Stop-and-Go Driving Behaviour: Initial Findings from Floating Vehicle Trials

J. Piao[*] and M. McDonald[+]
Transportation Research Group (TRG), Dept. of Civil and Environmental Engineering, University of Southampton, Southampton, SO17 1BJ, U.K.
Tel: [*]+44 (0)23 80593148, [+]+44 (0)23 80592192; Fax: +44 (0)23 80593152,
Email: [*]jpiao@soton.ac.uk, [+]mm7@soton.ac.uk; http://www.trg.soton.ac.uk

SUMMARY
This research is part of the work of STARDUST, an EU project aimed at assessing the extent to which Advanced Driver Assistance Systems (ADAS) and Automated Vehicle Guidance (AVG) systems can contribute to sustainable urban development. The data was collected using an instrumented vehicle in Oslo (Norway), Paris (France) and Southampton (UK). Over 1400 following events were recorded. Driving behaviour in stop and go traffic was analysed with a particular on maximum deceleration, braking frequency, start delays and stopping-distance-gaps.

INTRODUCTION

Most current microscopic simulation models are calibrated using data which dose not includes stop-and-go traffic. This is mainly due to a lack of adequate microscopic behavioural data in such circumstance. The potential of using new transport technologies such as Advanced Driver Assistance Systems (ADAS) to improve traffic conditions has greatly increased the importance of understanding driver behaviour. In this paper, initial findings of driver behaviour at low speeds, especial in stop and go traffic, are reported. This is part of the work of STARDUST, an EU project aimed at assessing the extent to which Advanced Driver Assistance Systems (ADAS) and Automated Vehicle Guidance (AVG) systems can contribute to a sustainable urban development. The objective of this behavioural study was to provide a realistic behaviour database especially in conditions of low speed traffic conditions, which will be used as a normative standard for human factor investigations, behavioural assessment, simulation and safety assessment in the later stage of this the project.

In the past, field data used for the study of driver behaviour have almost always been collected at discrete spatial and temporal points and at macroscopic level, for example, by measurements and video camera recordings at a fixed point(1). In many cases, such data cannot meet the requirements of studying microscopic driver behaviour, which requires longitudinal time series measurements. One of the novel methods of gaining data on driving behaviour is the use of floating vehicle, which is driven in the traffic stream as a platform from which to observe the behaviour of tested driver or adjacent drivers. The floating vehicles use microwave radar to measure inter-vehicle variables such as relative speed and distance, allowing far more accurate and flexible experiments to be undertaken. This approach is realistic, accurate, and may be the only method, which can produce sufficient quality and quantity of data to allow the continued development and validation of simulation methods (2). In this research, traffic data was collected using the floating vehicle approach.

DATA COLLECTION UNDERTAKEN

THE TEST VEHICLE USED

The car following data used in this analysis was collected using an Instrumented Vehicle (IV) which was developed at the Transportation Research Group of University of Southampton (2). The IV is equipped with a range of sensors allowing measurement of driver performance and how the motion of the vehicle relates to surrounding vehicles. The main sensors/equipments used in this data collection included:

i. An Optical Speedometer: using an interferometric device, which is insensitive to variations in the type or condition of the road surface (4), a DATRON DLS1 unit. The unit illuminates the surface of the road using a collimated beam and the reflected signal is transformed into a square wave which is proportional to distance travelled. Although complex, calibration tests over a measured mile have confirmed the accuracy of the unit, with a figure $<\pm 0.05\%$ variation being observed.

ii. A Laser Rangefinder: a unit capable of measuring the distance to a number of immediately adjacent vehicle (up to twenty targets simultaneously). The unit has an operational range in excess of 100m, with a measured accuracy of ±0.2m in range, operating at 76.5GHz. The rangefinder is mounted within the rear bumper facing backward direction, being sufficiently recessed to ensure that the unit does not protrude beyond the vehicle body, and minimise the chance of it being noticed by other road users.

iii. Video-audio monitoring system: allowing a permanent visual record of each experiment, allowing not only re-analysis of 'macroscopic features' that are apparent to the driver but are undetectable to the sensors (e.g. lane, visual conditions etc) and allow a clearer picture to be obtained of the state of the traffic, should signals returned from the radar become confusing.

In this research, car following data was collected in passive mode with the radar mounted in the rear of the vehicle. Observations were made of "anonymous" drivers following the IV in a normal traffic stream.

