfinished trajectories, for each new incoming raw data-point (if it fulfils certain simple conditions, most notably that its speed difference should be smaller than the actual speed of the probe car) it is tested to which of the already existing trajectories it fits best by looking for the smallest discrepancy between a prediction based on actual distance and actual speed difference:

$$\hat{x}(t_{new}) = x(t_{old}) + (t_{new} - t_{old})\Delta v_x,$$

and the value that is provided by the new measurement:

$$\Delta_x = x^{(data)}(t_{new}) - \hat{x}(t_{new}).$$

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The same is being done for the y-coordinate. The discrepancy between the predicted and the actual data-point is computed as the maximum of the discrepancies between the x and y-co-ordinates:

$$\Delta = \max\{\Delta_x, \Delta_y\}.$$

If no match is found, i.e., when Δ>1 m for all already existing trajectories, then a new trajectory is created with this data-point as its first entry. If an existing trajectory has not got any new point after about 1 second, then it is saved into a file which can be used to analyse the data in more detail, provided its length (the number of points in the trajectory) is greater than a pre-specified minimum length (the idea is to save only those long sequences where a meaningful analysis can be done).

So far, three data collection experiments have been run. The most successful one was a two hours drive through the city of Berlin, partially on arterials, partially on the freeway A 100 which connects the eastern parts of the city to the airport Tegel. The drive was performed in the afternoon rush-hour, where all roads were heavily used. Therefore, a lot of data from close-following situations can be found in the data-set. In the following, two examples of the data-analysis will be presented.

First, with the following plot it is confirmed that the usual car-following spirals exist in a plot of the trajectories in the distance-speed-difference plane, see Fig. 11. Data are from the forward looking radar, i.e. they show the behaviour of the driver of the instrumented car with respect to different cars in front. Here, several car-following manoeuvres are overlaid.

