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Lateral position of traffic negotiating horizontal bends

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The lateral position of vehicles at horizontal curves and roundabout circles has been studied, and it has been observed that drivers tend to straighten their travel path as much as possible when negotiating these bends in a corner-cutting fashion. In addition to skid resistance loss, this behaviour results in the early scuffing and removal of road markings. Preliminary data were collected in Northern Ireland at eight different sites over 15 lanes in total. It was found that the expected geometrical location of the wheel path is not the same as the actual observed location at certain sections of highways. On horizontal curves, the most travelled wheel path is shifted towards the convex side of the curve, and this shift increases with decreasing radius, such as at roundabouts, where it reaches a maximum displacement. This shift was about 140 cm in the outer circles of roundabouts and about 60 cm in the inner circles. For horizontal curves the figure was in the region of 30–40 cm.

1. INTRODUCTION

When roads are constructed, the surface characteristics are uniform laterally across the lane. However, some time after the road is opened to traffic, these characteristics start to change, especially within the wheel paths, owing to the higher concentration of trafficking. Depending on the type of bituminous material, trafficking and environmental conditions, properties such as skid resistance, texture depth and noise will change, eventually reaching a stage where further action is required. Variation in skid resistance is an important issue in terms of safety to the road user. It affects the planning of highway maintenance and makes it difficult to predict the life of the highway structure surface layer.[1] The importance of planned highway maintenance has been highlighted from the viewpoint of minimising expenditure.[2]

Queensland Main Roads Authority[3] developed investigatory criteria for the interpretation of skid resistance levels, and they identified roundabout approaches and roads with small-radius curves as their priority. Another important document, by the Transport Research Laboratory,[4] reported that for roundabout approaches the mean accident risk was higher than for minor junctions, but also stated that various sites exhibit significant differences in accident rates.

Ideally, the effect of lateral distribution of vehicles within a lane should be uniform along the road so that every part of the pavement wears at the same time. However, in the real world, a non-uniform lateral distribution of properties develops. Earlier researchers[5,6] studied axle loading of the pavement for heavy goods vehicles, and identified lane width, vehicle speed, existing cross-sectional rut depth and vehicle width as critical factors in the amount of 'wander'. It was found[7] that, in England, Germany and Belgium, vehicles in a lane are laterally positioned similar to a normal distribution in straight sections of roads. In a similar study[8] it was reported that wheel wander tends to be normally distributed, with a standard deviation ranging from 200 to 600 mm. However, this distribution, and the consequent load concentration pattern, does not always take the form of a bell-shaped normal curve, and the standards do not address these situations. An ongoing study by the authors revealed that the skid resistance characteristics of the road surface change longitudinally as well as laterally. Fig. 1 shows the relationship between the grip number and the longitudinal location of the test

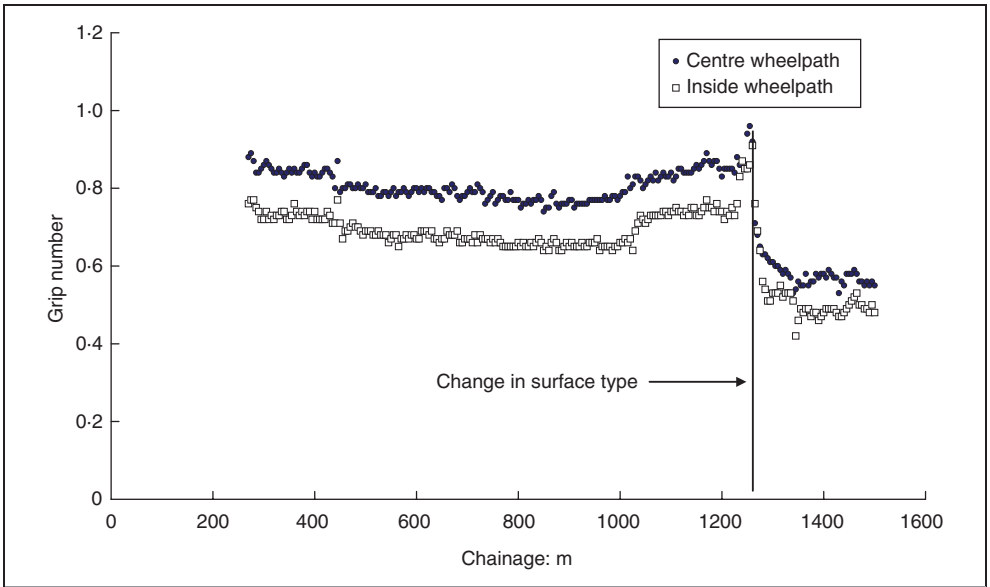


Fig. 1. Difference in grip between centre of inside wheel path and mid-point between wheel paths



Fig. 2. Examples of narrow lanes

device. The lower curve data are obtained from the centre of the inside wheel path. The upper curve readings are obtained on the mid-point between the two wheel paths. The figure also shows the abrupt change of this relationship with change in surface type. This paper addresses the magnitude of the gap between the upper and lower curves, underlining the importance of positioning the test device laterally across the road.

Standards state that the test devices used to measure skid resistance must be positioned on the wheel path,[9] which suggests that the most polished path should be surveyed, but the assessment of this is subjective. In the authors' experience, users of the test device had different understanding of this, even for straight sections of roads. At curves and roundabouts the assessment is likely to be even more variable. Also, it is impracticable to carry out additional preliminary tests at each site to determine exactly the most polished strips of roads, especially when it is difficult to do so by the naked eye. This also requires the closure of the road to traffic. But if relationships can be established between the amount of curvature and the location of the test device, the result will be a very useful saving in time. Although such relationships are not yet established, because of limited data, the scene is set, and the research direction is shown.

Traffic lanes are designed according to set standards, and their widths vary depending on specific requirements such as design speed, wind effects and level of service. For example, the US *Highway Capacity Manual*[10] specifies a range of lane widths from 3 m to 3·6 m, although it is possible to find lanes both narrower than 3 m and wider than 3·6 m. Vehicle widths are much less than these values. This shows that vehicles have a certain lateral freedom within a lane. This allowance increases with increasing design speed. For example, a 3·6 m lane width is recommended for motorways because of the higher speeds. In places where the lane is narrowed intentionally and then subjected to high HGV trafficking, for example in roadwork zones, extra care must be taken. In short, the narrower the lane, the smaller the lateral freedom and the greater the concentration of traffic load on the pavement across the width (Fig. 2). The lowest values of skid resistance have been obtained in narrower wheel tracks compared with wider wheel tracks.[11]

Based on initial visual observations, it was not difficult to notice that corner-cutting on bends, as shown in Fig. 3(a), happens more often than one might think, and may cause a change in concentration of wheel load. The preliminary findings of the present research have confirmed this. A similar situation occurs at roundabouts (Fig. 3(b)), where drivers may not follow the circulatory path and concentrate trafficking on a short cut across the designated lanes. This behaviour may even result in the early scuffing and removal of road markings.

