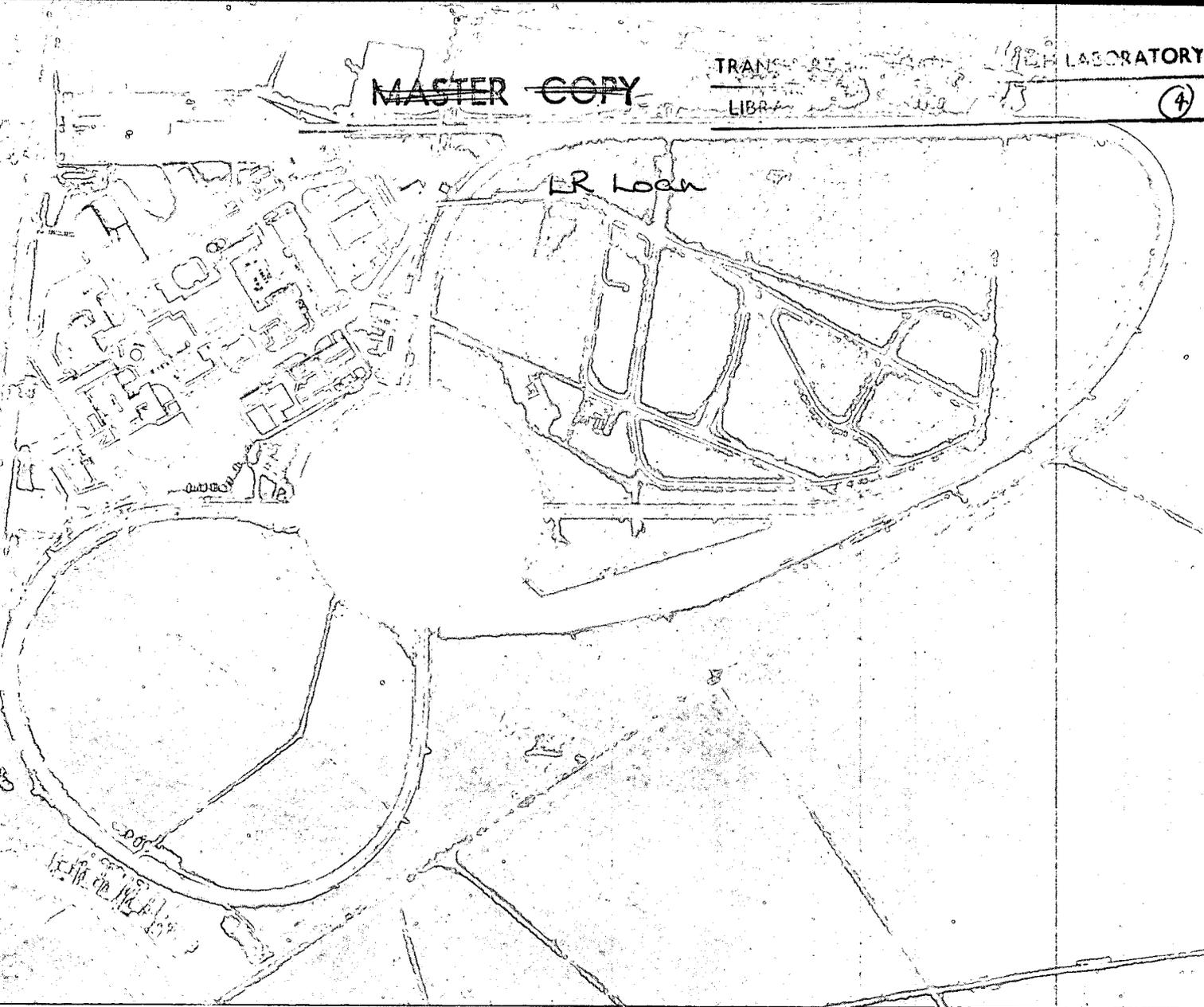


TRANSPORT and ROAD RESEARCH LABORATORY

DEPARTMENT of the ENVIRONMENT DEPARTMENT of TRANSPORT



Some aspects of motorway traffic behaviour in fog

by

M. E. White and D. J. Jeffery

**TRANSPORT and ROAD
RESEARCH LABORATORY**

**Department of the Environment
Department of Transport**

TRRL LABORATORY REPORT 958

SOME ASPECTS OF MOTORWAY TRAFFIC BEHAVIOUR IN FOG

by

M E White and D J Jeffery

**Any views expressed in this Report are not necessarily those of the
Department of the Environment or of the Department of Transport**

**Highway Traffic Division
Traffic Engineering Department
Transport and Road Research Laboratory
Crowthorne, Berkshire
1980
ISSN 0305-1293**

CONTENTS

	Page
Abstract	1
1. Introduction	1
2. Experimental site	2
3. The visibility of vehicles in fog	2
4. Results of the experiment	4
4.1 Traffic speeds in fog	5
4.2 Vehicle following times in fog	7
5. A discussion of the results	8
5.1 Traffic speeds	8
5.1.1 Day-light fog conditions	8
5.1.2 Night-time fog conditions	8
5.1.3 Anomalous behaviour	9
5.2 Inter-vehicle time gaps	9
6. Conclusions	10
7. Acknowledgements	11
8. References	11

© CROWN COPYRIGHT 1980

Extracts from the text may be reproduced, except for commercial purposes, provided the source is acknowledged

SOME ASPECTS OF MOTORWAY TRAFFIC BEHAVIOUR IN FOG

ABSTRACT

This report describes an experiment to determine the effect of fog on the speed and spacing of traffic on the M4 motorway.

A discussion of visual range in day and night-time fogs is included to show that these two conditions should be considered separately.

In the range of day-light fogs tested (visibility down to 150m) the relations between mean traffic speed and visibility are well defined and remain substantially unaffected until the driver's visibility distance, as given by a measure of the meteorological visual range, falls below about 200m. In a similar range of night-time fogs mean traffic speeds are more variable, but the trend is similar to day-time if the driver's visibility distance is taken as the maximum distance at which a vehicle rear light of about 2 candela intensity can be seen through a dipped headlamp beam.

In conditions where the visibility distance does not fall below about 150m, average traffic speeds are generally sufficiently low to enable most drivers to stop within their visibility distance, but the reduction in speed with reducing visibility is accompanied by an increase in close following causing an overall increase in risk. Around one-third of all vehicles follow within a 2 second inter-vehicle time gap when driver visibility distances are reduced to 150m in day or night-time fog conditions.

1. INTRODUCTION

Although fog is a common occurrence in the UK as a whole an individual outbreak is usually confined to a fairly small area of the country¹, so that at any particular location poor visibility will generally prevail for less than about 10 days per year². However fog on motorways can give rise to serious multiple vehicle accidents and there is a need to consider the question of how motorways can be made safer in fog.

One possible method is to improve artificially the visibility of vehicles, and support for this method is implied in the recently introduced legislation to make the fitting of high intensity rear red fog lamps mandatory on new vehicles.

A second possible method, which is currently being investigated by the Department on the M4 at the easterly approach to the Severn Bridge, is to employ fog detectors at the roadside to give advance warning of fog patches and to suggest safe maximum speeds. Other methods have also been proposed². But to assist the evaluation of such methods, and to provide the insight that may lead to further measures, an improved understanding of traffic behaviour in fog would seem to be desirable.

This report describes an experiment to investigate the effect of fog on motorway traffic, and in particular to show:

- i) the level to which the visibility falls before the traffic begins to modify its behaviour, and
- ii) how traffic speed and spacing varies with reducing visibility.

A discussion on driver visibility in day and night-time fogs is included to show that these two conditions should be considered separately. The results of the experiments are then given, and a discussion follows.

2. EXPERIMENTAL SITE

The data for this investigation were continuously collected at the TRRL Fog Detection Site³ on the M4 motorway during the months of December 1977 to February 1978. The site was located on the verge of the eastbound carriageway about 2 km east of the Theale Interchange (Junction 12), and was originally chosen because there are a number of flooded gravel pits in the area, which were thought likely to promote the formation of fog.

Estimates of driver visibility distances were obtained using a TRRL transmissometer type fog detector^{3,4}. This gives an analogue voltage output which is proportional to the attenuation experienced by a light beam after it has passed through 4m of atmosphere. The detector readings, which were continuously monitored on a chart recorder throughout the duration of the experiment, were subsequently interpreted in terms of visibility distances as described in Section 3.

