TRANSPORT RESEARCH LABORATORY

Lateral distribution of motorway traffic

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Executive Summary

Providers of tolling enforcement systems frequently use equipment which is operational over a width less than a full carriageway and use multiple beams to cover the width required. This inevitably results in a non-uniform lateral profile (of, for example, communications probability or correct enforcement probability). As a result, equipment aligned to cover the centre of motorway lanes may be less efficient at lane edges.

To understand better the potential seriousness of non-uniform lateral performance, TPF2 Division of DOT (now DETR) commissioned TRL to investigate and report on the lateral distribution of vehicles across motorway carriageways under a range of typical conditions. Although it had initially been thought that use could be made of an existing microscopic simulation model, it was concluded that a preferred option was analysis of video tapes from existing archive material of motorway scenes. Both manual and automatic analysis methods were considered and, for this application, manual analysis was chosen as the most flexible data capture method.

The results obtained suggested that different patterns of lateral displacement distribution exist for different scenarios. The main differences occurred at sites where there is: a gradient, a lay-by, significantly more lane-changing, different flow and speed conditions, and where there is a different mix of traffic. However, the lateral displacement of vehicles appears to be most affected by the proportion of HGVs and speed of traffic, and the close proximity of a slip road results in significantly more lane-changing.

1 Introduction

The UK's tolling and enforcement system must be capable of full multi-lane operation i.e. where the tolled vehicle is not constrained to a lane.

System providers tend to use equipment which is operational over a width less than a full carriageway and use multiple beams to cover the width required. This inevitably results in a non-uniform lateral profile (of, for example, communications probability or correct enforcement probability). As a result, equipment aligned to cover the centre of motorway lanes may be less efficient at lane edges.

To better understand the potential seriousness of non-uniform lateral performance, an investigation of the lateral distribution of vehicles across the whole carriageway was undertaken.

2 Potential data capture methods

2.1 SISTM (Simulation of Strategies for Traffic on Motorways)

SISTM is a microscopic (vehicle by vehicle) simulation model designed to replicate the behaviour of motorway traffic based on observations of traffic in heavy flow conditions. The model accurately reflects car following and lane changing behaviour but, as is usual with microscopic simulation, the data input requirements of the programs are substantial. They include data defining all aspects of the network, data on vehicle and driver characteristics and Origin and Destination (O-D) matrices for the whole period of the simulation. As the microscopic data which SISTM uses for modelling would still need to be collected manually, it was decided after discussion that video analysis would be the preferred approach in this project.

2.2 Automatic video analysis

TRL has an automatic video analysis system called Computer Aided Traffic Sensors (CCATS). The system works by placing templates (virtual loops) onto the video image. Data which can be extracted includes traffic counts, vehicle speeds, headways and lengths. It takes about 15 minutes to set up for each video tape, which can then be run in real time.

Although initially attractive, CCATS was rejected for the lateral position work for a number of practical reasons:

- a small vehicle can give the same reading as a large vehicle even if their central lateral position is different.
- the vehicle height can also affect this measurement.
- the above problems become more apparent when the camera is not directly over the lane of interest (and many of the video tapes available were not recorded with a field of view suitable for automatic analysis).
- analysis of a wider area cannot be obtained with this automated equipment.

CCATS, however, is very useful for characterising traffic density and was used in this capacity.

2.3 Manual video analysis

Manual analysis remains the most flexible and accurate data capture method, and was therefore the adopted methodology for this project.

3 Methods of lateral position measurement

Two causes of lateral variability were distinguished:

Situation 1. That caused by drivers taking up a variable lateral position during normal lane driving (which may be expected to be different for each lane of the carriageway).

Situation 2. Overtaking or lane changing manoeuvres which involves drivers positively deciding to leave their current lane.

3.1 In-lane lateral positioning

Characterising Situation 1 (in-lane lateral positioning) was a simple matter of measuring the lateral position of the centre of the vehicle across a defined line. Measurement of one hundred vehicles per lane was considered to be sufficient for reasonable statistical accuracy (for each site and condition). The centre position of the vehicle was classified into one of 16 bins across each lane (giving a precision of 3.65m/16 = 23cm). This resulted in a scale of -184cm to +184cm, where the central position was zero.

3.2 Lane changing manoeuvres

The 'defined line' approach excluded lane changing or overtaking manoeuvres as these vehicles would not have been included in either lane count. In many ways it is these rarer lateral positions which are of most interest for this study. Therefore, a second phase of manual analysis was undertaken which made use of time lapse and 'fast forwarded' video to identify target lane changing manoeuvres. The length of lane change manoeuvre was recorded for those manoeuvres which occurred wholly within the field of view.

The average lane changing manoeuvre length was estimated to the nearest 10m, by counting lane markings (each lane marking represented 7 metres with a 2 metre gap between them).

3.3 Combining data from the two measurements

The measurements of lateral displacement ('defined line') analysis and the measurements of lane changing manoeuvres were combined as described in sections 4.4 and 4.5 using formulae detailed in Appendix A.

Combining the two measurements allows an overall lateral distribution to be calculated and also enables correction of flow data obtained from CCATS where vehicles outside the scope of the templates (i.e. very close to the edge of the lane or changing lane) were not registered.

3.4 Data capture scenarios

The 'defined line' and 'lane changing' analysis was repeated for five different scenarios. These were determined by the availability of recorded video data, and were characterised as:

a high flow - 4 lane motorway

b medium flow (some flow breakdown) - the same 4 lane motorway

c high flow - different section of 4 lane motorway, and with a gradient

d medium flow (free-flowing) - 3 lane motorway

e low flow - 3 lane motorway

These are further described in Appendix B.

4 Data capture results

4.1 Flow data

Flows per lane for each of the motorways were obtained using CCATS. Vehicle flows were recorded for 40 minutes and then scaled up to produce hourly flows. Vehicles close to the edges of the lanes were not recorded by CCATS as they did not have a large enough proportion of their surface area within the template. CCATS divided the vehicles into three categories:
C1 - Cars
C2 - Light Goods Vehicles
C3 - Heavy Goods Vehicles

4.1.1 Flow Distribution by Lane

Table 1 Flows/hour (Category 1)

Motorway sites	*Lane 1*	*Lane 2*	*Lane 3*	*Lane 4*	*Total*
a) M25 Near Egham (16:00-16:40)	1224	1183	1479	2098	5984
b) M25 Near Egham (19:10-19:50)	1284	1137	1298	1421	5140
c) M25 Near Lyne (16:10-16:50)	713	1173	1656	1983	5525
d) M3 Virginia Water (16:10-16:50)	809	1486	1503	N/A	3798
e) M42 J6/5 Bobs Br. (16:00-16:40)	488	1194	1223	N/A	2905

The proportion of vehicles in the respective lanes of the five scenarios was examined for any differences. Pie charts (Figure 1 in Appendix B), illustrate the percentages of total flow for the individual lanes.

Comparing the four lane motorways, scenarios a, b, and c, it can be seen that:

- The two High Flow scenarios, a and c, both had proportionally higher numbers of cars in Lane 4.
- The Medium Flow, scenario b, had similar numbers of cars in all lanes.
- The High Flow + Gradient, scenario c, had a much larger proportion of cars in Lane 3 and much smaller proportion in Lane 1 than scenarios a or b.

Comparing the three lane motorways, scenarios d and e, it can be seen that there were proportionally fewer cars in Lane 1 and slightly more cars in the other two lanes in the Medium Flow scenario compared with the Low Flow scenario.

4.1.2 Lane occupancy

The percentage of the different categories of vehicles in each lane using data obtained from CCATS was calculated for all the scenarios to determine any differences in the mix of vehicles as shown in Table 2.