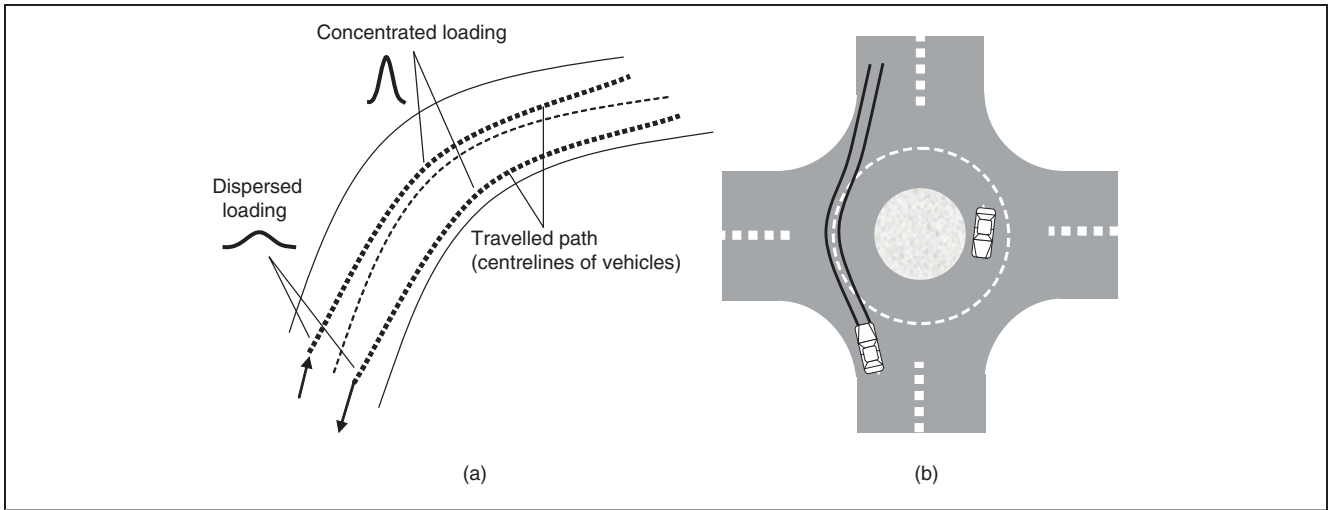


Fig. 3. Corner-cutting at (a) bends and (b) roundabout turning circles

2. DATA COLLECTION AND SITES

Data were collected at various sites in Northern Ireland during spring 2005. These sites were roundabouts and horizontal curves. Traffic flow at these sites was filmed by means of a digital camcorder. After the recording, the DV tapes were transferred to a PC in digital format for further analysis. The collection of data was considered to be within the low-risk category, for the following reasons.

(*a*) Lane widths were measured by using a trumeter as well as a measuring tape very early in the morning, when there was very little traffic.
(*b*) During filming, the observer was a considerable distance away from the traffic, at least 6–7 m. There were safe locations for each site.
(*c*) In order not to influence the drivers, the tripod of the camcorder was hidden away from their sight as much as possible, by positioning it next to a wall, a guard rail or a post. During filming, the observer sat down on the ground or behind a fixed object so that the drivers could not see him, and their driving pattern was not affected by his presence. Most importantly, because all the sites were bends, even if the drivers did become aware of the presence of the observer or a tripod, by the time they saw these, their vehicle's positions had already been recorded.

Eight sites were found to be suitable for the study, referred to as sites A to H. They are shown in the appendix. The size of those photographs has been reduced for concise presentation, but all the data analyses were carried out on larger images (640 × 480 pixels) for better accuracy. The screen scaling technique was used to measure the vehicle positions. (See reference 12 for other methods, and their advantages and disadvantages.) Screen ruler software, called MB-Ruler, was used to measure the distances on the screen in terms of the number of pixels. These distances were converted to real-world dimensions with the help of Excel spreadsheets' formula feature. Consider the photograph shown in Fig. 4. The horizontal line is the screen ruler. When the mouse is pointed at the apex of this right angle, 0·0 is displayed on a small window of the MB-Ruler software. As the mouse is moved away from this point the display shows the distance between the new position of the mouse and the original point in number of pixels. In this particular picture, the mid-point of the left-hand-side wheel of the vehicle (i.e. the passenger side) is 125 pixels away from the lane line, which is also the apex—that is, 0·00. Similarly, the edge of the lane is 230 pixels away from the apex, referring to the lane width on the screen. The real-world measurement of the lane width is 330 cm. Thus the real location of the left wheel of the vehicle is calculated as $125 \times 330/230 = 179$ cm from the lane line.



Fig. 4. Scale superimposition technique used in the data analysis

The characteristics of the data collection sites are given in Table 1. Previous research[12] used footbridges or overpasses to position the camcorder for best viewing. These studies were interested in straight sections of roads, whereas the present paper deals with bends. Thus it was not necessary to find elevated points such as bridges to mount the equipment. The camera was positioned on a carefully selected roadside point, where the traffic stream being

Site	Bend type	Bend direction	Bend curvature	Lane width: cm	Ave axle width: cm	V_v/V_t
A	Roundabout exit	–	–	Inside lane: 330	159	142/245 (60%)
				Outside lane: 350	149	76/205 (37%)
B	Circulating flow	Clockwise	$R = 11$ m	Inner circle: 450	146	185/215 (86%)
				Outer circle: 440	149	88/96 (92%)
C	Circulating flow	Clockwise	$R = 20$ m	Inner circle: 410	149	250/320 (78%)
				Middle area: 110	–	–
				Outer circle: 430	165	276/295 (94%)
D	Circulating flow	Clockwise	$R = 20$ m	Inner circle: 420	158	260/336 (77%)
				Outer circle: 420	158	291/334 (87%)
E	Horizontal curve	Clockwise	$\Delta = 6^\circ$	Northbound inside lane: 290	150	252/376 (67%)
F	Horizontal curve	Clockwise	$\Delta = 15^\circ$	Northbound lane: 330	162	164/262 (63%)
				Southbound lane: 320	161	171/282 (61%)
G	Circulating flow	Clockwise	$R = 20$ m	Inner circle: 480	135	104/135 (77%)
				Outer circle: 470	155	124/129 (96%)
H	Horizontal curve	Clockwise	$\Delta = 7^\circ$	Inside lane: 390	139	134/282 (48%)
				Outside lane: 370	148	100/210 (48%)

V_v/V_t, ratio of number of viewable vehicles to total number of vehicles passed.
R, radius of central island of roundabout.
Δ, deflection angle of curve (the higher the angle, the sharper the curve).