TRIAL DETAILS

The data collection was undertaken in the summer of 2002 in three European cities: Oslo (Norway), Paris (France) and Southampton (UK). This enables the investigation of the differences in driver behaviour between the UK, Norway and France, across a range of driving conditions. The car following data were collected on the following three types of roads:

- Urban motorway: crossing or adjacent urban areas, with recurrent congestion during peak periods;
- Urban arterial roads: in urban areas, with at least two lanes in each direction and a high speed limit (e.g. >60 km/h in Southampton), fewer intersections and recurrent congestion during peak periods.

- Urban streets: frequent signalised intersections, high traffic demand and congestion.

The roads selected for data collection in the three cities are shown in Table 1.

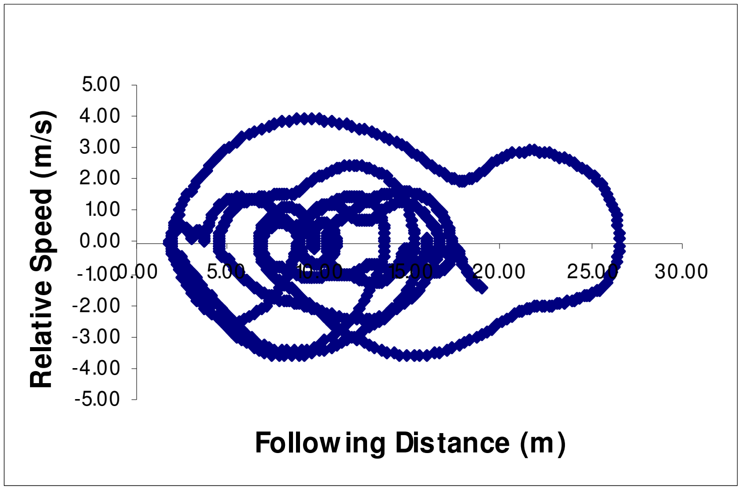
Table 1 Time and location for data collection

	Oslo	***Paris***	***Southampton***
	18/09/02-25/09/02	15/10/02-18/1002	09/09/02-12/09/02
Urban motorway	E18 South (10 km, most 3 lanes, 80-110km/h)	A6 from Ris-Orangis to Wissous (15km, 3 lane plus, 110-130 km/h)	M27 (J2-J8) and M271 (12 km, most 3 lanes, 112km/h)
Arterial roads	Ring road 2 (5km, dual-carriageway, 50km/h,)	Paris Bd Périphérique (10km, dual-carriageway, 80km/h)	A35 and A3024 (7.5km, dual-carriageway, 80km/h)
Urban street	Kvadraturen, inner city of Oslo (2.8km, 18 signalised junctions)	Place de la République to Place St Augustin (7km, 15 signalised junctions)	Winchester Road Burgess road, (5 km, 10 signalised junctions)

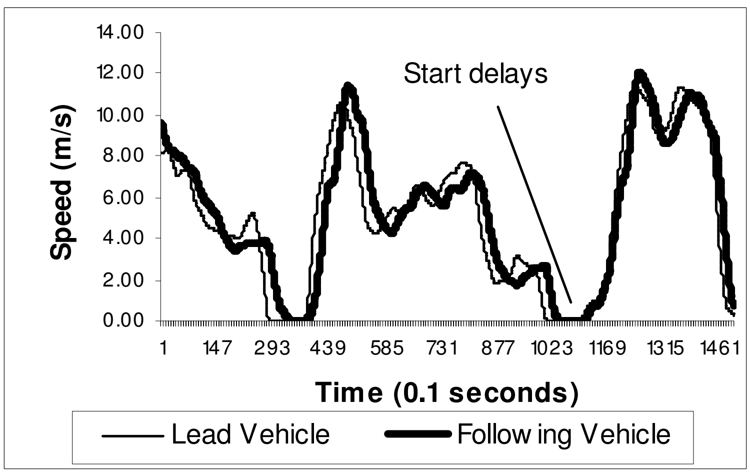
A total of over 50 hours of car following data were collected in Oslo, Paris and Southampton, in which 649, 453 and 307 car following time sequence were identified to be valuable for the analysis in the three cities respectively. The following parameters were measured or calculated for each time sequence (at an interval of tenth second):

- Frame number (corresponding to video footage recorded)
- PC Time (corresponding to the time when the recordings were made)
- IV speed (measured)
- IV acceleration (calculated)
- IV Brake Movement (measured)
- IV Brake load (measured)
- IV Throttle (measured)
- Following vehicle speed (calculated)
- Following vehicle acceleration (calculated)
- Relative speed of the following vehicle (calculated)
- Distance gap between the IV and the following vehicle (calculated)
- Time headway (calculated)