Table 2 Lane occupancy of category 1, 2 and 3 vehicles

Traffic lane and vehicle cat.	*(a) M25 High Flow (% Occup)*	*(b) M25 Med Flow (% Occup)*	*(c) M25 High+ Grad (% Occup)*	*(d) M3 Med Flow (% Occup)*	*(e) M42 Low flow (% Occup)*
Lane 1					
C1	85%	91%	80%	73%	57%
C2	5%	3%	10%	8%	9%
C3	9%	6%	10%	18%	34%
Lane 2					
C1	82%	86%	75%	87%	79%
C2	5%	4%	8%	8%	13%
C3	12%	10%	17%	5%	9%
Lane 3					
C1	84%	90%	85%	93%	88%
C2	10%	6%	9%	4%	11%
C3	7%	4%	6%	2%	1%
Lane 4					
C1	95%	97%	97%	N/A	N/A
C2	4%	3%	3%		
C3	1%	0%	0%		

Category 3 (HGV) occupancy was found to be highest in Lane 2 (M25 High Flow + Gradient), Lane 1 (M3 Medium Flow) and in Lane 1 (M42 Low Flow).

The overall mix of vehicles for the five scenarios was calculated and a stacked bar graph prepared to illustrate the percentages of vehicles in each category for each of the motorways (Figure 2 in Appendix B). The M42 (Low Flow) showed the highest proportion of HGVs and LGVs and M25 (Medium Flow) showed the lowest proportions of these two categories.

4.2 Lateral displacement distributions

The lateral displacement of 100 vehicles per lane for each scenario was measured. It was decided to look at just the behaviour of cars as the numbers of other vehicles were very small.

Figures 3-7 in Appendix B show the lateral distributions of each lane for each scenario.

The Lateral Displacement Distributions (Bar Charts) were examined and the following observations made:

- Comparing scenarios a and b, (High and Medium Flow 4-lane which are at the same site):

  Lane 1, and Lane 4 distributions were similar but Lane 2 and Lane 3 distributions were displaced further to the right in the Medium Flow scenario.

- Comparing scenarios a and c, (High Flow M25 near Egham with High Flow + Gradient M25 near Lyne):

  The central point of the distributions were similar for both scenarios but the range of measurements was smaller for the High Flow with gradient scenario.

- Comparing scenarios d and e, (Medium Flow M3 at Virginia Water and Low Flow M42 Junction 6 to 5 at Bob's Bridge):

  The Lane 1 distribution was similar for both scenarios but Lane 2 and Lane 3 distributions were both displaced further to the right in the Medium Flow scenario.

  Average lane position results are summarised in Table 3.

Table 3 Average lane position from centre of lane in centimetres (negative represents displacement to the left)

Motorway sites	*Lane 1*	*Lane 2*	*Lane 3*	*Lane 4*
a) M25 Egham (16:00) High flow	-58	-40	-7	35
b) M25 Egham (19:00) Med flow	-58	30	13	36
c) M25 Lyne (16:30) High +Grad	-32	-25	1	27
d) M3 V.Water (16:20) Med flow	-31	27	68	N/A
e) M42 J6/5 (16:10) Low flow	-43	4	19	N/A

The average lane positions were then examined:

It was interesting to note that Lane 1 and Lane 4 average lane positions were similar in all cases but Lane 2 and Lane 3 average positions were very different when comparing High and Medium Flow scenarios at the same site (M25 near Egham).

The two 3-lane motorways had very different profiles, particularly for Lanes 2 and Lane 3.

4.3 Lane changing

Lane changes for approximately 100 vehicles were monitored for each scenario using manual video analysis. The length of motorway in view (L) and the average length of a lane change (l) were estimated for each scenario by counting lane markings (a single lane marking + the space between markings = 9 metres). Table 4 shows the data scaled up to give the number of changes per hour between each lane (e.g. n_{12} refers to changes from lane 1 to lane 2) for each scenario. The time of measurement is also recorded.

It can be seen that the highest number of lane change manoeuvres were recorded in scenario c, the M25 (High Flow + Gradient) scenario. This is largely because of the wider field of view of the video images, but could also be because a gradient is likely to cause an increase in speed differentials.

4.4 Combining flows from in-lane and lane changing vehicles

As described in section 4.1, CCATS, which was used to measure hourly flows, did not record vehicles outside of its template area near the centre of each lane. To a reasonable approximation, vehicles outside of this template area can be assumed to be in the process of a lane change manoeuvre. Therefore, the figures in Table 1 under-represent flows and, if lane changers are allowed to contribute equally to counts in both lanes they use, the overall lane counts are given by the equations shown in Appendix A. Table 5 shows the effect of this correction.

The under-representation of vehicle counts caused by lane changing was very small, and less than the counting accuracy expected from video-based systems. Thus, for most practical purposes lane changers can be disregarded from overall flow measurements.

4.5 Combining lateral distributions from in-lane and lane changing vehicles

When measuring lateral distributions in section 4.2, vehicles that were not clearly in one lane or another were excluded from the measurements. To a reasonable approximation, such vehicles can be assumed to be in the process of a lane change manoeuvre; the incidence of vehicles travelling for prolonged periods straddling lanes being very low (with the important exception of motorcycles). Therefore, the lane positions in Table 3, and Figures 3 to 7, need to be revisited to take account of lane changing vehicles.

Vehicle lateral positions were categorised into one of 16 'bins', as described in section 3.1. Typically, in-lane observations only provided counts in 10 or 11 bins near the centre of a lane. Vehicles which were in the process of lane changing were discounted, but do, obviously, contribute to the distributions in the 'remaining' bins, near the edges of lanes. A formula for attributing lane changing vehicles to 'bins' is developed in Appendix A and can be simply extended to three and four lane motorways. Table 6, shows the number of bins between pairs of lanes that received no counts during the manual estimation of lane position, and the number of vehicles which should be apportioned to each bin to account for the lane changing that was subsequently recorded.

The percentage that these lane changing vehicles represent on the lateral distribution plots of Figures 3-7 is given by multiplying by $100/C_x$ where C_x is the vehicles/hour count in the relevant lane. Table 7 combines the lateral distributions of in-lane and lane changing vehicles. It can be seen that lateral positions near the edges of lanes now contain a small contribution to the overall distribution, although it is too insignificant to register on the graphical plots.

Table 4 Number of lane changes per hour for each of the scenario views

Scenario (time)	*L (m)*	*l (m)*	n_{12}	n_{21}	n_{23}	n_{32}	n_{34}	n_{43}
a) M25 High Flow (16:00 hrs)	100	69	14	27	21	43	31	53
b) M25 Medium Flow (19:00hrs)	100	69	5	8	4	20	5	20
c) M25 High Flow + Gradient M25 (16:00hrs)	500	90	42	150	258	72	156	96
d) M3 Medium Flow (16:00hrs)	100	75	54	32	53	34	N/A	N/A
e) M42 Low Flow (16:00hrs)	100	75	56	25	64	64	N/A	N/A

Table 5 Number of vehicles excluded from previous counts

Scenario (time)	*Lane 1 Veh missed/hr*	*Lane 2 Veh missed/hr*	*Lane 3 Veh missed/hr*	*Lane 4 Veh missed/hr*	*Total Veh missed/hr*	*% of Total flow/hr*
a) M25 High Flow (16:00)	0.823	2.091	2.94	1.68	7.5	0.13
b) M25 Med Flow (19:00)	0.261	0.73	0.965	0.496	2.4	0.05
c) M25 High Flow + Gradient (16:00)	0.911	1.659	2.328	1.437	6.3	0.11
d) M3 Med Flow (16:00)	1.868	3.736	2.154	N/A	7.8	0.20
e) M42 Low Flow (16:00)	1.614	4.179	2.566	N/A	8.4	0.29

Table 6 Lateral distribution of lane changing vehicles

Scenario (time)	*Lane 1-2 Bins*	*Changers/ hour/bin*	*Lane 2-3 Bins*	*Changers/ hour/bin*	*Lane 3-4 Bins*	*Changers/ hour/bin*
a) M25 High Flow (16:00)	10	0.0023	11	0.0030	11	0.0024
b) M25 Med Flow (19:00)	12	0.0062	13	0.0010	11	0.0032
c) M25 High Flow + Gradient(16:00)	10	0.0083	10	0.0101	10	0.0009
d) Medium Flow M3 (16:00)	9	0.0062	11	0.0039	N/A	N/A
e) Low Flow M42 (16:00)	12	0.0060	8	0.0099	N/A	N/A

4.6 Speeds

Speeds were collected using CCATS but, due to the angle of the camera, HGV speeds are overestimated by approximately 25% and this has been accounted for in the speeds detailed in Appendix B.