Table 1. Characteristics of the data collection sites

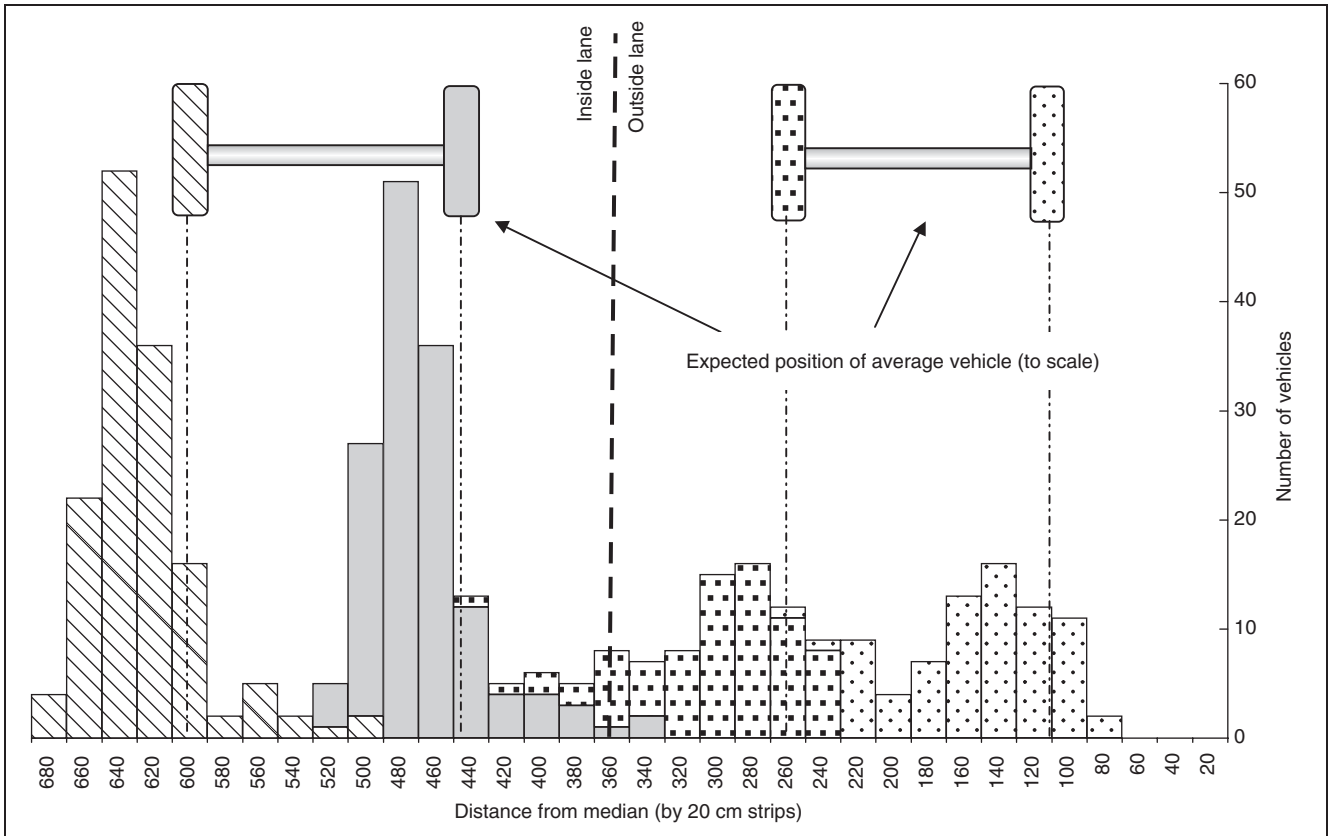


Fig. 5. Frequency distribution of vehicles, site A: traffic viewed from rear

considered could be viewed almost exactly from the front or the rear. The last column of Table 1 is provided to prevent any misinterpretation of the unequal amounts of vehicle numbers in each lane of certain sites. For example, by looking at Fig. 5, one might think that the number of vehicles using the inside lane during the data collection period was higher than the number of vehicles using the outside lane, and hence conclude that the lifespan of the surface of the inside lane would be shorter than that of the outside lane. However, the graph shows only the lateral distribution of those vehicles that were comfortably visible by the camera, without being blocked by other vehicles. The last column of Table 1 indicates that for site A, for instance, 245 and 205 vehicles passed but only 142 and 76 vehicle positions were recorded in the inside and outside lanes respectively.

3. THE FINDINGS

The lateral positions of vehicles for each site were entered into spreadsheets, and frequency graphs were produced. The bar chart in Fig. 5 is the distribution of wheel positions, whereas the axle pictures at the top show the expected position of vehicles. The widths of these axles are the average values obtained from the data. The positions of these axles are exactly in the centre of the lane. The diagram corresponds to the photograph shown in the appendix. For instance, the data for site A were collected by filming the traffic from behind. Therefore the diagonally hashed and solid grey bars in Fig. 5 refer to the left and right wheels of the inside lane vehicles (kerbside) respectively. Similarly, the chequered and dotted patterns denote the left and right wheels of the outside lane vehicles respectively.

The remaining sites are grouped into roundabout circulating flows and horizontal curves (Figs 6 and 7). The same shading scheme is used to distinguish the wheels. The corresponding photographs, given in the appendix, show whether the traffic was viewed from the front or the rear. At all the sites given in Fig. 6 the turning direction was clockwise. It can be seen from the diagrams that the actual vehicle position shifted towards the centre of the roundabout circle.

Figure 7 shows the frequency distribution of vehicles negotiating horizontal curves. At site E, only the inside lane was analysed, because the outside lane of the same direction was not viewable at a proper angle. Similar to the sites shown in Fig. 6, all the horizontal curve sites in Fig. 7 are clockwise and exhibit a shift of vehicles to the centre of the circular curve. In addition to these visual displays of shift, Table 2 provides their numerical values under two groups: roundabouts and horizontal curves.

Further analyses were carried out to see whether the lateral distribution of traffic at these locations is disturbed by the curvature effect. χ^2 tests were employed for this purpose, as shown in Table 3. The tests were repeated twice: one using the highest peak (actual) as the mid-point of the bell-shaped distribution, and one using the expected position of an average vehicle as the mid-point of the distribution. For example, consider the left wheel of the vehicles on the outer turning circle of site D, shown in Fig. 8, where the expected wheel position of an average vehicle is taken into account, whereas a good fit can be obtained on its own, as the dotted line curve shows. Independent of the expected position of the wheel, the distribution fits to a normal distribution on its own as 8·48 < 14·07, assuming that the mid-point is the 600–620 interval. However, the expected position of the mid-point should be the 660–680 interval. As the last four