Traffic measurements were obtained at a point in the road 200m downstream from the fog detector using two inductive vehicle detection loops buried in each lane of the three lane carriageway. A knowledge of the loop's dimensions and separation enabled the signals produced in the loops by vehicles passing over them to be interpreted in terms of the length and speed of each vehicle and the time since the previous vehicle, ie the intervehicle time gap. These three parameters were automatically derived and recorded digitally on magnetic tape for subsequent analysis by a computer program.

The separation of the fog and vehicle detection equipment was arranged to allow time for the driver to adjust the speed of the vehicle to the visibility conditions prevailing at the fog detector.

3. THE VISIBILITY OF VEHICLES IN FOG

The reduction of visual range (ie the maximum distance at which an object can just be seen) caused by fog is due to two aspects of the same physical process whereby light is scattered by the water droplets or ice particles which make up the fog. Firstly, this scattering effect reduces the amount of light arriving at the observer's eye from an object, and secondly light from other sources is scattered to form a luminous veil through which the object must be seen. These two effects combine to reduce the contrast afforded by the object with its background (but not to blur its edges), to wash out colour (all objects appear grey at their visual range), and consequently to reduce the visual range.

Fog density is generally measured in terms of an atmospheric extinction coefficient (σ) ie, the attenuation experienced by a light beam after it has passed through unit length of atmosphere. The visual range to non self-luminous targets can then be calculated from Koschmeider's law⁵:

$$V = \frac{1}{\sigma} \log_e \frac{1}{c} \dots \dots \dots (1)$$

or the visual range to a light of intensity I from Allard's law⁵:

$$V = \frac{1}{\sigma} \left[\log_e \left(\frac{I}{E_t} \right) - 2 \log_e V \right] \dots \dots \dots (2)$$

where c and E_t are measures of the perceptual abilities of the observer.

c , the contrast threshold, is the minimum contrast which can just be detected, and a value of 5 per cent is probably representative for drivers in a daytime road situation². Equation (1) then reduces to:

$$MVR = \frac{3}{\sigma} \dots \dots \dots (3)$$

which defines Meteorological Visual Range (MVR) and is probably broadly representative of the average driver's visibility distance to vehicle, pedestrian, or street furniture outlines in all practical daylight fog conditions. The variation of MVR with σ is shown by the dotted curve in Figure 1.

E_t , the illuminance threshold, is the minimum level of illumination produced by a light source at the observer's eye which can just be detected against the background luminance. Unlike c , E_t is strongly dependent on the background luminance (B) and is given by:

$$\log_{10} E_t = 0.675 \log_{10} B - 5.7 \dots \dots \dots (4)$$

This equation, which applies for all practical night and daytime light levels, has been determined by the Blind Landing Experimental Unit of the Royal Aircraft Establishment as applicable for aircraft pilots. The relationship may therefore tend to overestimate the perceptual abilities of the typical driver, but when used in conjunction with equation (2) it should nevertheless provide a fair estimate of driver visibility distances to lights. The graphs of Figures 2 and 3 show how the visual range to lights of various intensity varies with extinction coefficient for background luminances equivalent to day and night-time respectively.

The variation of visual range with extinction coefficient is further illustrated for a rear light of 2 candela intensity in a wide range of background luminance levels by the solid curves in Figure 1. British Standards⁶ specify the minimum intensity of new vehicle rear running lights at 1.5 candela. In practice most are brighter than this but they are subject to deterioration through age and dirtying. It is therefore probably unwise to assume a representative intensity of much more than about 2 candela.

Figure 1 shows that in daylight a vehicle outline will generally be visible from a greater distance than a representative rear light in all but the thickest fogs. Further, since the contrast threshold is essentially independent of background luminance in daylight, it is evident that the enhanced luminous veil caused by street lighting or vehicle headlights can neither improve nor diminish visibility, although a vehicle using headlights will obviously be more visible to oncoming motorists and pedestrians.

Until high intensity rear red fog lights are fitted to all vehicles it should therefore be reasonable to assume that driver behaviour in daylight fogs is largely dictated by the visibility distance to a preceding vehicle outline. A fair estimate of the representative driver's visibility should therefore be given by a measure of the Meteorological Visual Range.

At night however the problem of defining a representative target in representative conditions is more confused. First, because of the wide range of rear light intensities encountered, typically between about 2 and 12 candela for rear running lights, but ranging up to around 200 candela⁷ for a rear red fog light; and second, because of the strong dependence of visual range on background luminance – an increase in the level of background luminance caused by switching from dipped to main beam or driving from an unlit into a lit area may significantly reduce the visual range to a preceding vehicle's lights at night.

The ability of a driver to see in fog is therefore dependent upon a number of factors and the considerations discussed here suggest that traffic behaviour should be examined separately during day and night-time conditions.

4. RESULTS OF THE EXPERIMENT

The length of time at the site for which the atmospheric extinction coefficient was greater than 7.5×10^{-3} and $15 \times 10^{-3} \text{ m}^{-1}$ for both day and night is shown in Table 1. These results show that fogs with densities equivalent to an MVR of less than 400m prevailed for a total period amounting to about 66 hours, the individual periods in fact being spread over seven separate days.

TABLE 1
The occurrence of fog during Winter 1977/78

Ambient light conditions	$\sigma \geq 7.5 \times 10^{-3} \text{ m}^{-1}$ (MVR \leq 400m)	$\sigma \geq 15 \times 10^{-3} \text{ m}^{-1}$ (MVR \leq 200m)
	hrs	hrs
Day	21.5	6.75
Night*	44.75	19.5
Total	66.25	26.25

* Note: The MVR cannot be taken as representative of the visual range of lights in night-time fogs and is used here only as a measure of fog density (see Section 3).

In order to facilitate the analysis of the traffic data, it was split up into 15 minute blocks. For each block and for each of the three lanes, the following parameters were calculated:

- i) The number of vehicles which passed over the detectors.
- ii) The mean and standard deviation of the vehicle speeds.
- iii) A histogram of the intervehicle time gaps.
- iv) The mean and standard deviation of the intervehicle distances.

Associated with each of these 15 minute time periods was an estimate of the meteorological visual range which was obtained from the chart record of the fog detector output. This MVR was taken to be representative of the visibility for the whole of the 15 minute period and will therefore be subject to a margin of error arising from two sources:—

- i) The instrument, which for the purposes of the experiment was maintained regularly throughout the winter 1977/78, could not measure the transmissivity of the atmosphere to better than ± 0.5 per cent. This leads to an error in measured MVR of ± 8.5 per cent at 200m tapering to ± 4 per cent at 100m MVR.
- ii) The fog density often varied during the course of a 15 minute time period to an extent that should not introduce errors of greater than about ± 10 per cent on average to the representative MVR.

In the circumstances it is thought that representative MVR measurements are typically accurate to about ± 15 per cent in the range 10m to greater than 200m.

The traffic and fog data sets were aligned by means of manual time markers, which had been added routinely as the data were collected.

4.1 Traffic speeds in fog

In this report no attempt is made to separate out the effects of reduced visibility and the advisory speed signs, the nearest of which was about 2 km before the experimental site. It is probably reasonable to assume however that most of the observed effects are due to the fog rather than the advisory signs. This assumption is supported by evidence⁸ which suggests that the signs by themselves could only be expected to have a secondary effect.

A representative MVR was established for each of the 15 minute data blocks. Blocks which had experienced the same MVR were then combined. This produced 265 data sets, 103 in day and 162 in night-time fogs. These results were then further combined to show the performance of traffic on the carriageway as a whole and this produced 65 data sets, 22 in day and 43 in night-time fogs with vehicle populations, mean speeds, and standard deviations as shown in Table 2.

The variation of mean traffic speed with MVR in daylight fogs for each of the three lanes of the eastbound carriageway is shown in Figure 4. A similar graph for the whole carriageway is shown in Figure 5 together with curves showing the shortest stopping distances for cars; first as reported by the OECD⁹ to take account of the reduced friction coefficient of a damp road surface, and second as recommended by the Highway Code¹⁰. The graphs of mean traffic speeds versus equivalent MVR* for night-time low visibility conditions for lanes 1 and 2 are depicted in Figures 6 and 7 respectively (the flows on lane 3 were too low for such an analysis to be made). A similar graph for the whole carriageway at night is given for completeness in Figure 8. All the curves shown in Figures 4–8 have been fitted by eye.