Speeds for scenario b, the M25 Egham (Medium Flow), were very low and approximately the same in each lane whereas for the other motorways the speeds increased from Lane 1-3 or Lane 4.

5 Discussion

Before the study began, a number of factors were expected to affect lateral profile including:-

- the motorway site
- gradient
- merges and splits
- traffic flow and density
- mix of traffic
- traffic speed

These are discussed below.

5.1 Summary of observations

The five motorway scenarios were examined with regard to all the factors expected to affect the lateral displacement and the data collected. The most noticeable observation was that for the four lane scenarios, the lateral distribution for vehicles in Lane 1 tends to be displaced to the left, the distribution for vehicles in Lanes 2 and 3 is more central, and the distribution for Lane 4 is displaced to the right. For the three lane scenarios, the lateral distribution for vehicles in Lane 1 tends to be displaced to the left, the distribution for vehicles in Lanes 2 is more central and the distribution for Lane 3 is displaced to the right.

5.1.1 Effect of gradient and nearby slip road

Only one scenario (scenario c) included a gradient, and was about 0.5 miles from a slip road. This was compared with scenario a, which was a different location on the same motorway.

The following observations can be made:

- The number of lane-changing manoeuvres was much higher - 774 /hour compared with 189/hour.
- The average lateral displacements of vehicles were less for all lanes.
- The percentage of HGVs was higher in Lane 2.
- The average speed was lower for all lanes except Lane 4.

5.1.2 Effect of flow

The M25 at Egham High Flow Scenario was compared with the Medium Flow Scenario at the same location (these two Scenarios were on the same day). High Flow occurred prior to peak time, whereas Medium Flow occurred after peak time, and the reduction in flow was mostly caused by periods of congestion, ‘bunching’, and consequent flow breakdown. The observations revealed that the high flow had the following characteristics:

- The numbers of lane-changing manoeuvres were much higher (189/hour compared with 61/hour).
- The average lateral displacements were greater for Lanes 2 and Lane 3.
- The percentage of HGVs was higher for all lanes, probably due to the time of day.
- The lateral displacement seemed to increase with flow except for Lane 1. However, as noted above, where there is a gradient it was reduced.

5.1.3 Lane-changing

As expected, a higher number of lane-changing manoeuvres occur on a motorway with a gradient and near

Table 7 Overall lateral distribution of in-lane and lane changing vehicles (Percentages of vehicles per bin)

a) M25 High Flow (16:00)

Bin positions	*Lane 1*	*Lane 2*	*Lane 3*	*Lane 4*
-184	0	0.00019	0.00020	0.00011
-161	0	0.00019	0.00020	0.00011
-138	0	0.00019	0.00020	0.00011
-115	8	5	0.00020	0.00011
-92	20	12	2	0.00011
-69	24	19	7	0.00011
-46	24	21	11	3
-23	16	18	17	3
0	7	19	35	16
23	1	4	20	24
46	0.00018	0.00025	6	27
69	0.00018	1	2	22
92	0.00018	0.00025	0.00016	4
115	0.00018	0.00025	0.00016	0
138	0.00018	0.00025	0.00016	0
161	0.00018	0.00025	0.00016	0
184	0.00018	0.00025	0.00016	0

b) M25 Medium Flow (19:00)

Bin positions	*Lane 1*	*Lane 2*	*Lane 3*	*Lane 4*
-184	0	0.00005	0.00008	0.00023
-161	0	0.00005	0.00008	0.00023
-138	0	0.00005	0.00008	0.00023
-115	5	0.00005	0.00008	0.00023
-92	25	2	0.00008	0.00023
-69	22	16	0.00008	0.00023
-46	23	21	6	0.00023
-23	14	29	10	6
0	11	31	41	12
23	0.00005	1	17	27
46	0.00005	0.00009	18	34
69	0.00005	0.00009	5	15
92	0.00005	0.00009	3	6
115	0.00005	0.00009	0.00025	0
138	0.00005	0.00009	0.00025	0
161	0.00005	0.00009	0.00025	0
184	0.00005	0.00009	0.00025	0

c) M25 High Flow + Gradient (16:00)

Bin positions	*Lane 1*	*Lane 2*	*Lane 3*	*Lane 4*
-184	0	0.00071	0.00061	0.00005
-161	0	0.00071	0.00061	0.00005
-138	0	0.00071	0.00061	0.00005
-115	0	0.00071	0.00061	0.00005
-92	7	7	0.00061	0.00005
-69	16	10	3	1
-46	24	19	5	3
-23	29	29	20	12
0	13	24	39	19
23	7	5	23	19
46	4	5	8	21
69	0.00116	1	2	16
92	0.00116	0.00086	0.00005	7
115	0.00116	0.00086	0.00005	0
138	0.00116	0.00086	0.00005	0
161	0.00116	0.00086	0.00005	0
184	0.00116	0.00086	0.00005	0

d) M3 Medium Flow (16:00)

Bin positions	*Lane 1*	*Lane 2*	*Lane 3*
-184	0	0.00042	0.00026
-161	0	0.00042	0.00026
-138	0	0.00042	0.00026
-115	0	0.00042	0.00026
-92	6	1	0.00026
-69	23	3	0.00026
-46	20	3	0.00026
-23	20	7	0.00026
0	17	14	10
23	9	32	12
46	3	18	14
69	1	13	26
92	0.00077	6	20
115	0.00077	3	15
138	0.00077	0.00026	4
161	0.00077	0.00026	0
184	0.00077	0.00026	0

e) M42 Low Flow (16:00)

Bin positions	*Lane 1*	*Lane 2*	*Lane 3*
-184	0	0.00050	0.00081
-161	0	0.00050	0.00081
-138	0	0.00050	0.00081
-115	0	0.00050	0.00081
-92	16	0.00050	0.00081
-69	20	0.00050	2
-46	27	10	4
-23	18	16	9
0	13	37	30
23	2	25	21
46	9	8	20
69	0	1	10
92	2	1	4
115	0.00123	1	0
138	0.00123	0.00083	0
161	0.00123	0.00083	0
184	0.00123	0.00083	0

to a slip road. Flow does not seem to have a consistent effect on lane-changing. Higher proportions of HGVs seem to cause an increase in lane-changing manoeuvres. Average speed may have an effect on lane-changing as at lower speeds there seems to be less lane changing. An increase in lane-changing increases the number of vehicles further from the centre of lanes.

5.1.4 Mix of traffic

Lateral displacement appeared to be affected by the proportion[1] of HGVs. A Scatter plot (Figure 8 Appendix B) and a regression line illustrate the relationship. The 't' statistic obtained from Multiple Regression Analysis was 0.02 which is significant and suggests that a relationship between Ratio of HGVs to Cars and Lateral Displacement exists as follows:

Lateral Displacement (cm) =
14.22cm + (HGV ratio * -1.42cm)

5.1.5 Speed

Speed also appeared to have an effect on lateral displacement. A Scatter Plot (Figure 9 in Appendix B) was produced and there appears to be a relationship between lateral displacement and speed (at speeds over 50 mph). The 't' statistic obtained from Multiple Regression Analysis was 0.0004 which is highly significant and suggests that a relationship between Speed (over 50mph) and Lateral Displacement exists as follows:

Lateral Displacement (cm) =
-260.96cm + (Speed(mph) * 3.58cm)

5.1.6 Lateral displacements of vehicles other than cars

The lateral displacement measurements considered above have been for cars. However, measurements were taken for small samples of other vehicles and the following observations were made:

- HGVs – These tended to have very small lateral displacements (e.g. -46 to +46cms).
- Vans – These were similar to cars or possibly more centralised.
- Motorcycles – These had very variable lateral displacements. In very congested traffic conditions they were observed driving along the lane markings.