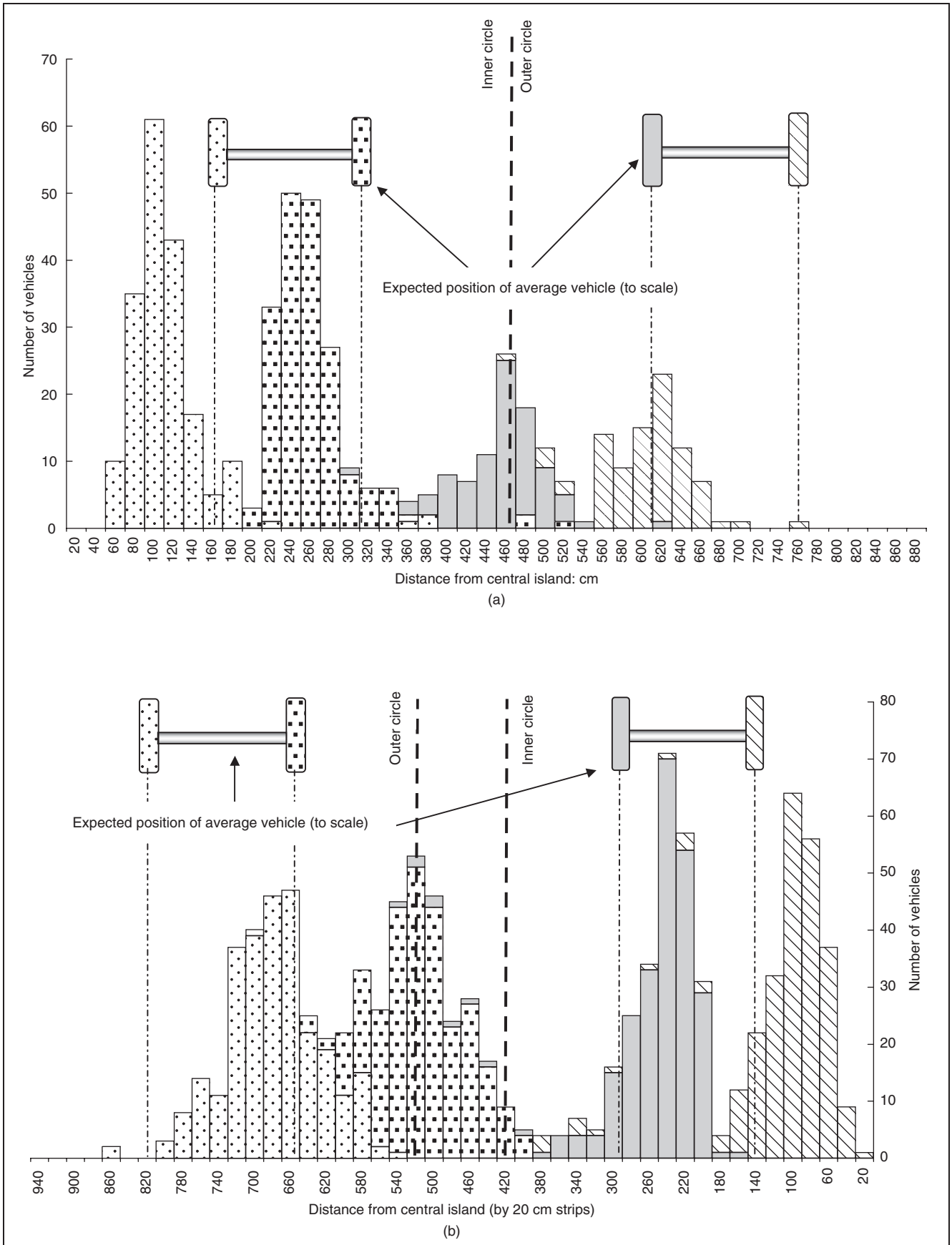
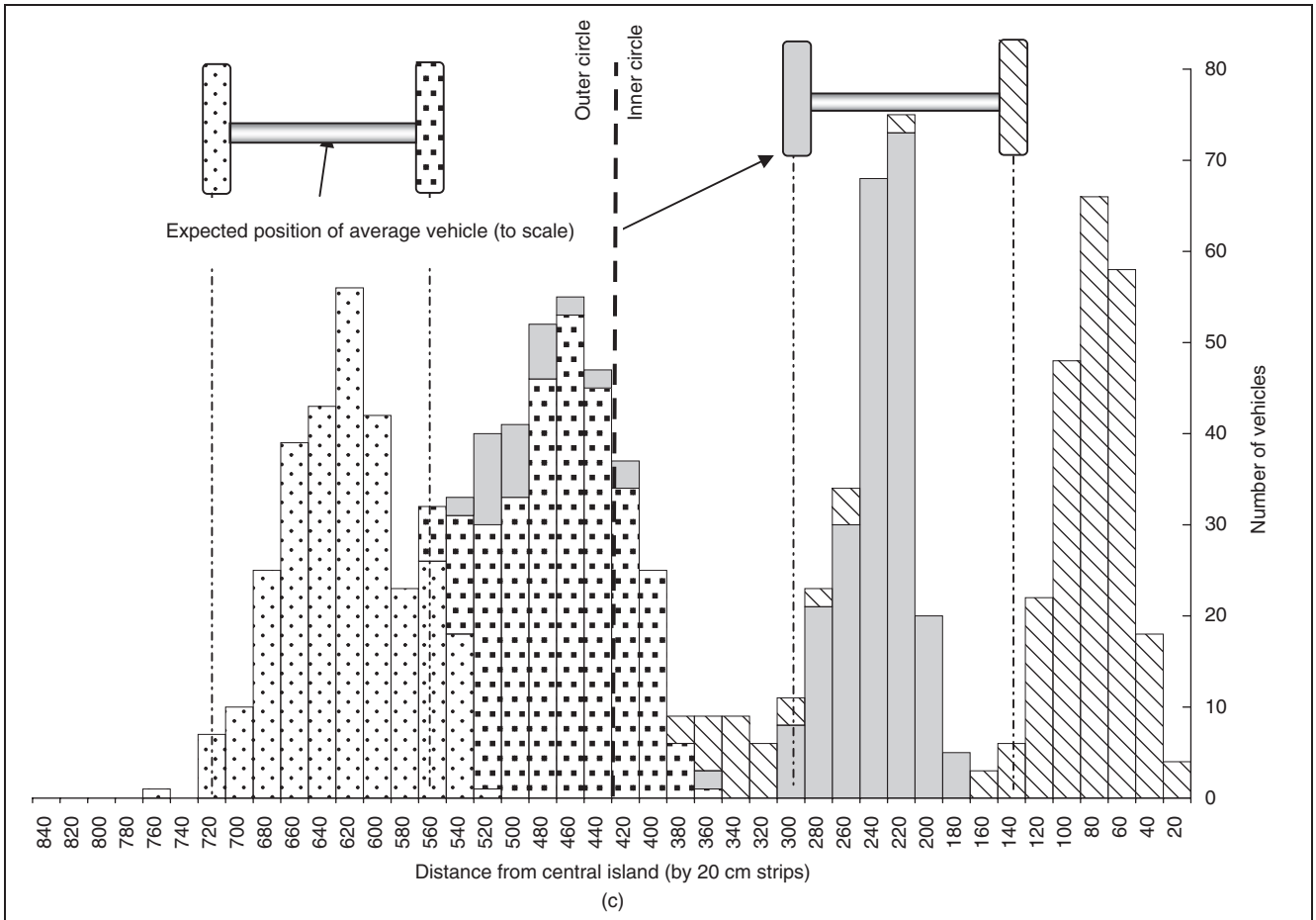