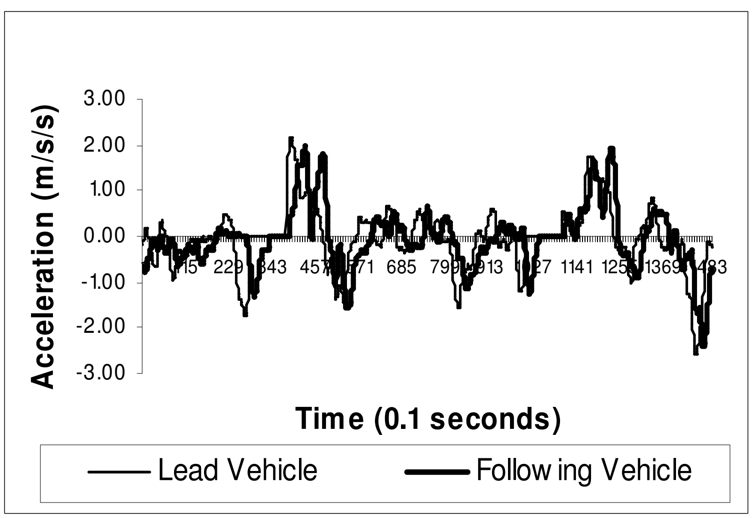
Figure 1(a)-(c) show an example of a car following event in whichspeed (absolute and relative), acceleration are clearly displayed.



(a)



(b)



(c)

Figure 1 An example of car following data (A35, in Southampton, 150 seconds)

RESULTS OF DRIVER BEHAVIOUR ANALYSIS

BRAKING FREQUENCY

Braking is an active control action taken by drivers. Frequent braking means fluctuation in vehicles speed, increased driver workload and reduced fuel efficiency. The data used for this analysis were collected on the motorways in the three cities, covering a wide range of speed from 0 to 120 km/h. In Oslo, Paris and Southampton, 337, 211 and 75 braking events were identified respectively.

The data for all the braking events was divided into 10km/h speed bands according to the speed at which the brake pedal was pressed. The braking frequency in the three cities is shown in Figure 2. Braking frequency here is defined to be the average number of brake applications per kilometre. It can be seen that the number of brake applications reduces as speed increases. When speed increases over 60km/h, braking frequency is reduced to less than 0.25, i.e. brake pedal application once every 4 kilometres. The most frequent use of brake occurred at speed lower than 10 km/h when drivers pressed the brake pedal as often as 25 times per kilometres. This is the situation when the traffic became heavily congested, drivers had to apply brake frequently to adjust vehicle movement to the stop and go traffic. The high braking frequency meant a high variation of speed and high work load, because most brake applications were followed by an acceleration manoeuvre.

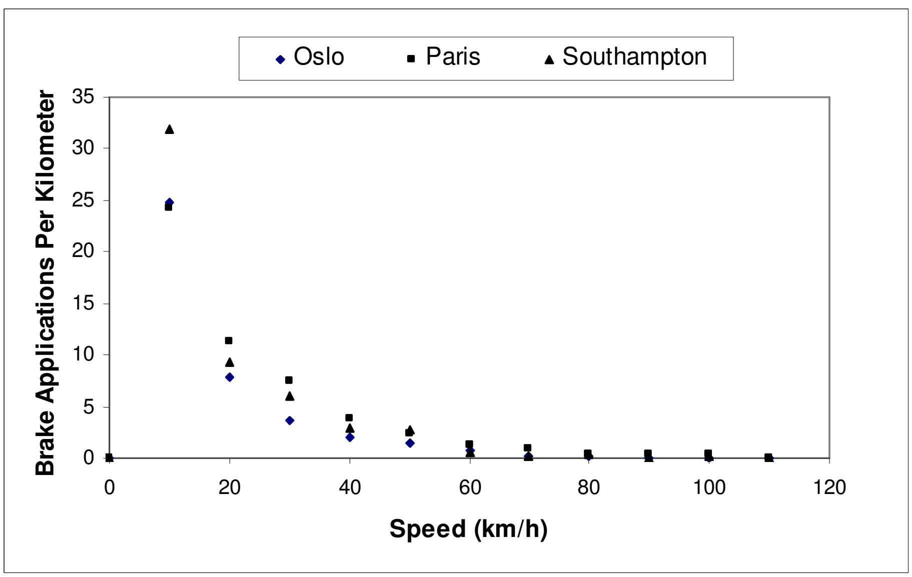


Figure 2 Braking frequency on motorways

MAXIMUM DECELERATION FOR EACH BRAKING

From section 3.1.1 it is clear that most braking occurred at low speeds. To further investigate braking behaviour, the maximum deceleration associated with each brake application is analysed. The distribution of maximum deceleration associated with each brake application is shown in Figure 3. The label represents the maximum deceleration value for the interval, thus the interval labelled -0.20 represents all average maximum deceleration in the interval from -