5.2 Other considerations

Conclusions drawn from snapshots of data at five sites should be considered as tentative and as providing only indicative results. A number of additional practical difficulties are noted as follows:

1 The length of lane change was difficult to measure accurately as it is difficult to determine at which point a vehicle starts and finishes its manoeuvre. It is also difficult to count the lane markings as the vehicle moves into the distance.

2 The field of view and vehicle length were estimated.

3 The angle of the camera made division of the lanes into 16 bins more difficult

4 The CCATS flows which have been used for cars may have included a small number of the smaller vans.

5 Lane 1 of the M25 scenarios is almost a slip lane, rather than a full lane, which means Lane 2 should possibly be considered as Lane 1.

5.3 Suggestions for further work

The video analysis study has provided information on the lateral displacement of motorway traffic (cars, light goods, and heavy goods) at several motorway locations. Further work could be undertaken to study a single representative site under a wider range of traffic and other conditions and could prove useful if micro modelling studies are undertaken to investigate specific tolling sites or as a contribution to modelling studies in European projects.

Additionally, the test track tolling trials have maintained a video record of the trials for both Bosch Gmbh and GEC-Marconi Communications tolling systems. A lateral distribution video analysis could be undertaken for the trials sites where anomalies have been noted in the trials data records.

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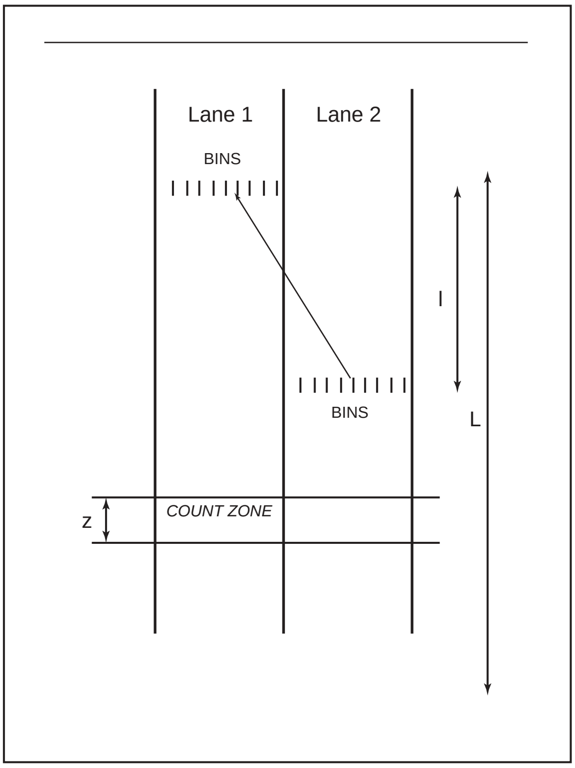
[1] *The ratio of HGVs to cars was used instead of the percentage of HGVs because the lateral displacement measurements referred to in this report are only for cars.*

Appendix A: Lateral distribution: Combining lane counts and lane changing



L = length of road over which traffic is observed

n_{12} = number of lane changes 1 to 2 per hour

n_{21} = number of lane changes 2 to 1 per hour

l = average length of lane change

c_1 = counts of veh/hr in lane 1 excluding lane changers

c_2 = counts of veh/hr in lane 2 excluding lane changers

b = number of 'bins' with zero counts by direct lateral position measurement*

z = one car length

* These bins received no counts from the first lateral position measurement study (either because no vehicles used these positions or because a vehicle was observed as being in the process of undertaking a lane change manoeuvre). The CCATS flow measurement similarly did not count vehicles in these central bins.

Allowing lane changers to contribute equally to counts in both lanes they use, the corrected lane counts are:

$$C_1 = c_1 + \frac{z(n_{12} + n_{21})}{2L} \qquad \text{(A1)}$$

$$C_2 = c_2 + \frac{z(n_{12} + n_{21})}{2L} \qquad \text{(A2)}$$

A vehicle changing lane is assumed to spend equal time in each of these b bins during transition length l. Therefore, the single count of one vehicle represents 1/b counts in each of the interim bins.

However, the probability of this happening at any given count zone (z) depends on the number of transitions, n_{21}, over distance L and the lane change length ι.

$$\text{Probability} = \frac{l}{L} * \frac{n_{21}}{(C_1 + C_2)/2}$$

So, for each interim bin it is necessary to add:

$$\frac{2l^* n_{21}}{bL(C_1 + C_2)} + \frac{2l^* n_{12}}{bL(C_1 + C_2)} = \frac{2l^*(n_{12} + n_{21})}{bL*(C_1 + C_2)} \qquad \text{(A3)}$$

The argument can be extended to three and four lane situations. For a three lane road, equation A3 is correct for bins between lanes 1 and 2. For those between 2 and 3 it becomes:

$$\frac{2l^*(n_{23} + n_{32})}{bL^*(C_2 + C_3)}$$

For four lanes, the above formulae are correct and for bins between 3 and 4, the additional term is:

$$\frac{2l^*(n_{34} + n_{43})}{bL^*(C_3 + C_4)}$$

The lane counts for a 3 lane road are:

$$C_1 = c_1 + \frac{z(n_{12} + n_{21})}{2L}$$

$$C_2 = c_2 + \frac{z(n_{12} + n_{21} + n_{23} + n_{32})}{2L}$$

$$C_3 = c_3 + \frac{z(n_{23} + n_{32})}{2L}$$

And for four lanes, C_1 and C_2 are identical, but C_3 and C_4 given by:

$$C_3 = c_3 + \frac{z(n_{23} + n_{32} + n_{34} + n_{43})}{2L}$$

$$C_4 = c_4 + \frac{z(n_{34} + n_{43})}{2L}$$

Appendix B: Scenario analysis

Tapes were chosen to avoid merges, splits, junctions and service areas except for scenario c. In each scenario, analysis was undertaken for each lane separately. The motorway and time of day were noted and the flow rate, speed, and mix of vehicles estimated.

The video tapes selected for analysis to comply with the previously defined scenarios were:

a High flow – 4 lane motorway

M25 Near Egham at the overbridge between junctions 13-12, Southbound, Friday 2nd July 1993, just before peak time (16:00). The bridge is situated approximately 1.5 miles from each junction and the nearest slip road which leads to the M3 is approximately 1 mile to the north.

Weather – Dry
Traffic – Free flowing

b Medium flow – the same 4 lane motorway, the same position and date, just after peak time (19:00).

Weather – Dry
Traffic – Some flow breakdown

c High flow – a different stretch of 4 lane motorway (with a gradient)

M25 near Lyne at the overbridge between junctions 12-11 Southbound, Wednesday 30th June 1993, just before peak time (16:30). The bridge is situated approximately 0.5 mile south of the nearest slip road which leads off of the M3.

Weather – Dry

Traffic – Free flowing

d Medium flow – 3 lane motorway

M3 at Virginia Water at the overbridge between junctions 2-3, Westbound, Tuesday 12th October 1993, just before peak time (16:20). The slip road from M25 is approximately 0.5 mile before the bridge.

Weather – Dull/Wet

Traffic – Free flowing

e Low flow – 3 lane motorway

M42 at Bob's Bridge, Near Solihull, between junctions 6-5 Southbound, Friday 15th October 1993. The bridge is approximately 1 mile after the slip road from A45.