Fig. 6. Frequency distribution of vehicles: (a) site B, traffic viewed from front; (b) site C, traffic viewed from rear; (c) site D, traffic viewed from rear; (d) site G, traffic viewed from front



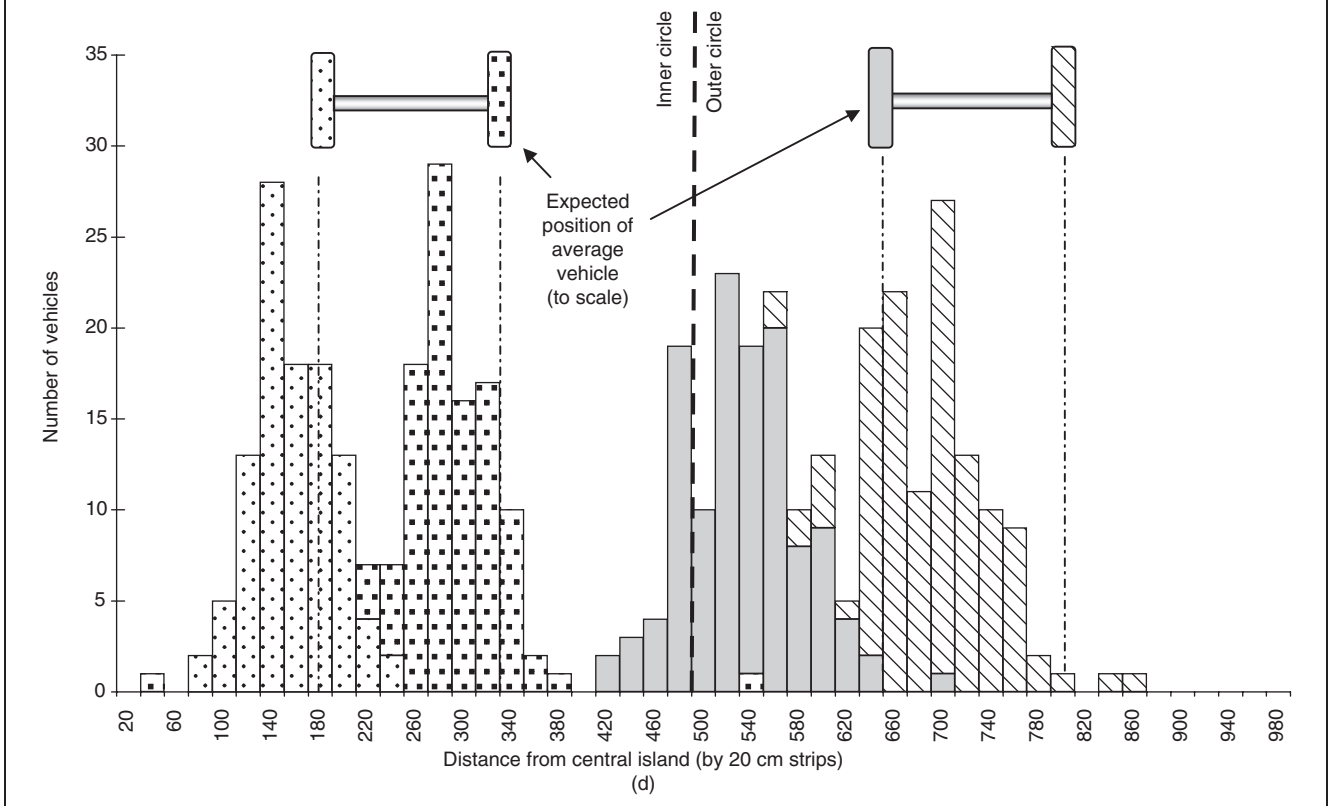
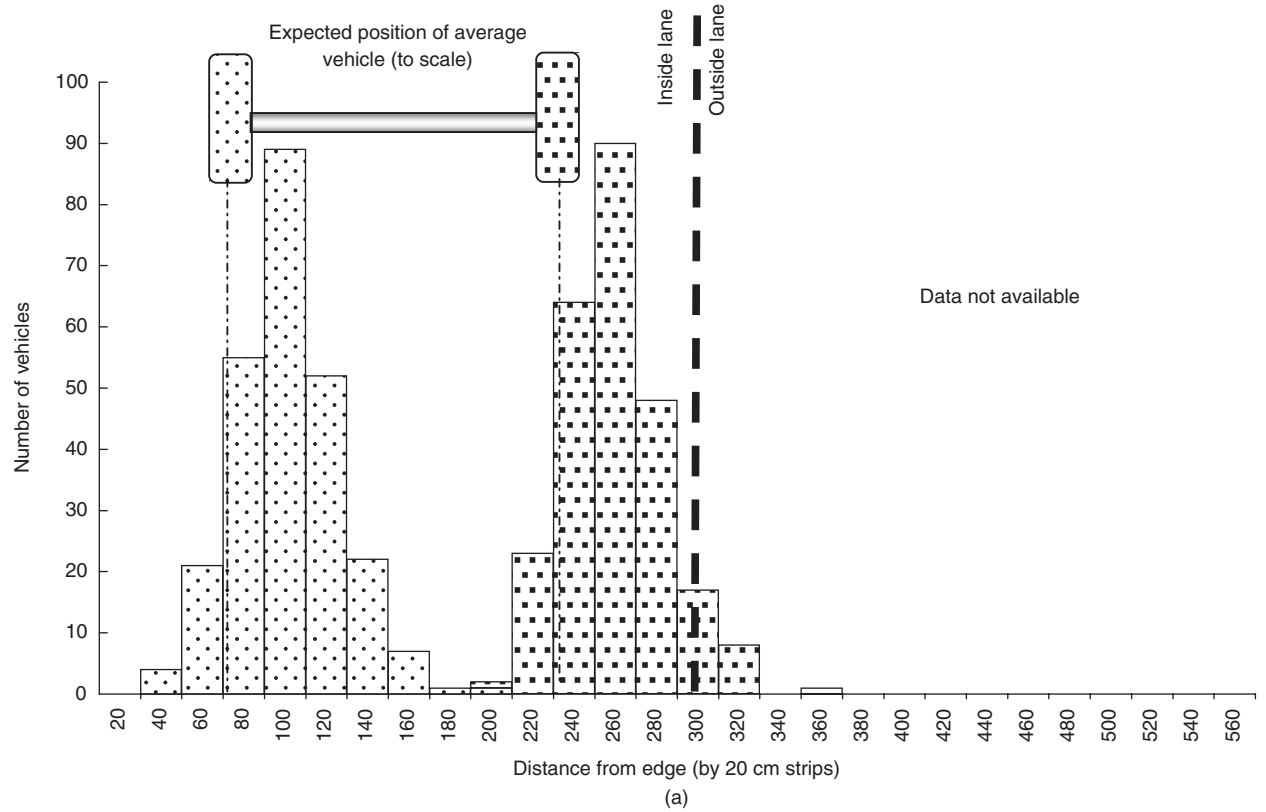