0.20g to -0.15g. It can be seen that most of the maximum deceleration were in the range of -0.3g to 0g. Over 35% of maximum deceleration was between -0.05g and -0.10g, i.e. light braking. It was considered that most of such braking events were conducted by drivers to adjust their vehicle speed to their desired values, instead of bringing their vehicle to stop. Severe braking (e.g. <-0.3g) accounted for less than 2% of the total events, and much less than -0.7g which is generally considered to be maximum deceleration on dry pavement.

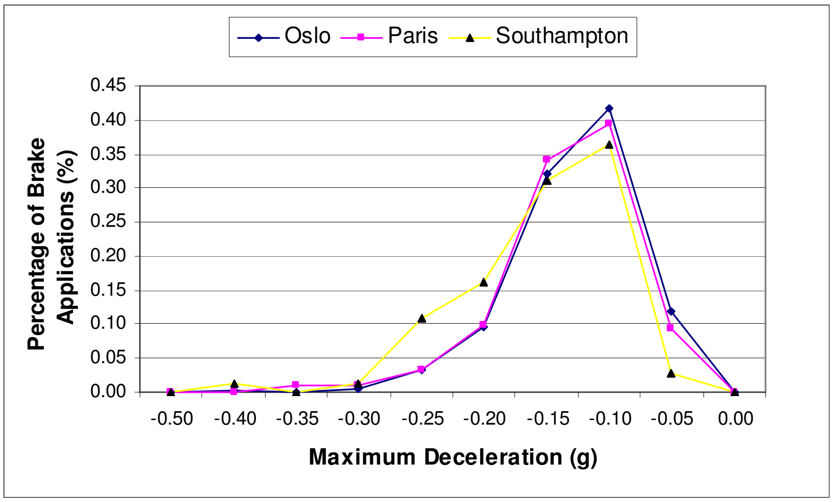


Figure 3 distribution of maximum deceleration

START DELAYS AND STOPPING-DISTANCE GAPS

Start delays

Most vehicles experience delay when starting because of driver reaction time, maneuver delays, mechanic delays and human error. In this section, start delays at signalized intersections and on non-junction roads are considered.

<u>On urban streets</u>
203, 279 and 192 start delay events were identified in Oslo, Paris and Southampton respectively. In these events, the following vehicles started later than the IV (those events in which the following vehicle start earlier than the IV were not accounted for).

The average start delays are shown in Table 2 which were calculated to be the time differences in starting to move between the IV and the following vehicle. It can be seen that the mean start delays at signalized intersections were 0.88, 0.97 and 0.94 seconds in Oslo, Paris and Southampton respectively. In average, the following vehicle started to move with a delay of 0.93 seconds.

Table 2 Start delays on urban roads

City Street	Start Delays in Time (sec.)	
	Mean	Standard deviation
Oslo (n=203)	0.88	0.62
Paris (n=279)	0.96	0.64
Southampton (n=192)	0.94	0.59

The mean start delays in the three cities have been analysed using ANOVA. The test results show that the difference in start delays between the three cities were not significant, $F(2, 668)=1.347$, $p=0.268$.

<u>On motorways</u>

Start delay events on motorways were collected in heavily congested traffic. From 42, 35, and 19 start delay events were identified in Oslo, Paris and Southampton respectively. The average start delays on the motorways is shown in Table 3. It can be seen that the mean start delays are 1.25, 1.19 and 1.36 seconds in the three cities with an average start delays of 1.27 seconds.

Table 3 Start delays on motorways

	Start Delay in Time (sec.)	
	Mean	Standard deviation
Oslo (n=42)	1.25	0.75
Paris (n=35)	1.19	0.78
Southampton (n=19)	1.36	0.92

To compare the start delays between those on urban streets and on motorways, independent t-tests were conducted for each city. The test results show that start delays on urban streets are significantly less than those on motorways (Oslo, $t(242)=-3.419$, $p=0.001$; Paris, $t(311)=-1.881$, $p=0.061$; Southampton $t(207)=-2.733$, $p=0.007$). The comparison of start delays between those on urban streets and on motorways is shown in Figure 4. It can be seen that the mean start delays on motorways was 1.27 seconds, compared to 0.93 on urban streets. On urban streets, most start delay events occurred at signalized intersections. These differences could have been partly the results of additional information available to the drivers e.g. other signals aspects or ahead traffic movements.