Weather – Dry/Sunny

Traffic – Free flowing

Table B1 Speed profiles (average lane speed – all vehicles)

Site and time		*Lane1 mph*	*Lane2 mph*	*Lane3 mph*	*Lane4 mph*
M25 Egham					
scenario a (16:00)	High Flow	66	69	73	78
scenario b (19:00)	Med Flow	35	34	36	34
M25 Lyne					
scenario c (16:00)	High Flow + Gradient	61	60	72	79
M3 Virginia Water					N/A
scenario d (16:00)	Med Flow	66	75	81	
M42 Bob's Bridge					N/A
scenario e (16:00)	Low Flow	62	77	87	

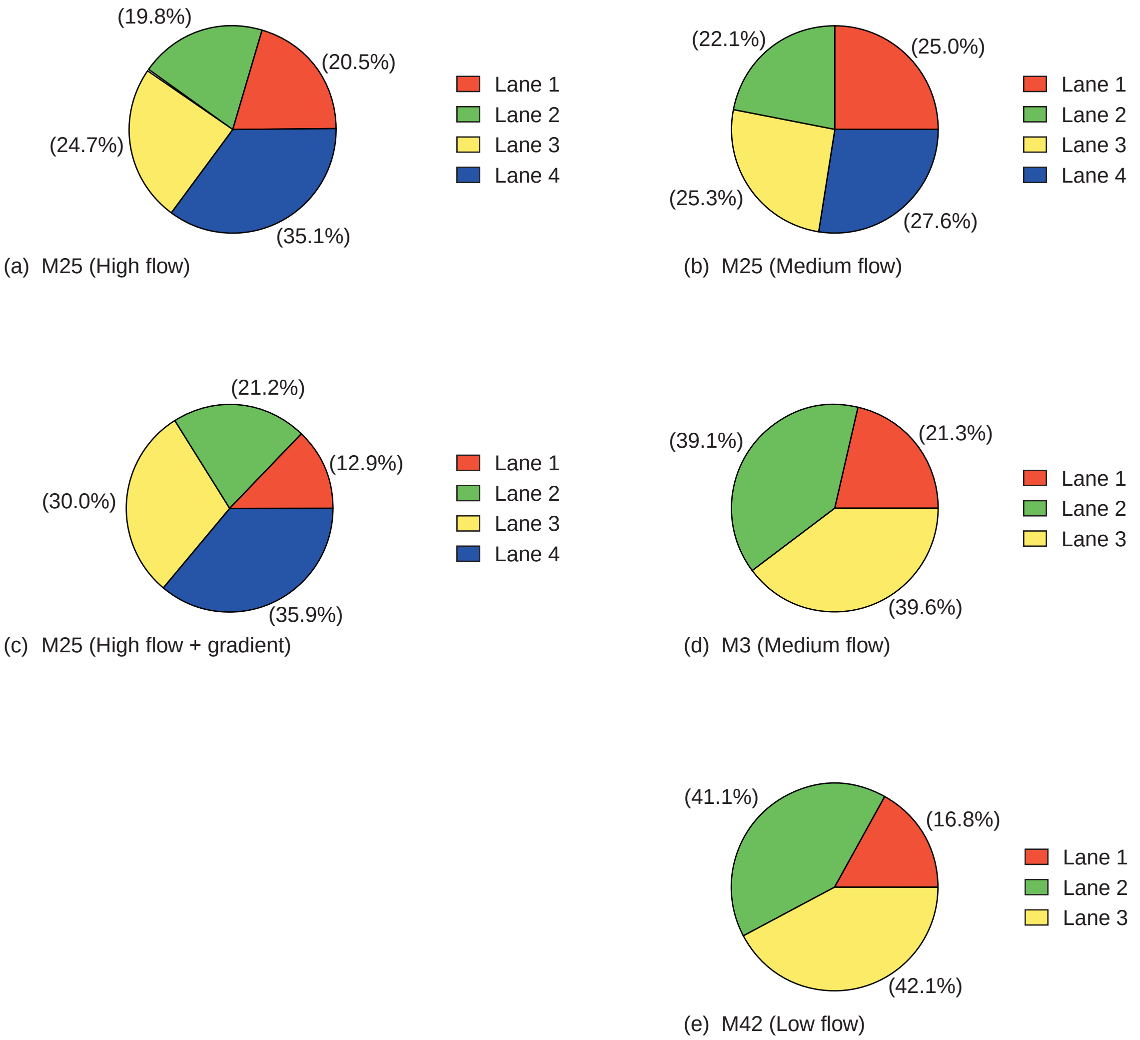


Figure 1 Percentages of cars in each lane for the five different scenarios

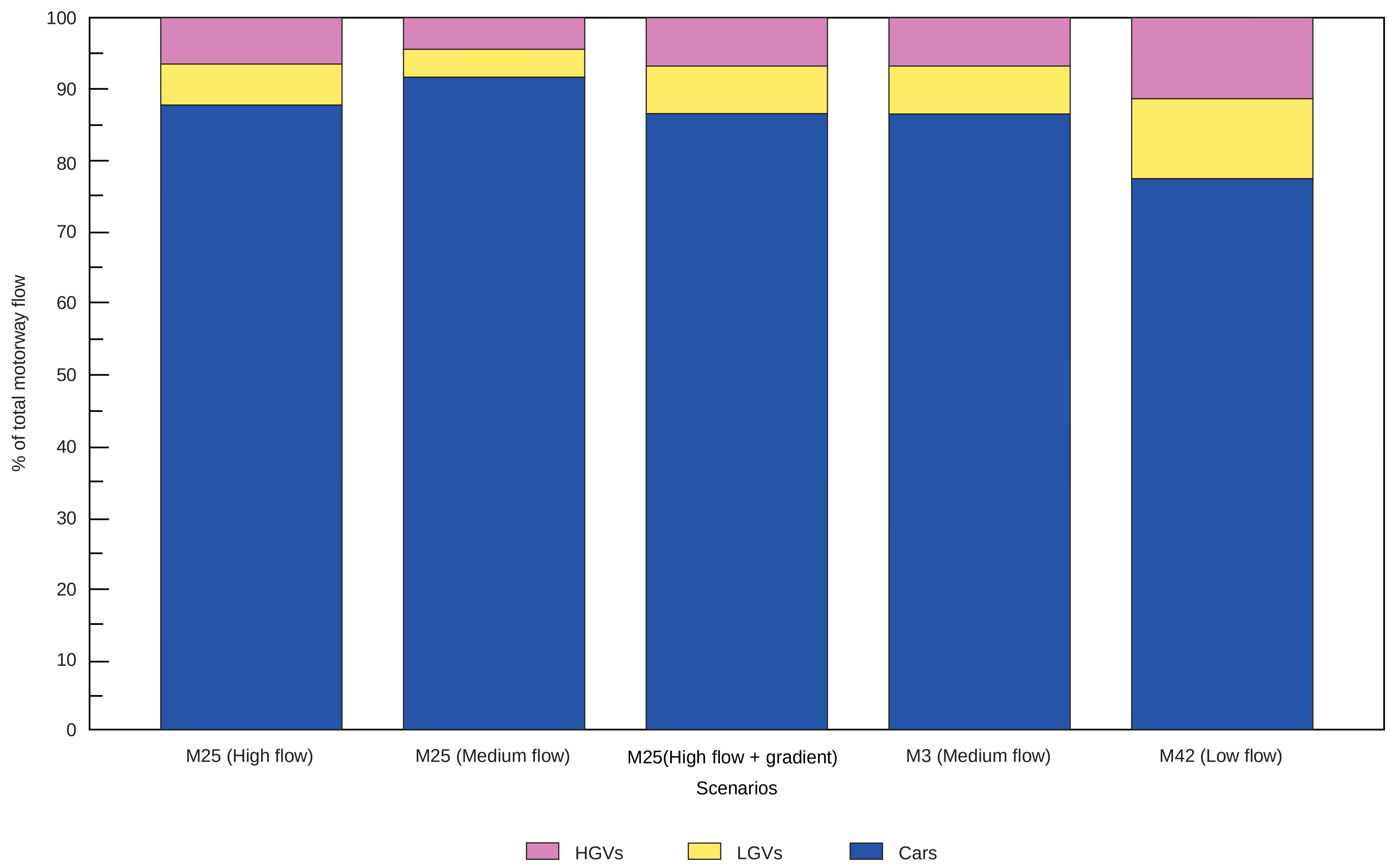


Figure 2 Stacked bar graph showing percentages of the different categories of vehicles in each lane for the five different scenarios