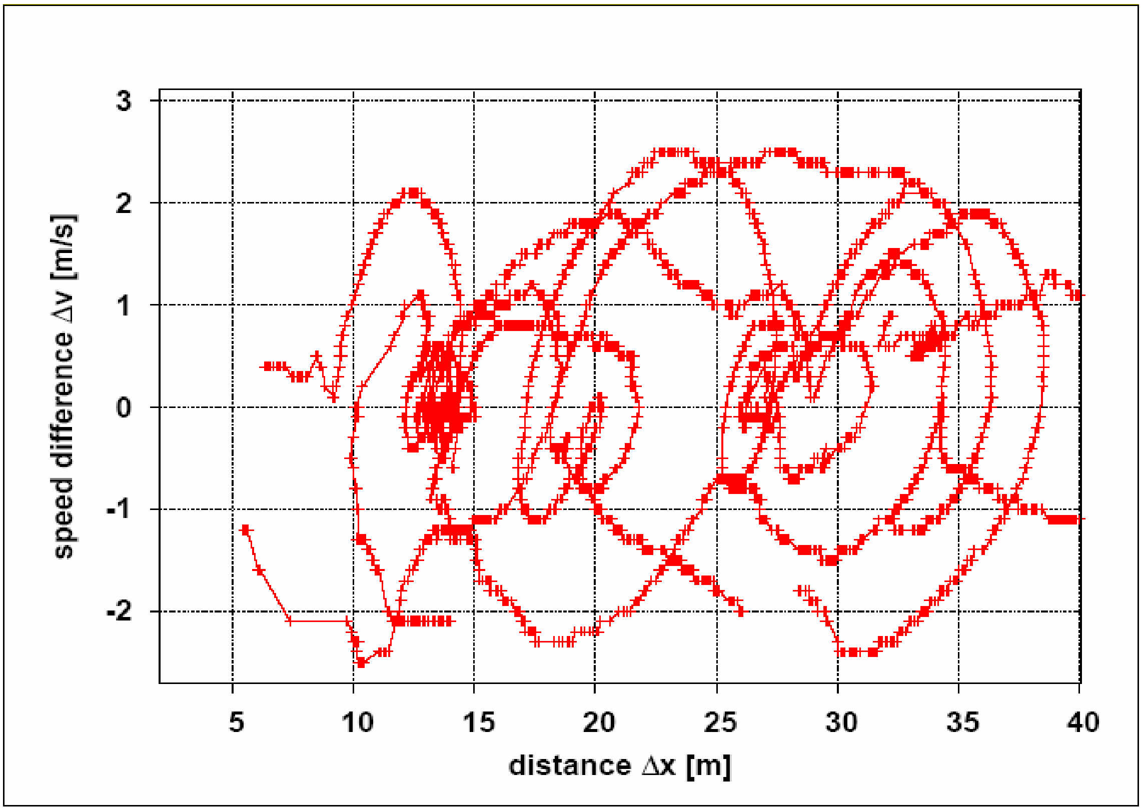

Figure 11 Trajectories in speed-difference vs. distance plane

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An additional analysis has been performed on this data-set. During the drive, many different cars were followed by the driver of the instrumented car, and many different cars were following the instrumented car. In Fig. 12, it can be clearly seen that there is a strong difference between the driver of the instrumented car (or, respectively, between the instrumented car and other cars) and the vehicles following this car.

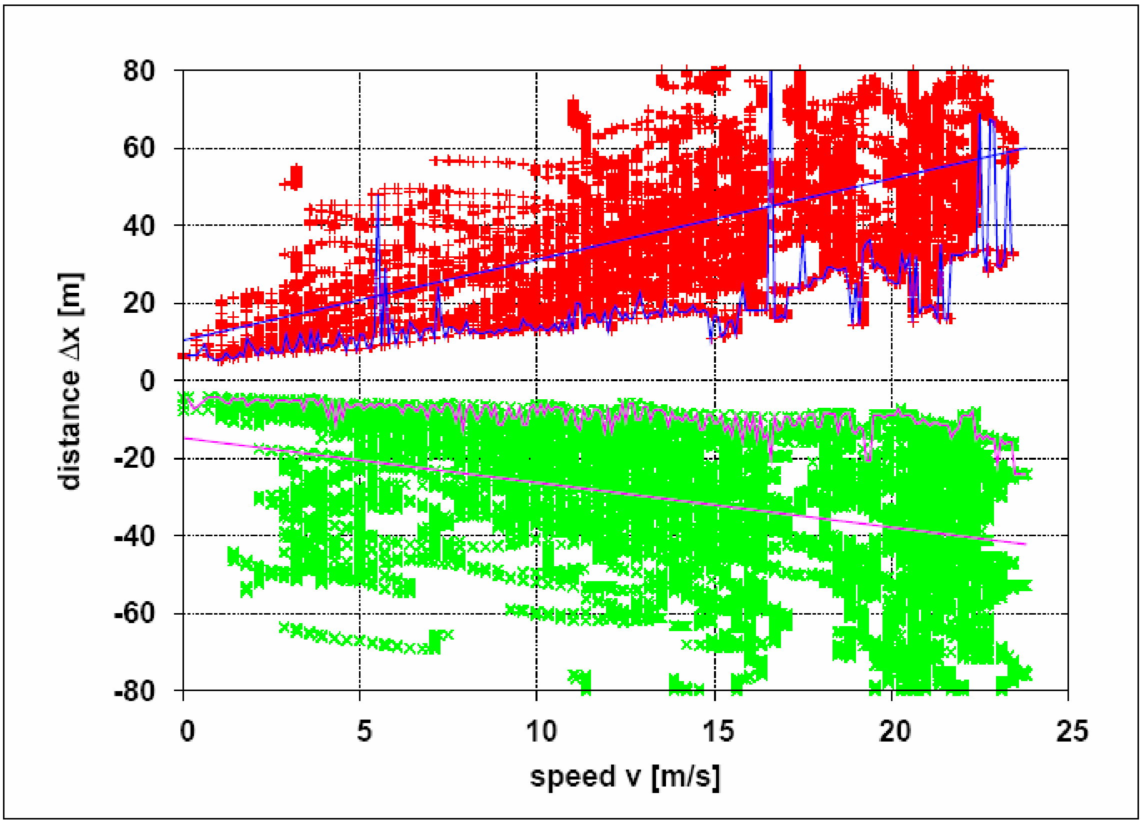

Figure 12 The distance (net headway) vs speed of the instrumented car

Only those trajectories have been used in this analysis, where the average speed difference over the whole trajectory is smaller than 2 m/s, indicating stable following episodes. Positive values of distance correspond to cars to be followed, while negative distances correspond to cars following. The straight lines are linear regressions to the respective data, the jagged lines are the minimal distances as a function of speed.