As can be seen from Figures 4 and 5 the relationship between speed and meteorological visual range during daylight hours is quite regular. The traffic remains substantially unaffected until the MVR drops to around 200m. Below this value the mean speed drops quickly with falling visibility to show a linear trend. (The daytime MVR never fell below 150m at the fog detector location during the whole of the winter 1977/78.)

* See footnote to Table 1.

TABLE 2

The mean speed of traffic in fogs

Fog density measured in terms of representative MVR*	Day			Night		
	Mean speed (km/h)	Standard deviation (km/h)	No. in sample	Mean speed (km/h)	Standard deviation (km/h)	No. in sample
(m)						
397	95.1	15.2	508	99.5	15.5	759
384	101.2	16.1	899	92.4	15.3	267
330	94.4	14.6	582	—	—	—
321	—	—	—	98.4	16.1	304
312	97.5	14.9	555	90.8	16.6	47
304	99.7	16.0	3334	96.3	16.3	198
297	96.5	15.3	1493	88.9	15.4	721
296	—	—	—	90.8	9.8	18
289	98.6	16.3	2828	98.4	15.6	1103
257	—	—	—	82.2	12.4	123
251	96.7	15.2	4093	90.5	15.1	2007
246	96.5	15.4	835	88.2	15.6	654
241	98.5	18.9	1122	89.7	16.4	288
240	98.8	17.4	244	—	—	—
236	101.1	16.0	489	87.1	16.1	518
231	99.1	15.9	973	92.9	15.8	1316
222	—	—	—	86.0	19.0	64
210	—	—	—	98.5	15.9	35
206	101.9	16.3	708	88.4	16.9	631
203	103.1	16.3	1038	90.2	15.6	423
199	101.2	16.4	1145	96.1	18.0	1238
196	104.3	15.8	2168	94.7	18.1	1200
192	—	—	—	102.9	13.4	331
186	—	—	—	100.1	16.8	117
183	—	—	—	81.3	14.6	97
180	—	—	—	87.3	14.7	38
177	—	—	—	86.1	14.6	632
175	—	—	—	81.9	16.4	102
174	—	—	—	81.8	17.5	78
172	—	—	—	87.9	13.7	73
169	84.1	17.2	1861	74.9	15.1	322
167	93.2	19.1	431	81.0	16.9	335
160	—	—	—	78.6	13.7	47
157	—	—	—	77.6	17.3	9
155	—	—	—	75.0	19.7	20
153	78.8	12.2	800	64.2	11.5	1713
151	73.7	11.7	501	64.9	11.2	514
149	76.3	11.5	775	—	—	—
140	—	—	—	81.4	14.7	62
136	—	—	—	85.7	14.4	65
135	—	—	—	85.7	15.5	189
124	—	—	—	88.9	16.8	258
121	—	—	—	79.1	7.9	55
120	—	—	—	70.7	7.4	31
119	—	—	—	74.9	11.0	67
111	—	—	—	80.0	14.3	41

* Estimated accuracy \pm 15 per cent, see Section 4.

Erratum

Line 192 above should read:

192

102.9

13.4

331

—

—

—

The situation after dark is not amenable to such a simple description because the MVR cannot be readily interpreted in terms of visual range in night-time fogs. It cannot be deduced directly from Figure 1 because no account is taken there of the increased veiling luminance caused by a driver's own headlights. However data reported by the OECD⁹ (and supported by the results of American research¹¹) provides a basis for relating MVR to the visual range to a vehicle lit by mainbeam, and to a rear light of about 2 candela illuminated by a dipped beam. The data of Figure 8, converted on this basis, are replotted in Figure 9. It may be noted that a very similar curve would have been obtained for the visual range to a representative rear light if the translation had been achieved using the deep twilight results of Figure 1.

The stopping distances are also included in Figure 9 for comparison as before.

4.2 Vehicle following times in fog

Figure 10 shows the combined distributions of the number of vehicles in ½ second following time intervals*, for each of the three lanes, for selected data blocks with MVRs equal to 153, 192m and no fog conditions, during day-light. Figure 11 shows the same graphs for 153 and 196m equivalent MVR and clear conditions at night.

Data blocks were selected because unlike traffic speed, vehicle following behaviour is difficult to interpret and compare in rapidly varying fogs at differing times of the day when the vehicle flows may be substantially different. Consequently while the speed curves of Figures 4–8 are derived from a consideration of all the data obtained in the experiment, the distributions of vehicle following times presented in Figures 10 and 11 were specially selected to provide representative and comparable data sets during periods of essentially stabilised fogs and at times when the free vehicle flows were similar at around 1000 vehicles per hour per carriageway. The selected data for day and night-time conditions are summarised in Tables 3 and 4 respectively.

TABLE 3

Traffic parameters in stable daylight fogs

Lane	Representative MVR †	Mean speed v (km/h)	Flow q (veh/hr)	Per cent of vehicles within 2 seconds following time	Per cent change in number of vehicles within 2 seconds from no fog conditions
1	153	70.7	424	33	136
	192	92.3	500	16	14
	∞	89.5	488	14	0
2	153	76.6	528	42	121
	192	105.0	624	31	63
	∞	106.7	556	19	0
3	153	89.0	120	37	164
	192	122.8	200	30	114
	∞	134.3	140	14	0

Note: MVR = ∞ denotes essentially clear visibility conditions. † See footnotes to Tables 1 and 2.

* Note: The following time is the time taken between the back of one vehicle and the front of the next passing a point in the road, but because the detector loops have an effective length of 2.2m the measured time gaps are short by the time taken for the front of the following vehicle to cross the loop. The resulting errors of 0.1 and 0.16 seconds at 80 and 48 km/h respectively are not thought likely to significantly affect the conclusions of this report.

TABLE 4

Traffic parameters in stable night-time fogs

Lane	Representative MVR*	Mean speed v (km/h)	Flow q (veh/hr)	Per cent of vehicles within 2 seconds following time	Per cent change in number of vehicles within 2 seconds from no fog conditions
1	153	57.0	368	17.4	190
	196	87.8	396	6.0	0
	∞	98.5	340	6.0	0
2	153	56.7	452	46.1	181
	196	105.1	360	10.0	-39
	∞	116.2	464	16.4	0
3	153	67.8	68	29.5	84
	196	121.6	28	0.0	-16
	∞	134.3	100	16.0	0

* See footnotes to Tables 1 and 2.

The results show that the proportion of drivers who drive within 2 seconds of the vehicle in front increases markedly as the visibility decreases.

5. A DISCUSSION OF THE RESULTS

5.1 Traffic speeds

5.1.1 Day-light fog conditions. In day time fogs, affording MVR of greater than about 150m (Figure 5), average speeds are such that most drivers should be able to stop within their visibility distances. However, heavy goods vehicles often require longer distances than cars and a consideration of the standard deviations around the mean speeds (Table 2) indicates that a small proportion of drivers may well travel too fast.

5.1.2 Night-time fog conditions. The mean speed of traffic in night-time fogs is more variable, probably because of the strong dependence of 'apparent' visibility distance on vehicle rear light intensity and the level of background luminance – both of which are subject to wide variation.

The average speed of traffic when related to the visual range to a 2 candela rear light seen either through dipped headlight beams or directly in deep twilight conditions is somewhat similar to the day-time results in Figure 5. It would therefore seem reasonable to accept that overall mean traffic speeds in night-time fogs are largely dictated by the visual range to a representative rear light of about this intensity. Also, that the effect of dipped headlights is to increase the background luminance to a level which, on average, roughly corresponds with deep twilight conditions.

When the visual range to a representative rear light in a night-time fog is about 150m, the visual range to a vehicle or street furniture outline in the same fog is only about 50m. Platoon leaders and following drivers may therefore drive according to widely differing 'apparent' visibility distances especially if the platoon leader is out of sight of other vehicles.

The results obtained in this investigation may be compared with those of a previous investigation¹² in which it is suggested that the relationship between traffic speed and visual range does not differ significantly in day and night-time fogs. The present results show that MVR may indeed provide a reasonable estimate of representative driver visibility distance at night, but only over a limited range, cf curves 5 and 7 in Figure 1. There must therefore be some doubt as to the interpretation of the visibility distances reported by reference 12 in which the day and night-time results were combined. But there can be no doubt that this earlier experiment encompassed much denser fogs than those reported here. In consequence the findings of the present report (which suggest that most drivers could stop within their visibility distance in fogs having MVR down to about 150m in day time and 110m in night-time), do not conflict with the earlier findings which suggest that a very high proportion of drivers could not stop within their visibility distance in very thick fogs having MVR down to about 50m. Other apparent discrepancies, for example, in the mean speed of traffic in clear conditions, probably arise because while this report considers all traffic, reference 12 confines its attention to the behaviour of cars and light commercial vehicles only.