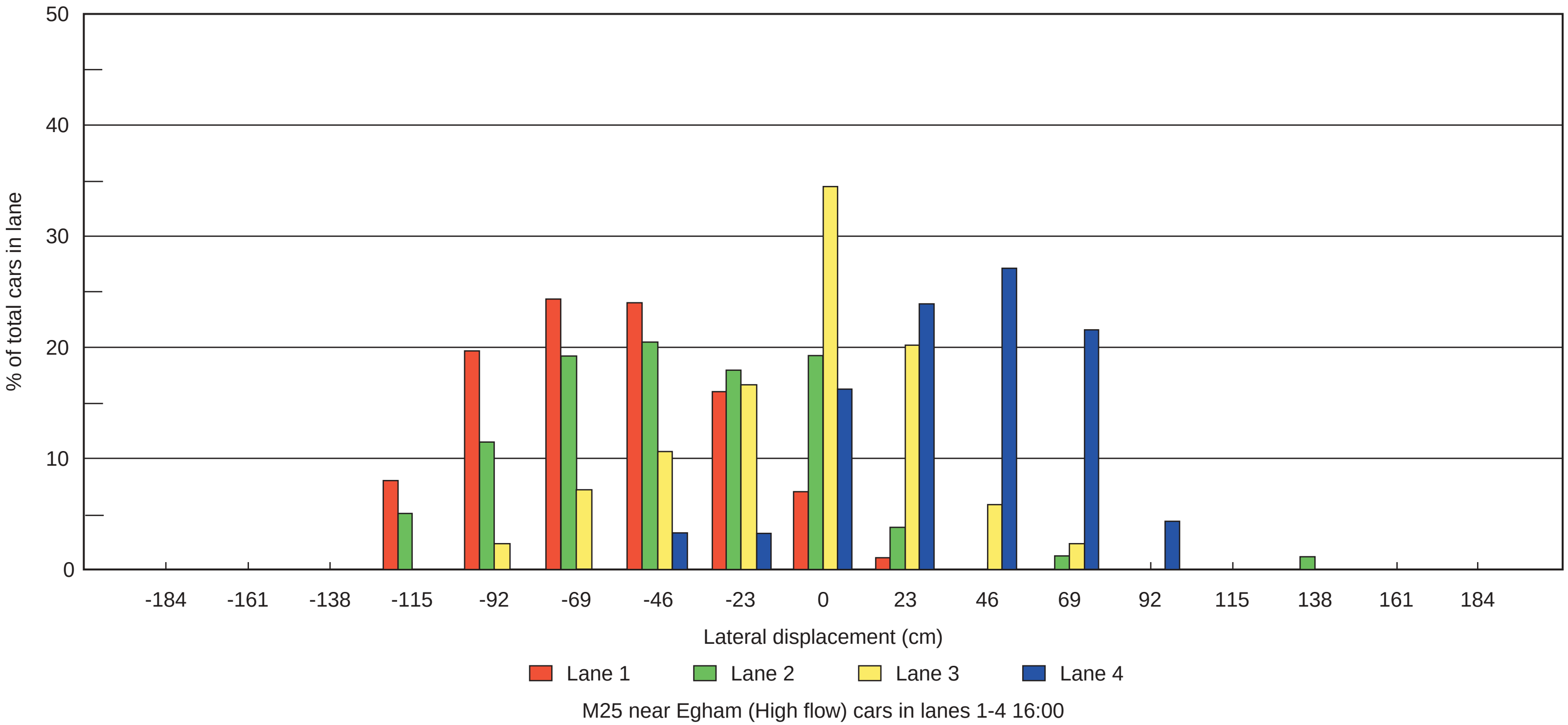


Figure 3 Bar chart showing lateral displacement distributions of cars in all lanes (High flow)

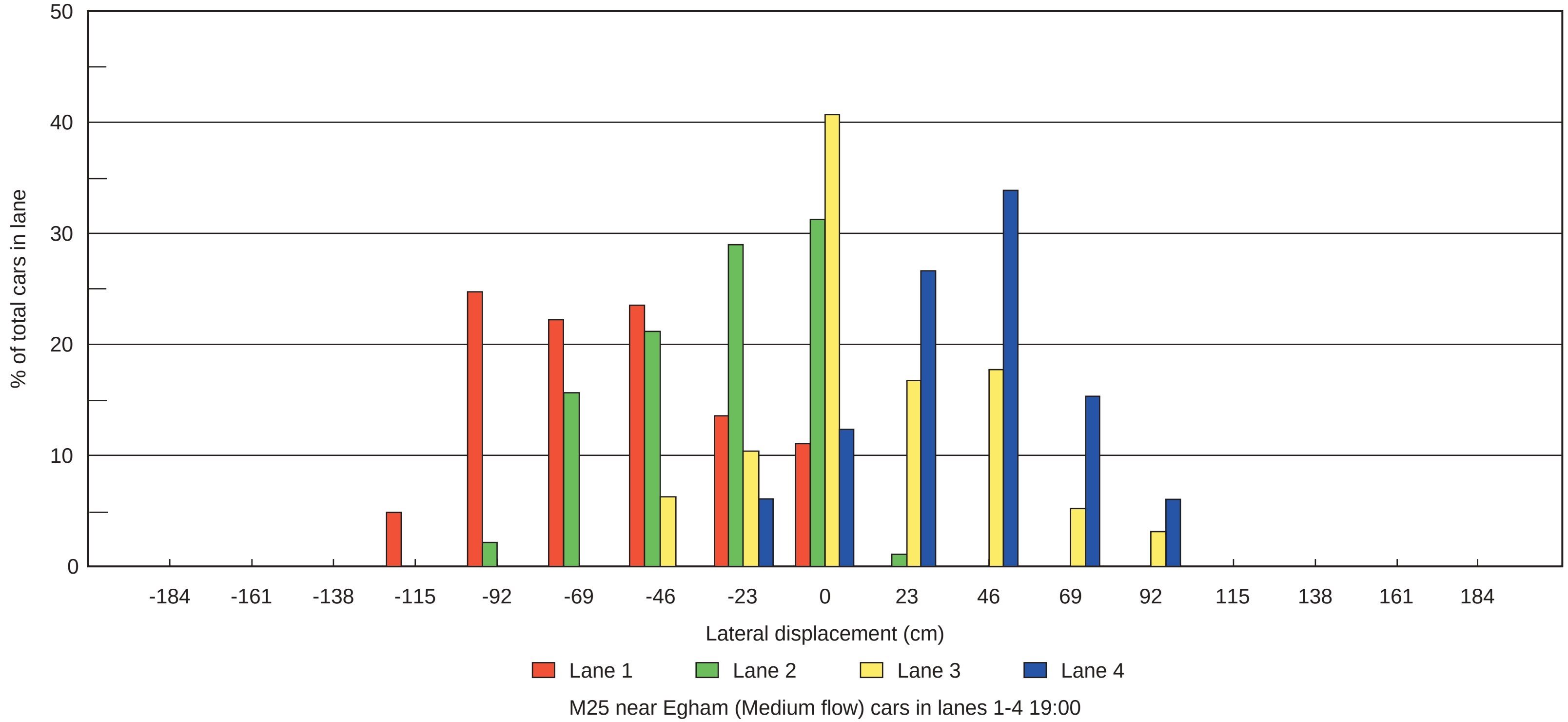


Figure 4 Bar chart showing lateral displacement distributions of cars in all lanes (Medium Flow)