Both the average headway as well as the minimum headway as function of speed reveal clear differences between cars in front and cars behind the instrumented car. When analysing the whole data-set, the average headway as defined in the following simple equation (no indications of more complicated distance-speed relationships can be seen in Fig. 12) :

$$\Delta x = v\tau + g_0$$

is τ = 1.15 s for the cars behind, while it is τ = 2.21 s for the cars in front. The same tendency is found for the minimum following distance, here the values are τ = 0.36 s (behind) and τ = 0.94 s (in front), respectively. The results found are in line with the results found for the DGPS-data above, and with results given elsewhere. A minimum (time)

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headway of 0.4 s for dense rush-hour traffic is usually found, with an average time headway around 1.15 s which corresponds to a maximum flow of 3100 cars/h (for small aggregation times) seems quite likely. The significant difference in the car following behaviour of the instrumented vehicle driver and the drivers behind can be attributed to the fact that in this case the instrumented vehicle is a small van with somewhat slower acceleration-deceleration characteristics than the typical passenger cars. Additionally, it is well-known, that drivers under surveillance are driving more relaxed, i.e., are usually keeping a bigger distance.

Less successful have been the usage of the acceleration sensor. Although of high quality, its signal is completely corrupted by the jerk produced be the engine, so that the signal is almost useless. It is much cleaner and less error-prone to derive the acceleration from the data of an additional speed sensor (which is a high-precision sensor that works by analysing the texture of the road optically) by using an appropriately tuned Savitzky Golay filter (Press at al, 1992).

5 Conclusions

This paper has reviewed three methods of data collection for microscopic simulation: video recording, DGPS and the S.M.S. Drive Recorder System. Each method has distinct advantages and limitations.

Video recording can be used to collect time series data of vehicle platoons travelling along a selected road section. The advantages of the method are that data can be collected from large numbers of vehicles and that the drivers are not influenced by the data collection method, therefore the collected data can be considered unbiased. The data can be used to study both car following and lane changing behaviour – in fact, video recording seems to be the only suitable method for studying lane changing behaviour. The limitations of the method include (i) the length of the road section that can be studied is usually maximum 150-200 metres due to the limited view of the camera and the accuracy requirements; (ii) it is often difficult to find suitable high vantage points for the position of the camera; (iii) data analysis – calculation of vehicle position, speed and acceleration for each vehicle from the video recording – is a very difficult and resource-intensive process, unless automated image processing methods can be used. One promising technology which aims to eliminate these limitations is the data collection system under development at the ATLAS Research Center, University of Arizona, based on aerial digital video recording, global positioning systems (GPS), and automated image processing (Mirchandani et al. 2003).

The experiment with the differential GPS system has shown that DGPS can be used to collect useful information for studying individual car following behaviour and vehicle progression characteristics. This method can provide data from the same individual drivers over long sections of road including different roadway and traffic conditions allowing a more detailed analysis of individual driver behaviour. Data analysis is much simpler and faster than in the case of video recording as the vehicle positions, and then speed and acceleration, can be automatically calculated from the DGPS data. However, data can only be collected from those few vehicles that are fitted with the DGPS, and the drivers are instructed to be part of a specific experiment, which may cause some concern as to the reliability of the collected data.

The S.M.S. Drive Recorder System indeed provides huge amounts of data that can be analysed almost automatically. However, as is usually the case with car-following experiments, the context has to be set-up carefully. For example, runs on another freeway have been performed, where much less traffic than in the data from the Berlin roads was present. The data-sets resulting from these runs on more or less free roads only returned limited amounts of usable data.

As usual, however, this method also has a number of difficulties and limitations. The big amount of data to be cleaned is hard to control, and it still gives just an incomplete picture of the surroundings of the instrumented car. The collected data is useful to study the car following behaviour of the drivers following the instrumented car, but the influence of the instrumented car on this behaviour must be considered as a limiting factor. As in the case of video recording (from fixed vantage points), most of the trajectories of following vehicles are not long enough to provide suitable data about the consistency of car following behaviour. Further research should be conducted to investigate how this system could be used to study lane changing behaviour in congested urban traffic situations.

The experiments with these data collection techniques show that each method can provide some useful results for microscopic simulation model development, calibration and validation purposes, but the results are still quite far from the expectations of an "ideal" dataset: continuous spacing-, speed- and acceleration profiles of large vehicle platoons moving through various rural highway and urban road sections over long distances and under different traffic conditions. The NGSIM (2003) project will hopefully satisfy these expectations by providing researchers and developers of microscopic traffic flow models with exactly this type of data: space-time trajectories of vehicles in various congested traffic scenarios. Apart from this, further research is required to investigate such aspects of driver behaviour as aggressiveness, and factors influencing lane selection.

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