Fig. 6. Continued



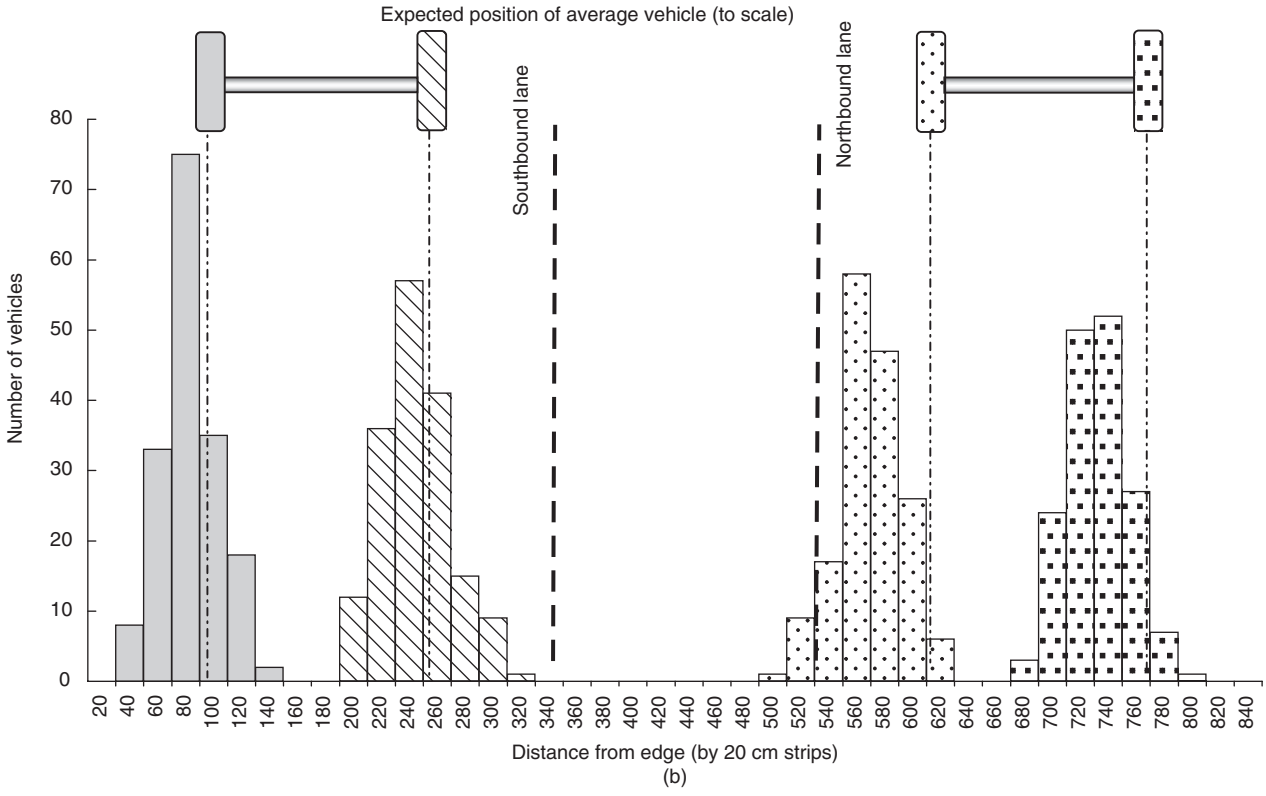


Fig. 7. Frequency distribution of vehicles: (a) site E, traffic viewed from rear; (b) site F, traffic viewed from front; (c) site H, traffic viewed from front

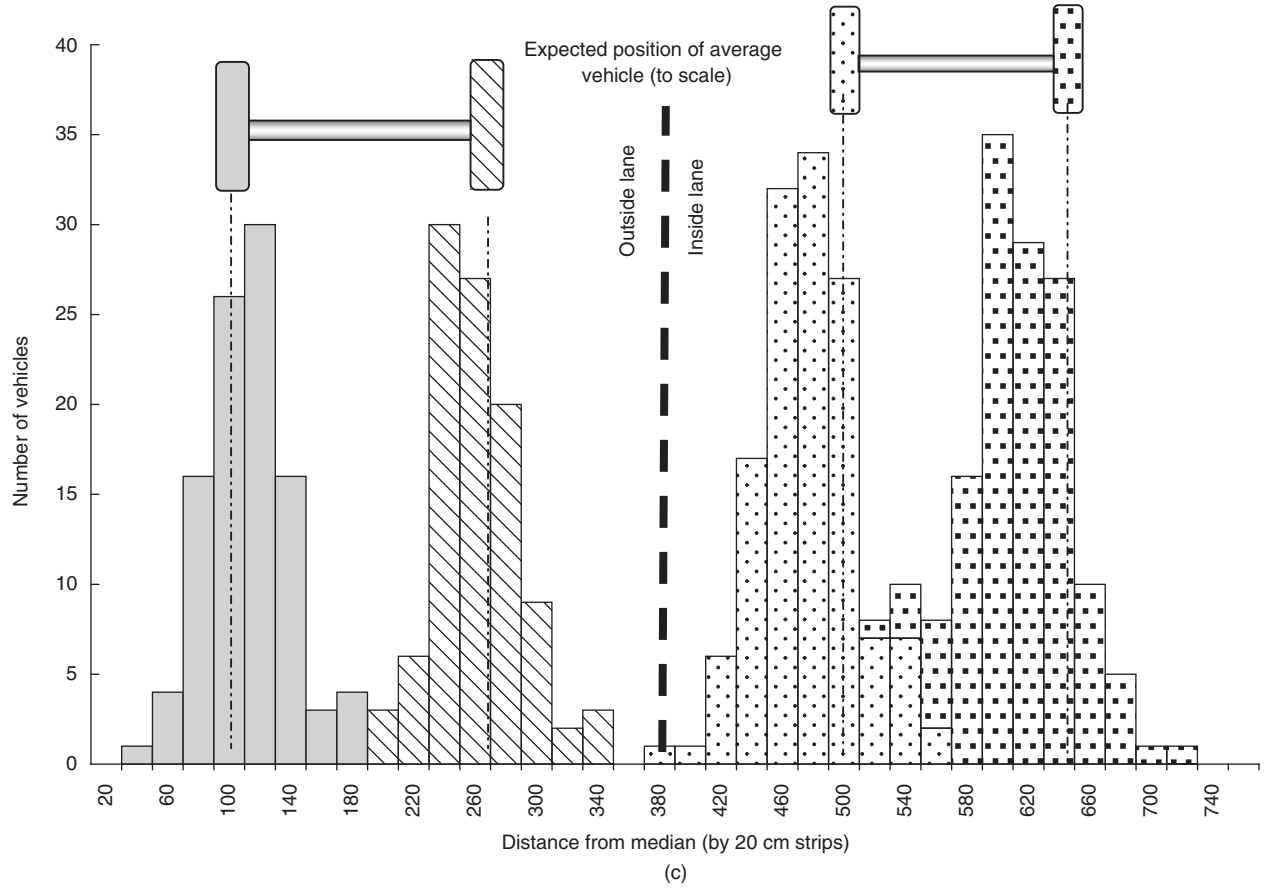


Fig. 7. Continued

columns of the table indicate, for the same wheel, the distribution cannot be represented by a normal curve (292 > 5·99).