5.1.3 Anomalous behaviour. The daylight speed curves show a significant (at the 0.01 level) rise in the average speed of the traffic, by about 5 km/h over the clear weather average speed of around 100 km/h, in each lane when the visual range is about 200m MVR. (There is perhaps some evidence that a similar phenomenon occurs in night-time fogs but it is less well defined.) This speed increase which is observed at a critical level of visibility when drivers should be moderating rather than increasing their speed, may possibly be related to the evidence obtained in other studies (although usually at lower levels of visibility) which suggest that drivers in fog may tend to over-estimate their visibility distances¹³. A number of other factors may also contribute^{7,14}, but the overall effect could be to delude the motorist into driving at a speed which appears to be slower than it really is. Further research would be required to confirm this.

5.2 Inter-vehicle time gaps

The distribution of vehicle following times shown in Figure 10 for free flow in daylight and clear weather conditions is in close agreement with that observed by a previous investigation¹⁵. But the results reported here (Figures 10 and 11) clearly show an increased tendency for vehicles to platoon as the visibility reduces during both day and night-time fog conditions.

At driver visibility distances of about 150m by day or night, up to about 30 per cent of vehicles, ie around 2.5 times the proportion in normal flow with clear weather conditions, close up to follow within a time gap of less than 2 seconds – the minimum recommended by the Highway Code¹⁰ but for good conditions on dry roads. This appears to demonstrate that fog promotes platooning and provokes less safe following behaviour.

In the worst case of fog and platooning reported here (see Table 4 and Figure 11, lane 2 results), average speeds of around 60 km/h were recorded in a night-time fog whose density was equivalent to an MVR of 150m. In this visibility even unlit vehicles would have been seen in outline from about 55m, and following drivers could have kept such vehicles in view at 60 km/h whilst maintaining a safe time gap of 3.3 seconds. Rear lights could have been followed at around three times this gap. In fact, the modal value of the observed time gaps in lane 2 was 0.75 seconds (corresponding to less than 13 metres).

Close following behaviour cannot therefore be explained solely in terms of reduced visibility distance per se. It may be that psycho-physiological factors play a part, or fog may so degrade conspicuity that

drivers with poorer eyesight are compelled to follow more closely in order to obtain adequate visual clues about the impending deceleration of a leading vehicle.

Alternatively, platoon leaders may achieve their position by effectively baulking the progress of inherently faster drivers who, by the reasoning of Section 5.1.2, may have a greater 'apparent' visibility distance and who may therefore tend to follow more closely in anticipation of overtaking.

But whatever the reason, many drivers clearly fail to comply with the fog code¹⁰ which exhorts them to follow at greater time gaps; and since they appear to follow more closely than is necessary to maintain visual contact with the vehicle in front it is thought unlikely that high intensity rear red fog lamps will substantially improve their spacing.

Nevertheless, brighter lights may enable drivers to see two or more vehicles ahead in fog and the consequently improved ability to anticipate the immediately preceding driver's actions may contribute to safer driving¹⁶. In addition, brighter lights will give earlier warning of a stationary vehicle and should also contribute towards reducing multiple vehicle accidents in fog.

A similar reservation may apply for fog detection schemes. These might be used to control traffic speeds in fogs but it seems unlikely that they can substantially affect the tendency of traffic to close up as speeds are forced lower. Nevertheless fog detection schemes may provide benefits simply by reducing the number of drivers who adopt speeds much greater than the average, and the results of German trials¹⁷ with a system which warns of fog, but does not advise safe speeds, suggest that accidents may be significantly reduced. If it is desired to indicate a safe speed, the mean speeds currently adopted by the traffic would appear to be appropriate. Over the range of fogs tested these speeds should allow most drivers to stop within their visibility distance, and since they are evidently preferred, could expect to achieve a high degree of compliance. The results of studies in the USA¹¹ suggest that indicating speeds much below these may actually lead to an increase in the spread of vehicle speeds.

6. CONCLUSIONS

Measurements of the speed and spacing of traffic on an unlit section of the M4 motorway have been obtained in day and night-time fogs affording drivers visibility distances down to about 150m.

Driver visibility distances in daylight fogs will generally be determined by the distance at which non self-luminous targets such as vehicle, pedestrian, or street furniture outlines can just be seen, and a measurement of the Meteorological Visual Range should provide a fair estimate of the representative driver's visibility distance in these conditions.

The results for the range of daylight fogs tested show that the relations between mean traffic speed and visibility are well defined. Traffic speeds remain substantially unaffected until the Meteorological Visual Range falls below about 200m.

In contrast, mean traffic speeds in a similar range of night-time fogs are more variable. This is probably largely due to the strong dependence of a driver's 'apparent' visibility distance on both the range of rear light intensities, and the range of background luminances which may be encountered. In consequence it is difficult to specify a representative target in representative conditions although mean results similar to

those for day time are obtained when the speed of traffic is plotted against the maximum distance at which a rear light of about 2 candela intensity can just be seen through a dipped headlamp beam. This criterion which approximates to the Visual Range to a 2 candela light in deep twilight conditions probably provides a useful estimate of the representative driver's visibility distance in night-time fog.

Overall, the results suggest that in conditions where the visibility distance does not fall below about 150m traffic tends to adopt mean speeds in fogs so that most drivers could stop well within their visibility distances. A reduction in speed with falling visibility is however accompanied by a marked reduction in inter-vehicle time gaps and an increased tendency to platoon. At driver visibility distances of about 150m, by day or night, around 30 per cent of vehicles, ie about 2.5 times the proportion in clear weather conditions, follow within 2 seconds of the preceding vehicle – the minimum recommended by the Highway Code for driving in good conditions on dry roads. Drivers therefore are considerably more at risk.

The observed close following behaviour cannot be explained solely by the reduced visibility distance per se; and it is concluded that many drivers follow closer than is necessary to maintain visual contact with the vehicle in front. It is therefore thought unlikely that brighter rear lights or fog detection schemes can modify this aspect of driver behaviour although it is believed that both should nevertheless prove beneficial in contributing to safer driving and alleviating accidents.

7. ACKNOWLEDGEMENTS

The work described in this report was carried out in the Highway Traffic Division (Division Head: K Russam) of the Traffic Engineering Department of TRRL.

The authors wish to thank Mr J Montague who wrote the traffic data computer program and Mrs V Minter for assisting in analysing the data.

8. REFERENCES

1. TRANSPORT AND ROAD RESEARCH LABORATORY. Fog and Road Accidents 1975. *TRRL Leaflet LF 652*. Crowthorne, 1977 (Transport and Road Research Laboratory).
2. MOORE, R L and L COOPER. Fog and road traffic. *Department of the Environment, TRRL Report LR 446*. Crowthorne, 1972 (Transport and Road Research Laboratory).
3. DOUGLAS, H A, D J JEFFERY and F JEZZARD. The measurement of fog on motorways. *Meteorological Magazine*. Vol. 107, 1978.
4. TRANSPORT AND ROAD RESEARCH LABORATORY. The TRRL Fog Detector. *TRRL Leaflet LF 597*. Crowthorne, 1977 (Transport and Road Research Laboratory).
5. MIDDLETON, W E K. Vision through the atmosphere. Univ. of Toronto Press, 1952.
6. BRITISH STANDARDS INSTITUTION. Tail lights for vehicles including cycles. BS 2516, 1954. (British Standards Institution).