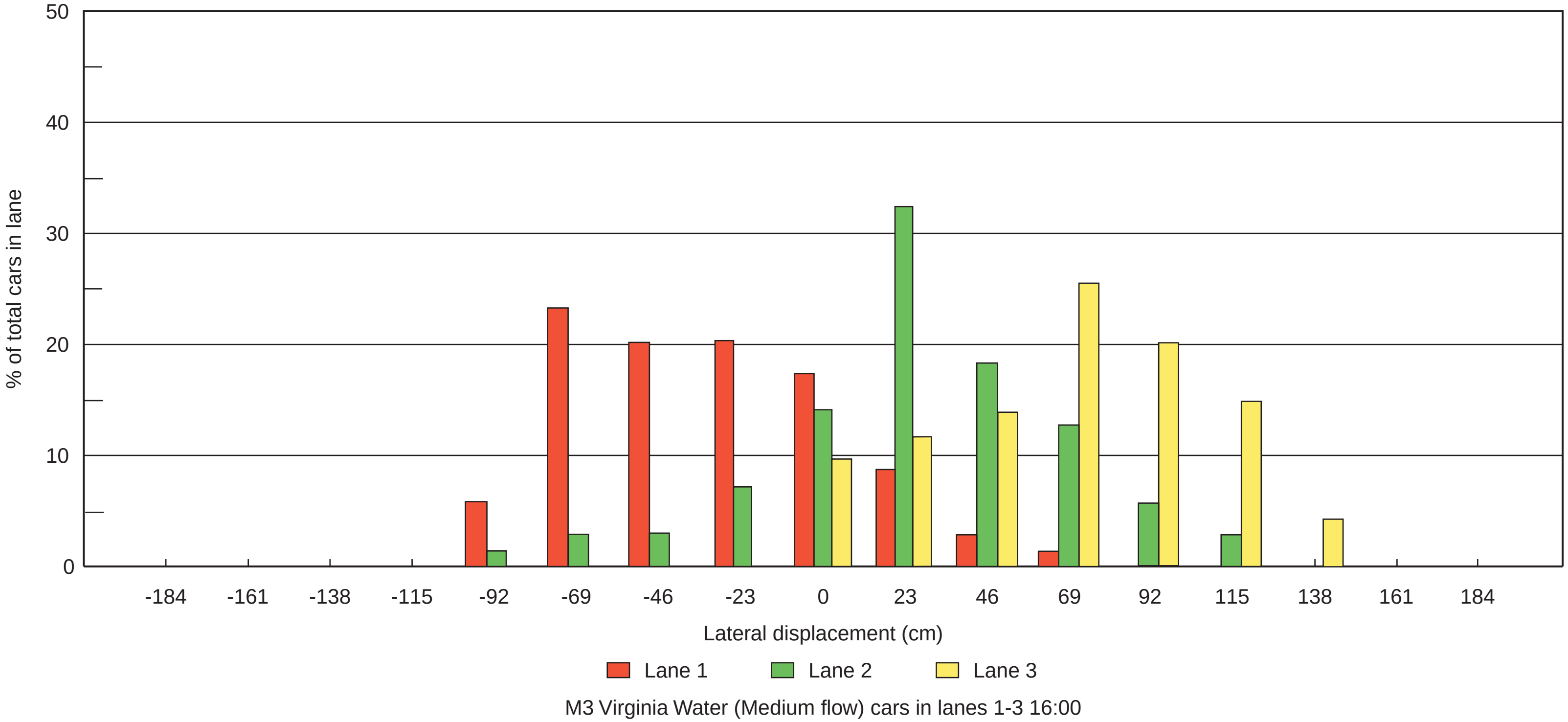


Figure 5 Bar chart showing lateral displacement distributions of cars in all lanes (Medium flow)

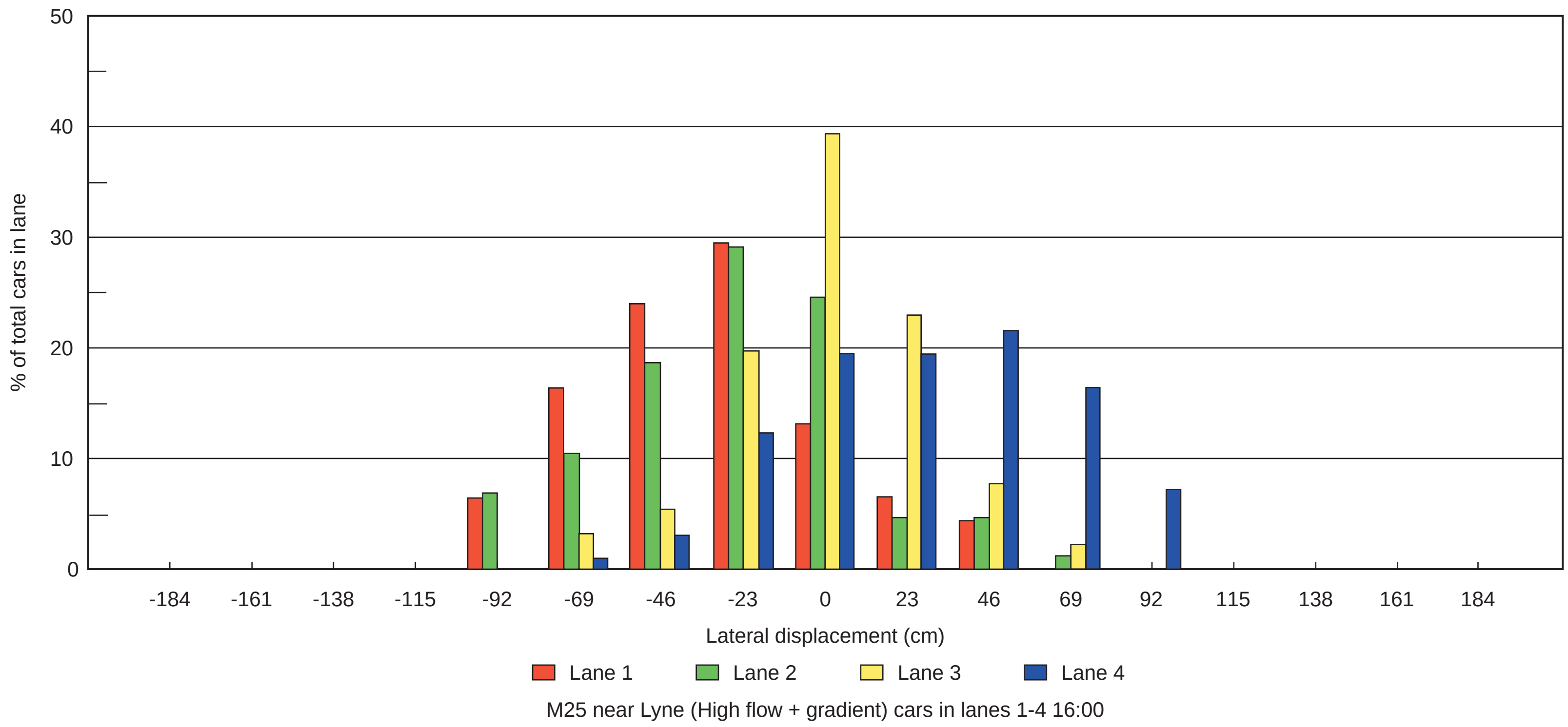


Figure 6 Bar chart showing lateral displacement distributions of cars in all lanes (High flow + gradient and slip road)