Table 3 shows that, for nearly all the sites, the lateral distribution of vehicles lost its normality (bell-shape) feature when the expected position of the peak was taken into account. However, it is too early to suggest an empirical model to formulate the amount of lateral shift as a function of the magnitude of curvature. No relationships were sought between vehicle speed and lateral shift. This was mainly because there

	Site		Actual vehicle position: cm				Expected vehicle position: cm		d_{offset}: cm	
			Mean (s.d.)		Peak point					
			Left wheel	Right wheel	Left wheel	Right wheel	Left wheel	Right wheel	Left wheel	Right wheel
Roundabouts	B	Inner circle	250 (43)	104 (44)	240	90	300	150	60	60
		Outer circle	594 (46)	445 (44)	610	450	750	600	140	150
	C	Inner circle	246 (57)	97 (57)	230	90	280	130	50	40
		Outer circle	670 (52)	504 (49)	660	510	810	645	150	135
	D	Inner circle	261 (90)	103 (87)	210	70	290	130	80	60
		Outer circle	612 (45)	454 (42)	640	450	710	550	70	100
	G	Inner circle	281 (47)	146 (32)	270	130	320	170	50	40
		Outer circle	678 (51)	523 (49)	690	510	790	640	100	130
Horizontal curves	E	Inside lane	91 (25)	249 (24)	90	250	65	225	25	25
	F	Northbound lane	722 (22)	560 (23)	720	550	760	600	40	50
		Southbound lane	74 (20)	235 (24)	70	230	85	245	15	15
	H	Inside lane	606 (33)	466 (32)	590	470	630	490	40	20
		Outside lane	251 (27)	102 (27)	230	110	260	95	30	15

d_{offset}, distance between peak point of actual wheel position and expected position of the same wheel.
The right wheel is always the driver-side wheel, and the left wheel is always the passenger-side wheel, throughout the paper.

Table 2. Actual and geometrically expected vehicle positions

Site	Lane	Wheel	Bell-shape on its own				Centred at expected peak point			
			Degree of freedom	Calculated $\sum \chi^2$	χ^2 from table	Normal distribution fit?	Degree of freedom	Calculated $\sum \chi^2$	χ^2 from table	Normal distribution fit?
A	Inside	Left	4	31·20	9·49	No	3	17·60	7·81	No
		Right	4	31·30	9·49	No	3	20·80	7·81	No
	Outside	Left	5	7·64	11·07	Yes	3	18·00	7·81	No
		Right	4	8·76	9·49	Yes	2	17·20	5·99	No
B	Inner	Left	6	44·70	12·59	No	2	80·50	5·99	No
		Right	6	57·50	12·59	No	3	41·10	7·81	No
	Outer	Left	5	11·30	11·07	No	1	39·20	3·84	No
		Right	5	10·60	11·07	Yes	1	48·00	3·84	No
C	Inner	Left	9	111·00	16·92	No	4	128·00	9·49	No
		Right	8	91·90	15·51	No	4	39·60	9·49	No
	Outer	Left	8	15·80	15·51	No	1	298·00	3·84	No
		Right	8	7·94	15·51	Yes	1	98·40	3·84	No
D	Inner	Left	11	417·00	19·68	No	5	312·00	11·07	No
		Right	11	359·00	19·68	No	5	237·00	11·07	No
	Outer	Left	7	8·48	14·07	Yes	2	292·00	5·99	No
		Right	6	7·72	12·59	Yes	2	268·00	5·99	No
E	Inside	Left	4	4·46	9·49	Yes	1	96·10	3·84	No
		Right	3	8·19	7·81	No	1	148·00	3·84	No
F	Northbound	Left	2	0·10	5·99	Yes	2	2·13	5·99	Yes
		Right	3	5·20	7·81	Yes	2	2·90	5·99	Yes
	Southbound	Left	2	6·50	5·99	No	2	6·30	5·99	No
		Right	3	5·30	7·81	Yes	3	5·30	7·81	Yes
G	Inner	Left	5	11·40	11·07	No	5	33·50	11·07	No
		Right	4	4·25	9·49	Yes	6	5·40	12·59	Yes
	Outer	Left	7	18·70	14·07	No	5	683·00	11·07	No
		Right	6	11·40	12·59	Yes	5	83·30	11·07	No
H	Inside	Left	4	3·32	9·49	Yes	4	5·65	9·49	Yes
		Right	4	5·26	9·49	Yes	4	13·30	9·49	No
	Outside	Left	2	5·50	5·99	Yes	2	5·50	5·99	Yes
		Right	3	1·04	7·81	Yes	3	1·02	7·81	Yes

Table 3. Goodness-of-fit tests for 5% level of probability with a minimum class size of 5