7. TRANSPORT AND ROAD RESEARCH LABORATORY. Visibilities of objects and lights in fog. *TRRL Leaflet* LF 643. Crowthorne, 1977 (Transport and Road Research Laboratory).
8. TRANSPORT AND ROAD RESEARCH LABORATORY. Motorway traffic behaviour. *TRRL Leaflet* LR 825. Crowthorne, 1979 (Transport and Road Research Laboratory).
9. OECD. Adverse weather, reduced visibility and road safety. A report prepared by an OECD Road Research Group, Paris 1976 (Organisation for Economic Cooperation and Development).
10. DEPARTMENT OF THE ENVIRONMENT. The Highway Code. London, 1978 (H M Stationery Office).
11. Highway Fog Visibility Measures and Guidance Schemes. *Transportation Research Board, NCHRP Report* 171. Washington DC, 1976.
12. SUMNER, R, C BAGULEY and J BURTON. Driving in fog on the M4. *Department of the Environment Department of Transport, TRRL Report* SR 281. Crowthorne, 1977 (Transport and Road Research Laboratory).
13. ROSS, H. Mist Murk and Visual Perception. *New Scientist*. 19 June 1975, pp 685–660.
14. BROWN, I. Motorway Crashes in Fog – Who’s to Blame? *New Scientist*. 24 December 1970, pp 544–545.
15. SUMNER, R and C BAGULEY. Close following behaviour at two sites on rural two-lane motorways. *Department of the Environment Department of Transport, TRRL Report* LR 859. Crowthorne, 1978 (Transport and Road Research Laboratory).
16. KOCHMOND, W C and K PERCHONOK. Highway Fog Nat Co-Op. *Highway Research Program. Report* 95. US Highway Research Board, 1970.
17. BEHRENDT, J. Fog Warning on Motorways in the Federal Republic of Germany. *Transportation Research Board Circular. Driver Visibility under varying adverse weather conditions. Number* 193. March, 1978.