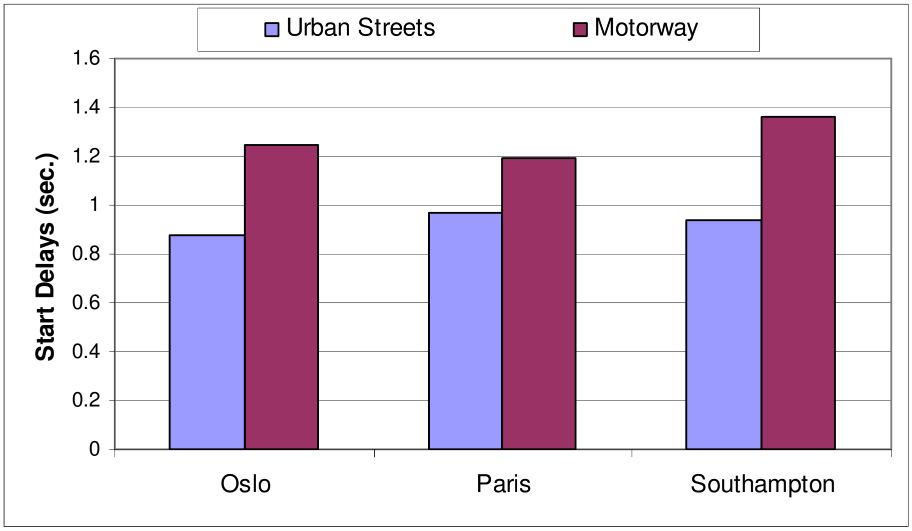


Figure 4 Start delays on urban street and motorways

Discussion: Any reductions in start delays would suggest a capacity benefit. Some potential to reduce start delays exists by using advanced driver assistance systems (ADAS). For example an automatic Stop and Go technology, which is based on sensors to detect an ahead vehicle and can significantly reduce "driver" reaction time. It is expected that the impact of such systems on reducing start delays will be particularly beneficial in multilane situations either on urban streets or on motorways. Such impacts will be investigated by simulation in next stage of this project.

Stopping-distance gaps

When a vehicle stops in a queue, the following driver chooses a distance to separate the his/her vehicle from that in front. The stopping-distance gap is defined as the distance between the rear bumper of the front vehicle and the front bumper of the following vehicle. In this section, distributions of the stopping-distance-gaps on different road conditions are analyzed based on the data collected in the three cities.

<u>On urban streets</u>
The data used were those collected on urban roads with signalized intersections. In the three cities, 249, 339 and 243 signal events were identified in which both the IV and the following vehicle stopped fully before the stop line with the IV being the front vehicle. The mean stopping-distance-gaps in the three cities are as shown in Table 4. It can be seen that the stopping-distance-gaps on urban streets is 1.79m.

Table 4. Stopping-distance-gaps on urban streets

	Urban Street (m)	
	Mean	Std.D
Oslo (n=249)	1.89	0.68
Paris (n=339)	1.65	0.62
Southampton (n=243)	1.83	0.7

Firstly, one-way ANOVA was used to examine the difference in stopping-distance gaps between the three cities. F-test results showed that the difference in stopping-distance-gaps between the three cities are significant, F(2,820)=11.351, p=0.001. To further identify the difference between the three cities, a Post Hoc Test was conducted. Table 5 shows the Post Hoc Test results. It can be seen that the differences in stopping-distance-gaps between Paris and Oslo and between Paris and Southampton are significant at the 5% level.

Table 5 Post Hoc Test to comparing stopping-distance-gaps between the three cities

Multiple Comparisons

Dependent Variable: ALLC
Tukey HSD

(I) City	(J) City	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Oslo	Paris	.2423*	.05454	.000	.1142	.3703
	Southampton	.0571	.06175	.625	-.0879	.2021
Paris	Oslo	-.2423*	.05454	.000	-.3703	-.1142
	Southampton	-.1852*	.05636	.003	-.3175	-.0528
Southampton	Oslo	-.0571	.06175	.625	-.2021	.0879
	Paris	.1852*	.05636	.003	.0528	.3175

*. The mean difference is significant at the .05 level.