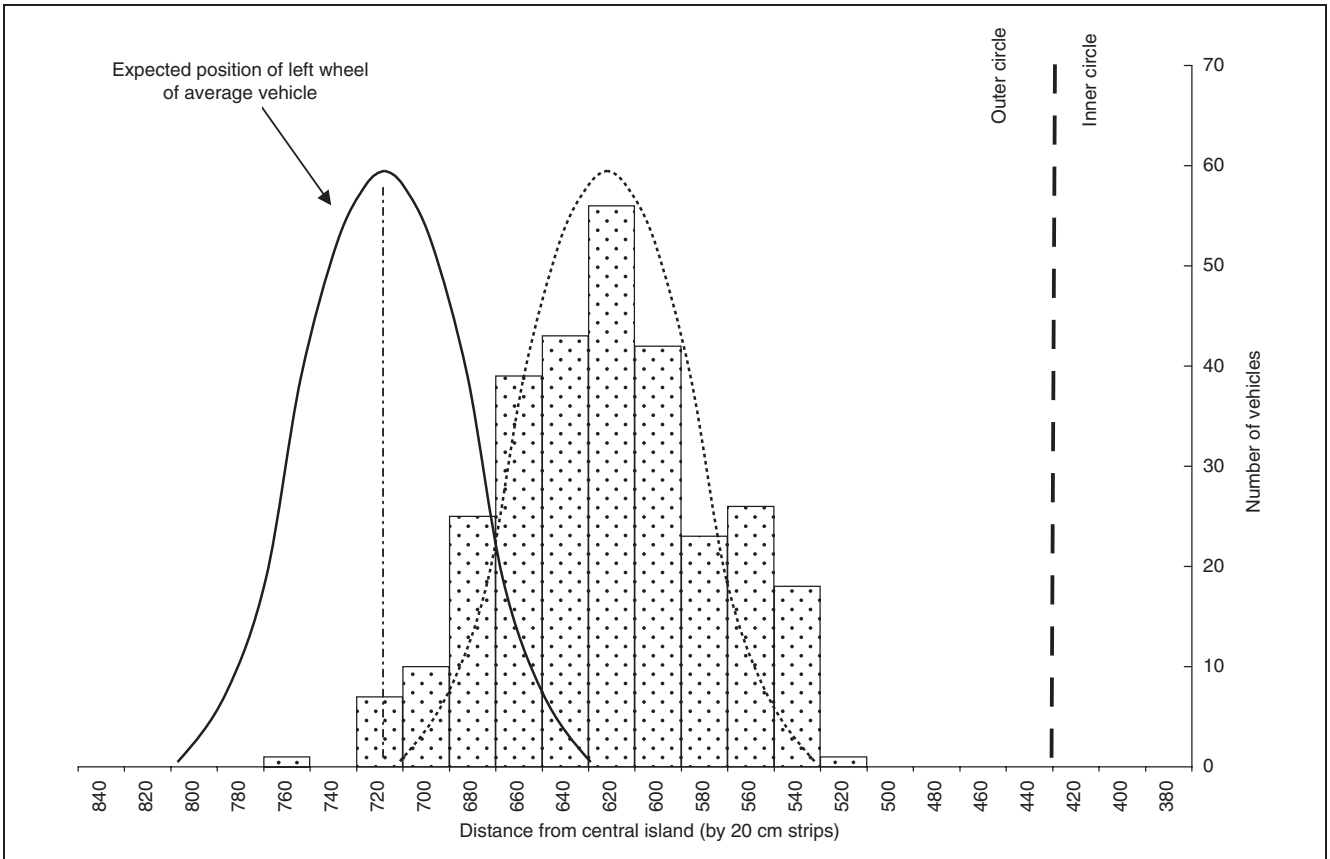


Fig. 8. Illustration of a poor fit to a normal curve

was little speed variation among the vehicles, especially at roundabouts, and also because it was not easy to measure the speed and the lateral position simultaneously.

4. CONCLUSIONS

The preliminary findings of the study have shown that the expected geometrical location of the wheel path is not the same as the actual observed location at certain sections of roads. The main reason for these shifts is the bend effect of the road. Cross-fall, curve type, kerb height and vehicle speeds have an effect on the vehicles' lateral position. Skid resistance testing must be carried out carefully by taking into account the findings of the present paper. For example, at site F, if the test device is located on the 90th centimetre from the lane line (as the geometrically expected position of the wheel track) instead of the 40th centimetre, the peak point that is subject to the highest loading will be missed by about 50 cm. Note that this is a moderate figure to represent an average situation. The figure would be greater at other sites, such as the outer circle of roundabout C, particularly the left-hand-side wheel, where the miss is about 1·5 m. This will lead to misleading readings and hence result in a misleading measurement of safety for the road user. It should be remembered that these are among the highest-risk locations for a skidding-related accident to occur. It was found that, even at the same site, the skewness of the distribution may vary between lanes. For example, it is clear from sites C and D that traffic loading is more concentrated in the inner circles than in the outer circles of the roundabouts. This reflects the possibility of uneven skid resistance loss across the lanes in the same location. But current standards and guidelines lack detail in these respects, and there is potential for further research.

It was not the objective of this paper to associate the findings with accident rates. The purpose was to identify the need for more accuracy in data collection at certain sites, and to demonstrate a video-imaging technique that can easily be used for this purpose by highway engineers. It is recommended that if the test vehicles are fitted with additional sensors to record the lateral position of the device, the readings will be more representative.



Fig. 10. Site B: Carrickfergus, Castle roundabout



Fig. 11. Site C: Hazelbank roundabout, near Esso petrol station

Appendix. DATA COLLECTION SITES



Fig. 9. Site A: Carrickfergus, Castle roundabout, Larne exit



Fig. 12. Site D: Hazelbank roundabout, near Esso petrol station, western side of central island



Fig. 13. Side E: A2, Carrickfergus, near Model Primary School, northbound



Fig. 15. Site G: Whitehouse roundabout, end of M5, eastern side of central island



Fig. 14. Site F: A2, Greenisland, near Belfast High School, northbound



Fig. 16. Site H: A2, near East Antrim Institute, northbound

REFERENCES

1. Jellie J. H., Woodward W. D. H. and Woodside A. R. The early life safety of high stone content surfacings. *Proceedings of the European Eurobitume Conference*, Vienna, 2004 (CD-ROM).
2. Kennedy C. K. Introduction to pavement evaluation techniques and cost-effective management of highway networks. *Assessment of Flexible Pavements Lecture*. QPA Short Course, University of Newcastle , Newcastle upon Tyne, September 2004.
3. Austroads. *Guidelines for the Management of Road Surface Skid Resistance*. Austroads, Sydney, Australia, 2005, Report No. AP-G83/05.
4. Viner H. E., Sinhal R. and Parry A. R. *Linking Road Traffic Accidents with Skid Resistance: Recent UK Developments*. Transport Research Laboratory, Crowthorne, 2005.
5. Blab R. and Litzka J. Measurements of the lateral distribution of heavy vehicles and its effects on the design of road pavements. *Proceedings of the 4th International Symposium on Heavy Vehicle Weights and Dimensions*, Michigan, USA, 2005, pp. 389–395.
6. Blab R., Molzer C. and Litzka J. Modification of the Austrian guideline for standardized asphalt pavements. *Proceedings of the 8th ISAP Conference, Seattle*, 1997, Paper No. 8015.
7. Gunay B. An overview of the lateral properties of road traffic flow. *Traffic Engineering and Control*, 2001, **42**, No. 11, 401–405.
8. Timm D. H. and Priest A. L. *Wheel Wander at the NCAT Test Track*. Auburn University, Auburn, AL, 2005.
9. Highways Agency. Methods for measuring the skid resistance of pavement surfaces. *Design Manual for Roads and Bridges*. Highways Agency, London, 2004, HD28/04.
10. Transportation Research Board. *Highway Capacity Manual*. National Research Council, Washington, DC, 2000.
11. Hosking R. *Road Aggregates and Skidding*. HMSO, London, 1992.
12. Gunay B. Methods to quantify the discipline of lane-based-driving. *Traffic Engineering and Control*, 2003, **44**, No. 1, 22–27.

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