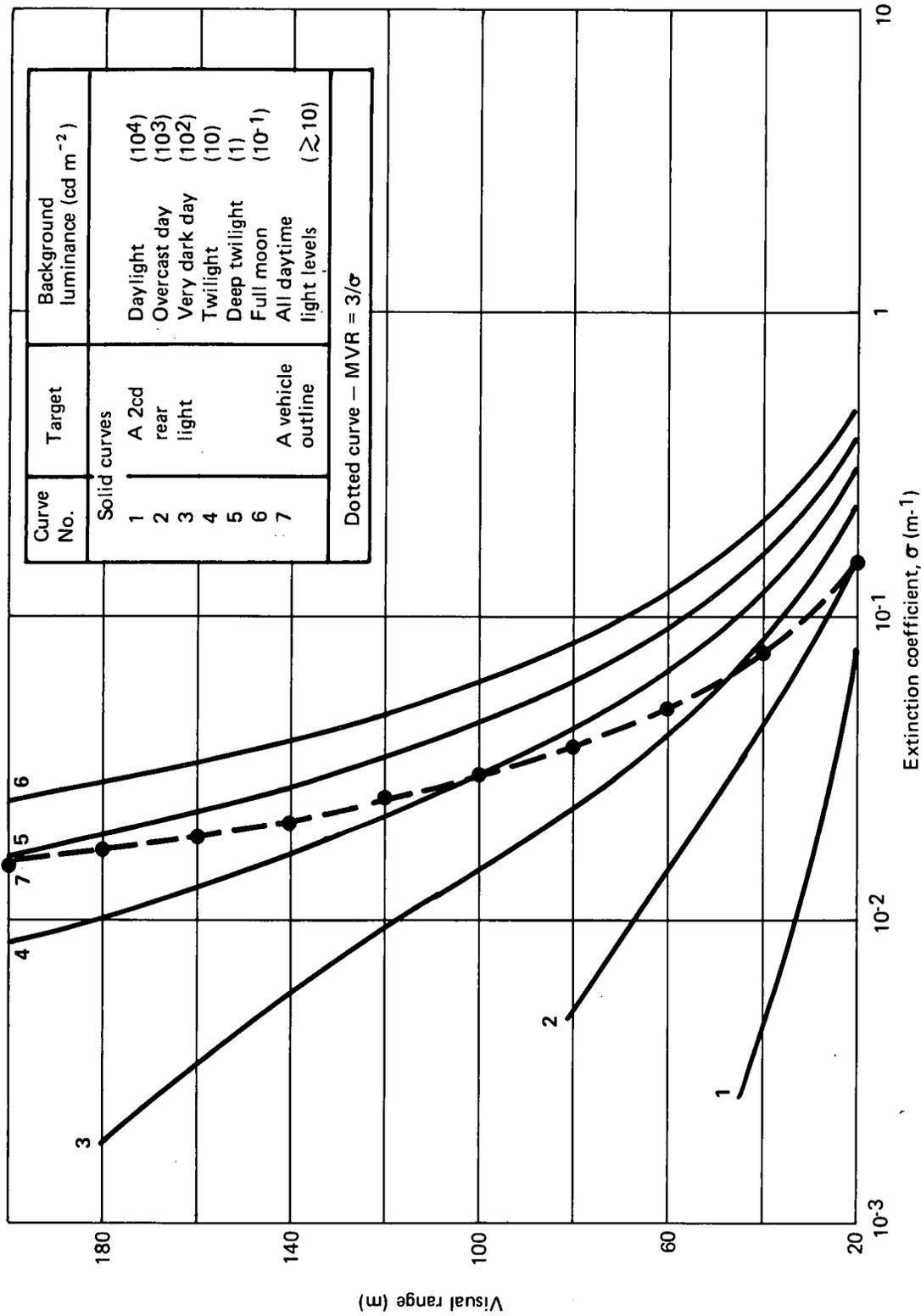


Fig. 1 THE VARIATION OF VISUAL RANGE WITH EXTINCTION COEFFICIENT

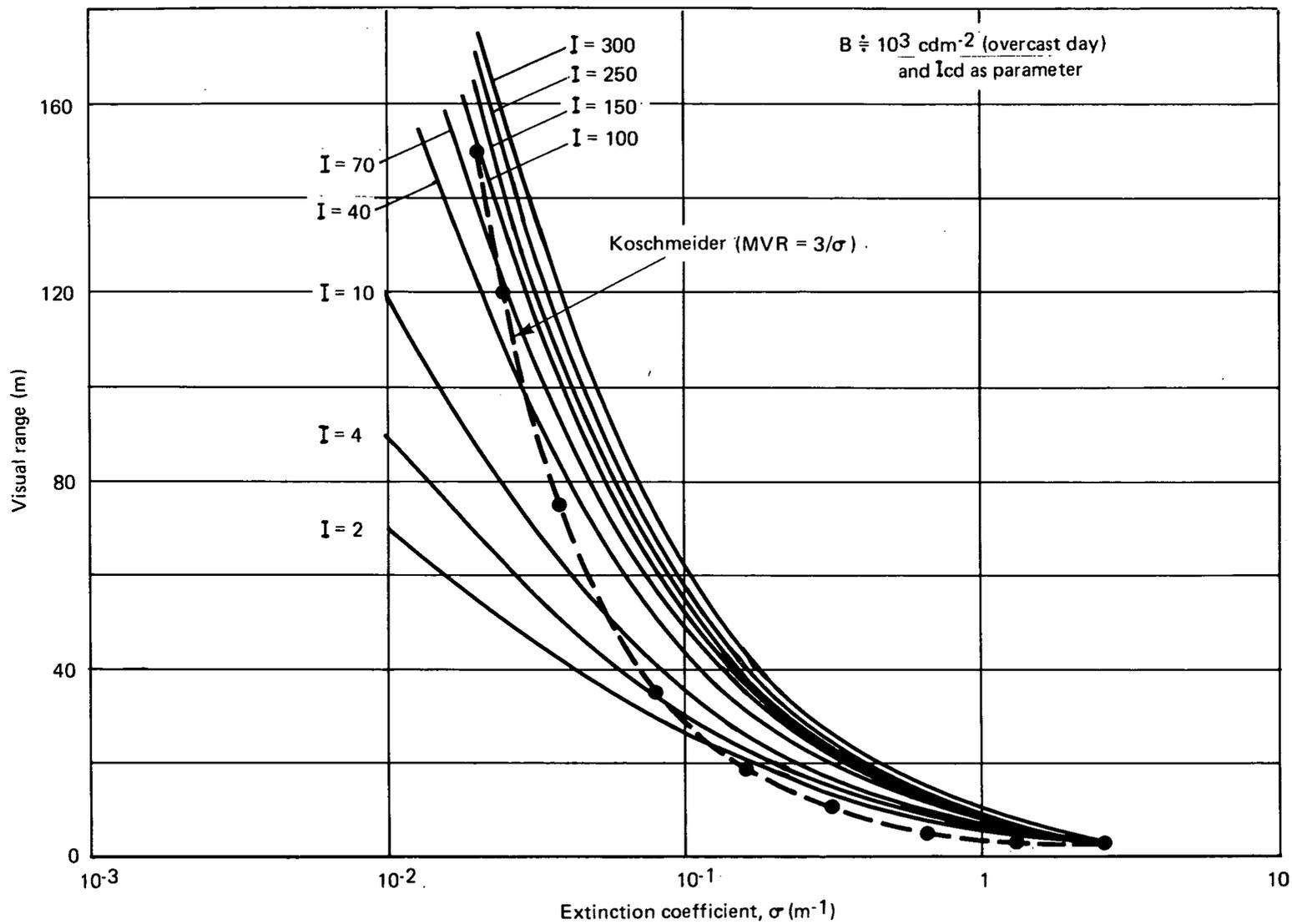


Fig. 2 VISUAL RANGE v EXTINCTION COEFFICIENT

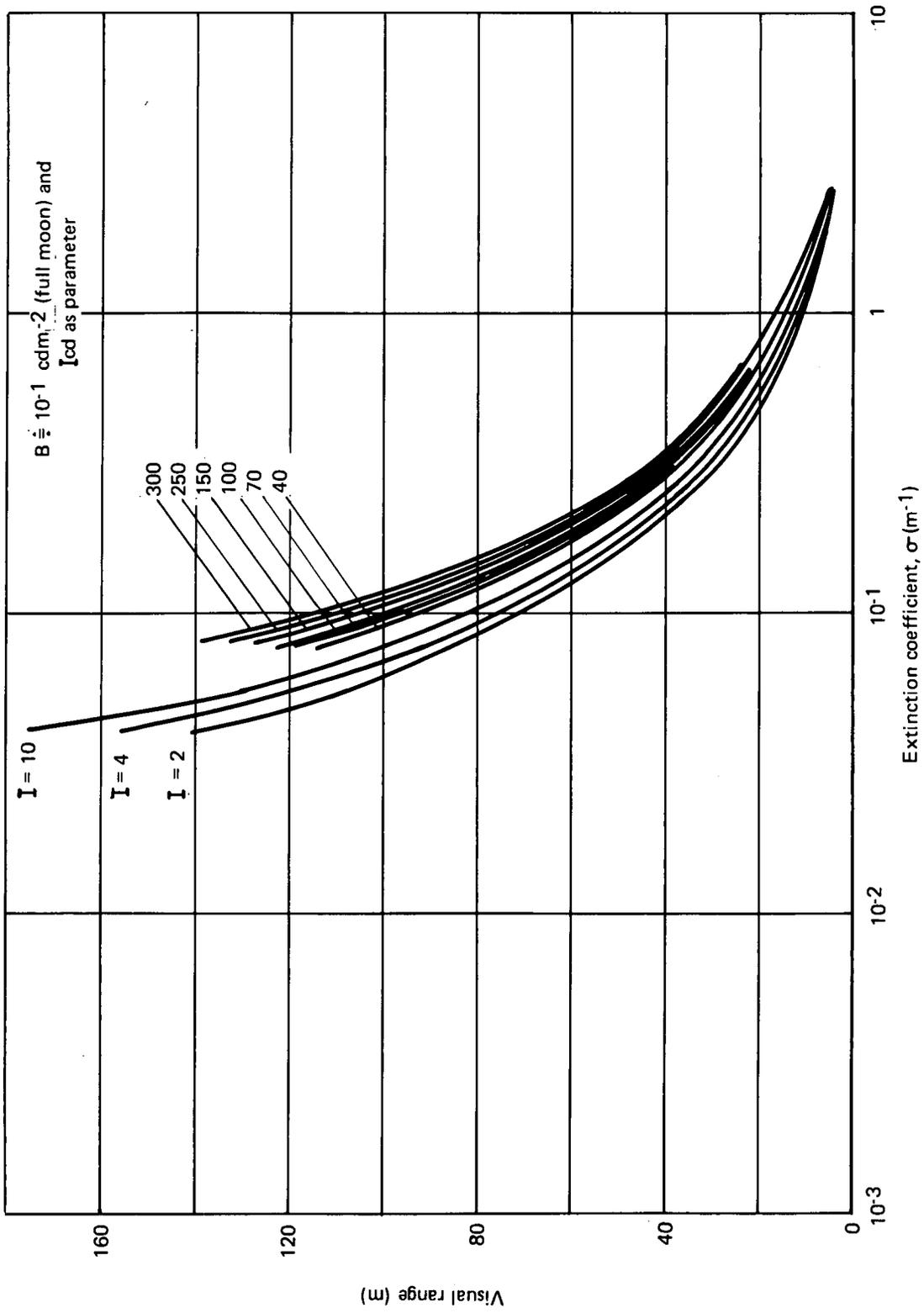


Fig. 3 VISUAL RANGE v EXTINCTION COEFFICIENT

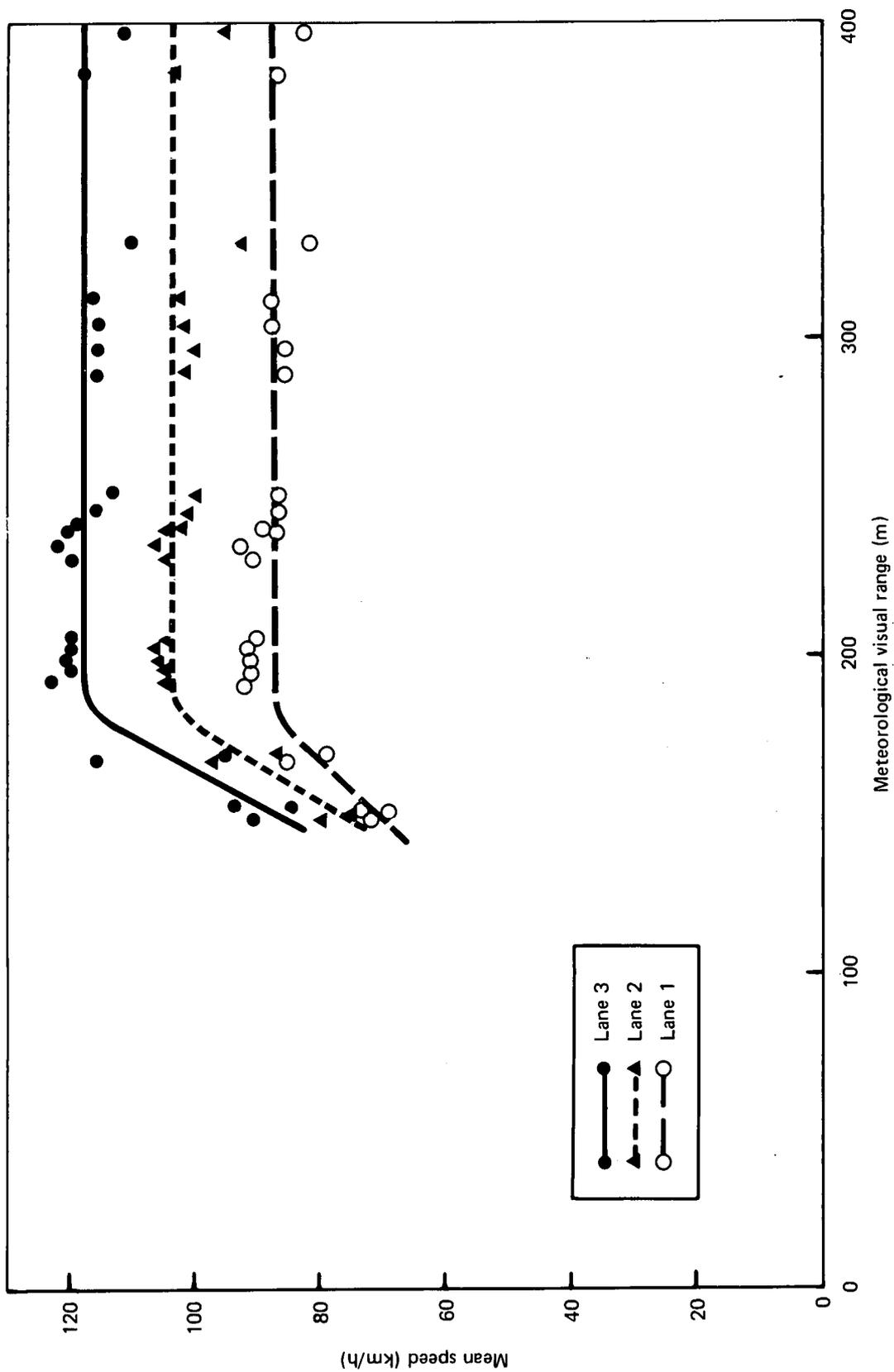


Fig. 4 MEAN SPEED OF TRAFFIC v METEOROLOGICAL VISUAL RANGE (Daytime)