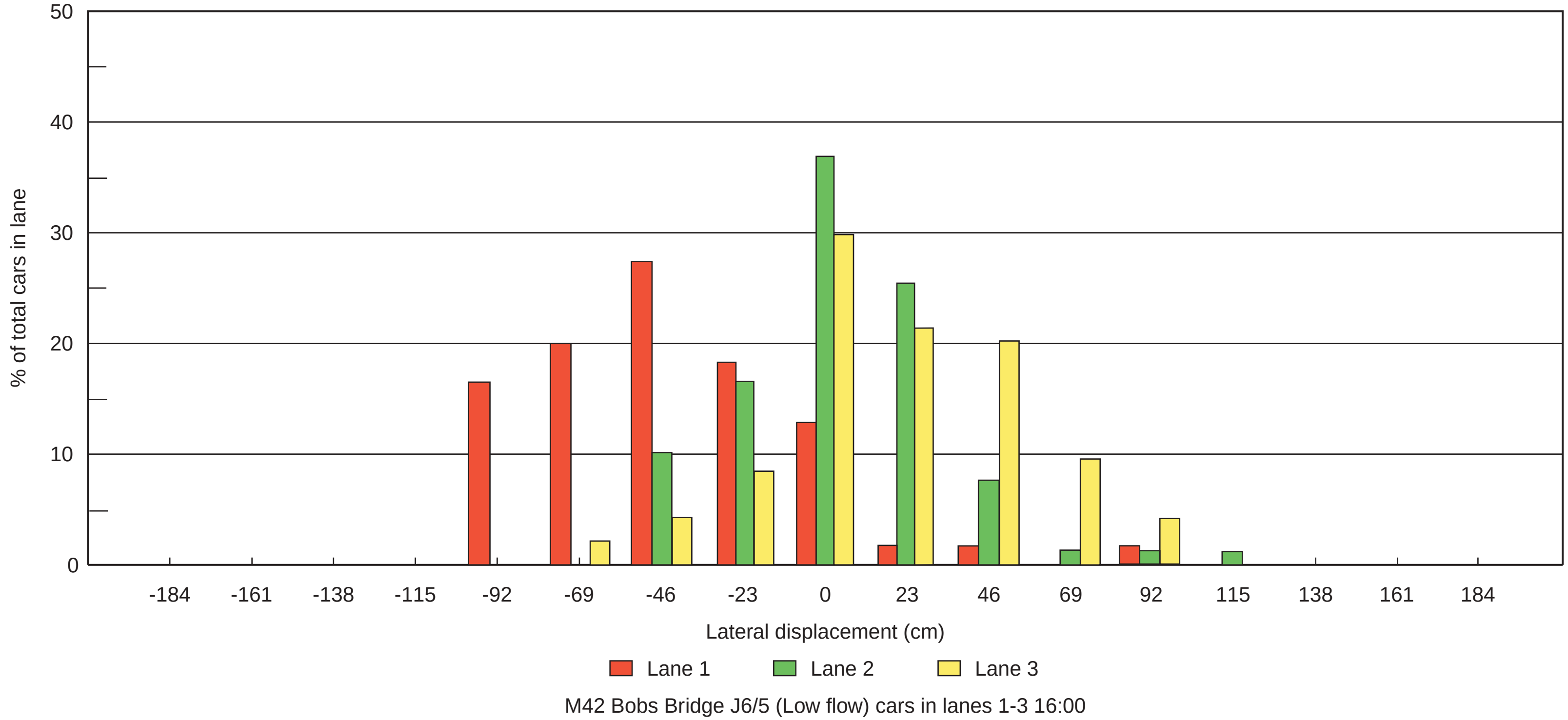


Figure 7 Bar chart showing lateral displacement distributions of cars in all lanes (Low flow)

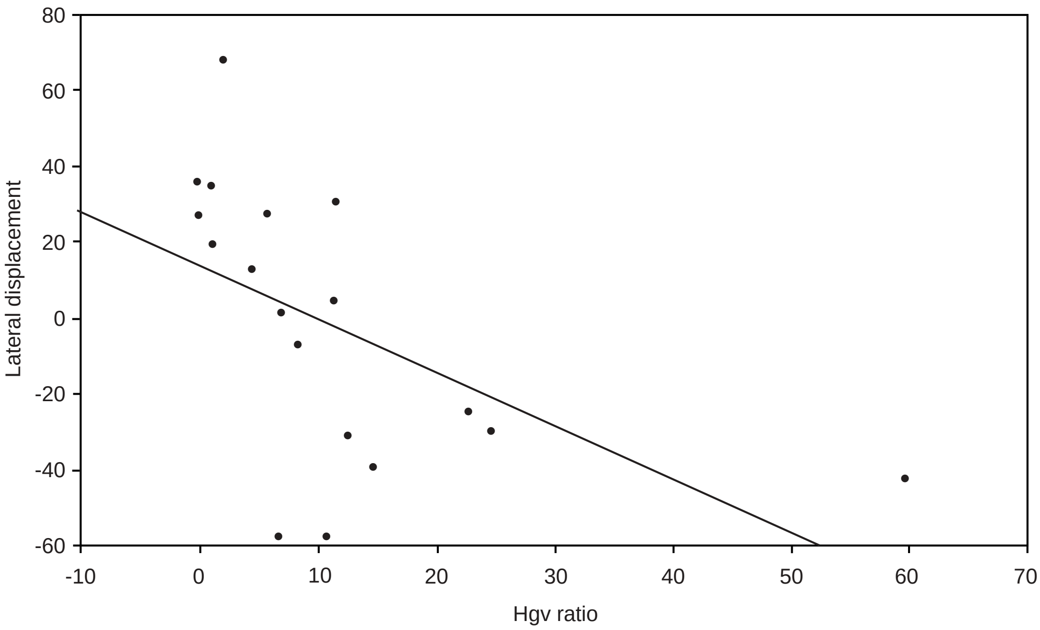


Figure 8 Lateral displacement of cars by ratio of HGVs to cars

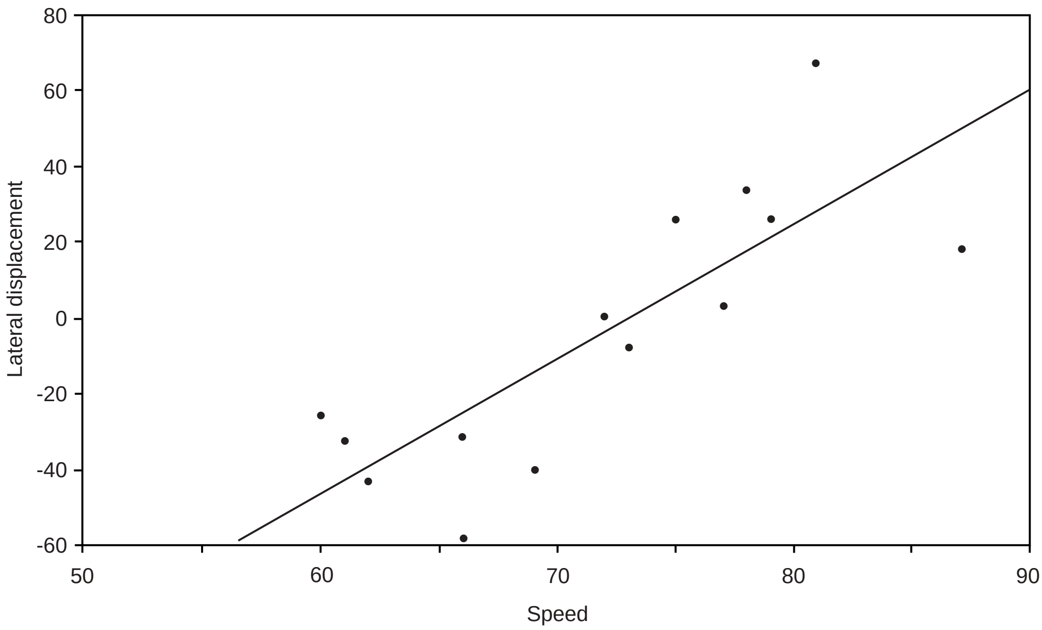


Figure 9 Lateral displacement of cars by speed (over 50mph)

Abstract

Providers of tolling enforcement systems frequently use equipment which is operational over a width less than a full carriageway and use multiple beams to cover the width required. This inevitably results in a non-uniform lateral profile. As a result, equipment aligned to cover the centre of motorway lanes may be less efficient at lane edges.

TRL was commissioned to investigate and report on the lateral distribution of vehicles across motorway carriageways under a range of typical conditions. The preferred option of analysis was that of video tapes from existing archive material of motorway scenes.

The results obtained suggested that different patterns of lateral displacement distribution exist for different scenarios. The main differences occurred at sites where there is a gradient, a lay-by, significantly more lane-changing, different flow and speed conditions, and where there is a mix of traffic. The lateral displacement of vehicles appears to be most affected by the proportion of HGVs and the speed of traffic.