On motorways

The mean stopping-distance-gaps on motorways is shown in Table 6. It can be seen that the average stopping-distance gap on motorways is 1.98m. The homogeneity of the mean start delays in the three cities has been tested using ANOVA. The test results show that the difference in start delays between the three cities are not significant, F(2, 102)=1.515, p=0.225.

Table 6 Stopping-distance-gaps on motorways

	Motorway (m)	
	Mean	Std.D
Oslo (n=47)	1.83	0.51
Paris (n=41)	2.06	0.8
Southampton (n=20)	2.04	0.54

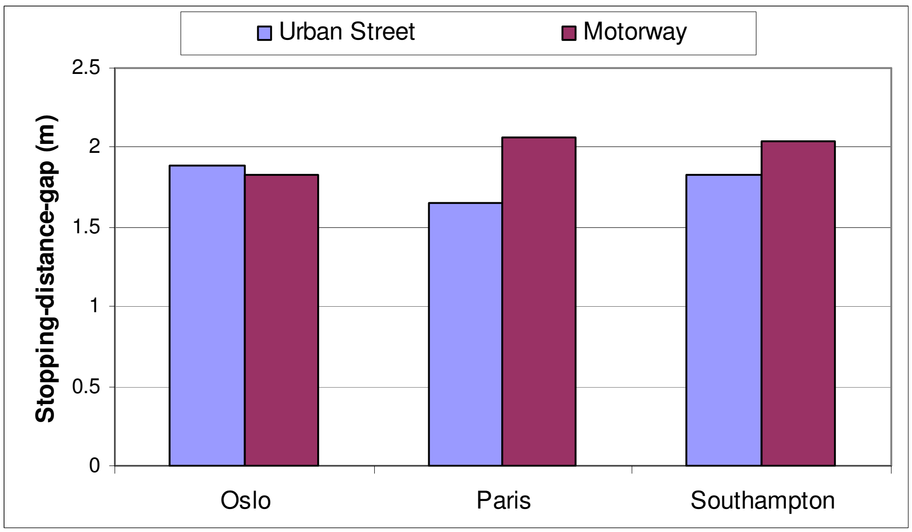


Figure 5 Stopping-distance gaps on urban streets and motorways

Discussion: Field data show that stopping-distance gaps are widely distributed in queues. Any reductions in stopping-distance gap or its variability would suggest a benefit in increasing storage capacity and the traffic capacity of a road link. These effects will be particularly strong in multilane situations either at signalized intersection or on motorways. There is some potential to use driver assistance systems (e.g. automatic Stop and Go) to shorten such stopping-distance-gaps or at least their variability. Compared to manual control, the systems control is based on a sensor which can increase the accuracy the distance control.

CONCLUSION

Driver behaviour in stop and go traffic have been analysed using field data collected in three European cities: Oslo, Paris and Southampton. The analysis was focused on braking frequency, maximum deceleration, start delays and stopping-distance-gaps. The results from the three cities show that start delays on motorways were significantly higher than those on urban streets, which implied that there could be greater benefit using Stop&Go on motorway than on urban streets. Braking frequency at speeds lower than 10km/h could be as high as 25 times per kilometres, although when speed was over 60km/h, brake applications were reduced significantly. In the next stage of this project, the current microscopic simulation models will be recalibrated based on the newly obtained diver behaviour database, and the impacts of Stop and Go systems on traffic efficiency, traffic safety and environment will be investigated in details.

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REFERENCES

1. Brackstone M and M McDonald. Modelling of motorway operations. In Transportation Research Record. 1485, TRB, National Research Council, Washington, DC., 1995, pp50-60.
2. Brackstone M and M McDonald. The microscopic modelling of traffic flow: weakness and potential development. Workshop on Traffic and Granular Flow: HLRZ, Julich, Germany, Oct. 1995. Wolf, D.E., Schreckenberg, M. and Bachen, A, eds. World Science, Singapore, 1996, pp 151-66.
3. Broolhuis K. De Waad, D., and M. Muller. Measuring driver performance by car following. Ergonomics, Vol. 37, No. 3, 1994. pp427-34.
4. Sakai I, Chilton N. J., Pacaud S.J., Hazelden R. J. and S.J. Proser. Optical speed over ground sensors for on-board vehicle speed measurement. Colloquium on Automotive Sensors, Digest No. 1992/107. IEE, London, UK. 1992.