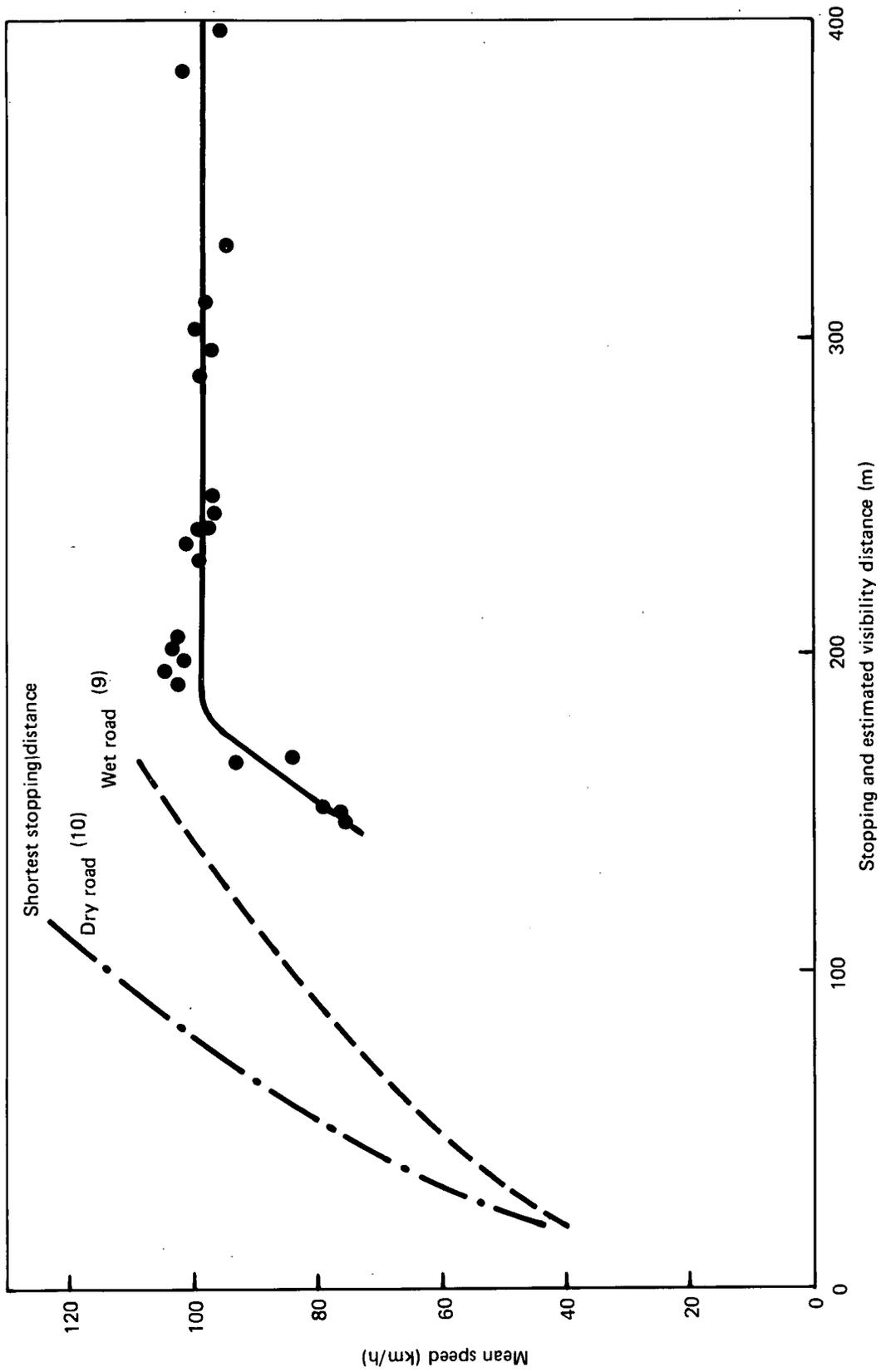


Fig. 5 MEAN SPEED OF TRAFFIC v METEOROLOGICAL VISUAL RANGE AND STOPPING DISTANCE IN DAYTIME FOG

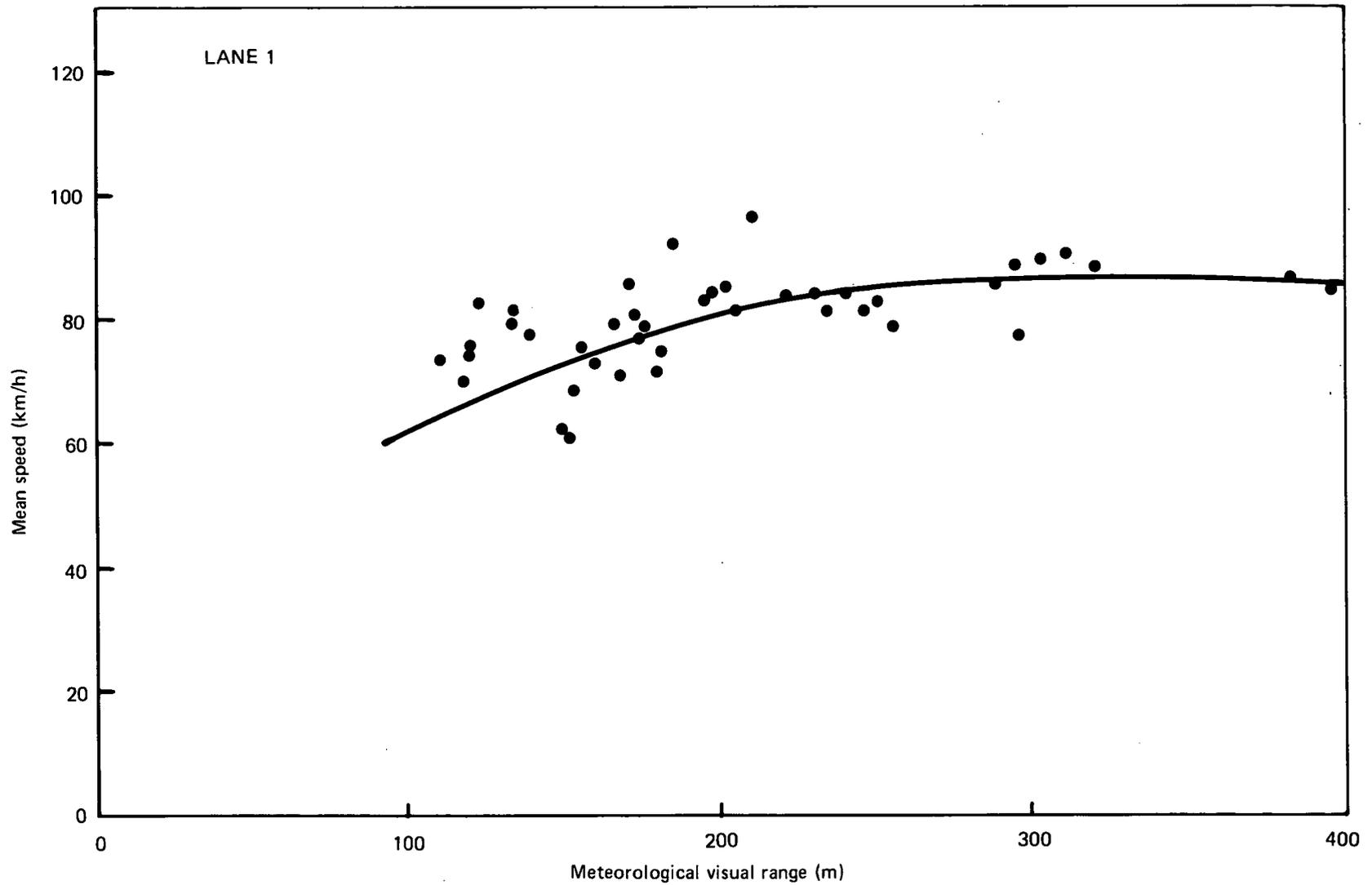


Fig. 6 MEAN SPEED OF TRAFFIC v FOG DENSITY AS MEASURED IN TERMS OF METEOROLOGICAL VISUAL RANGE (Night-time)

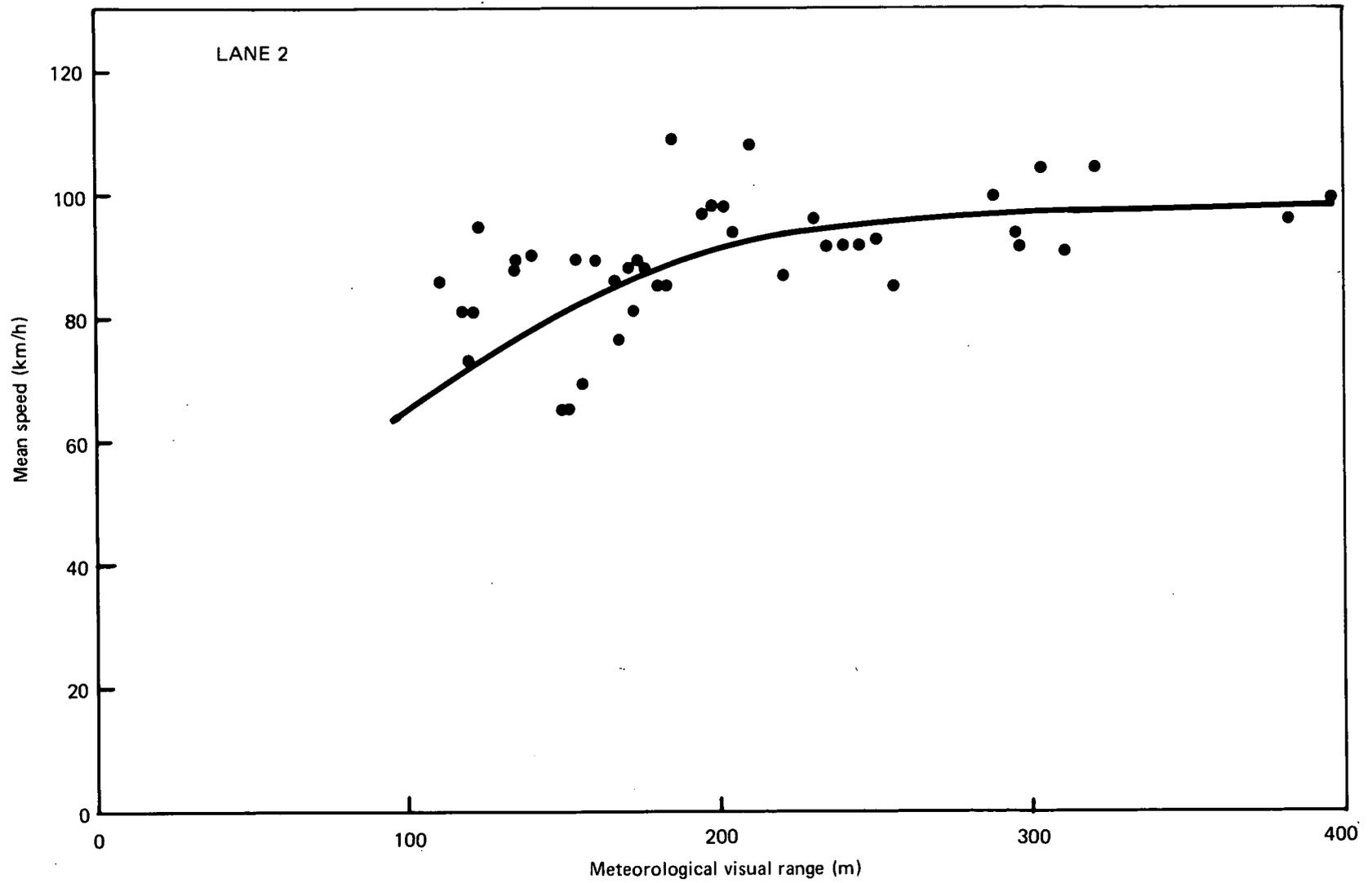


Fig. 7 MEAN SPEED OF TRAFFIC v FOG DENSITY AS MEASURED IN TERMS OF METEOROLOGICAL VISUAL RANGE (Night-time)

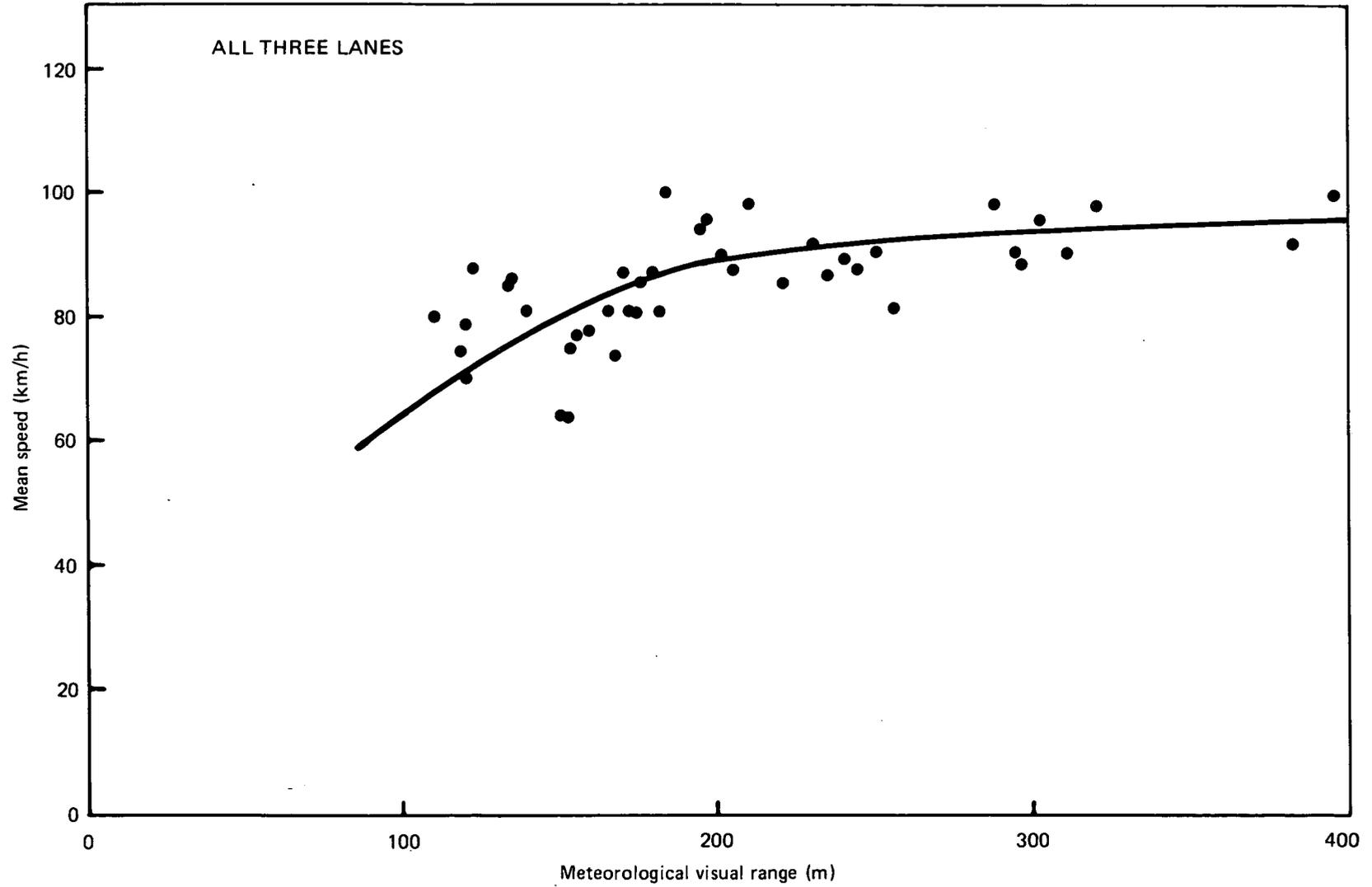


Fig. 8 MEAN SPEED OF TRAFFIC v FOG DENSITY AS MEASURED IN TERMS OF METEOROLOGICAL VISUAL RANGE (Night-time)

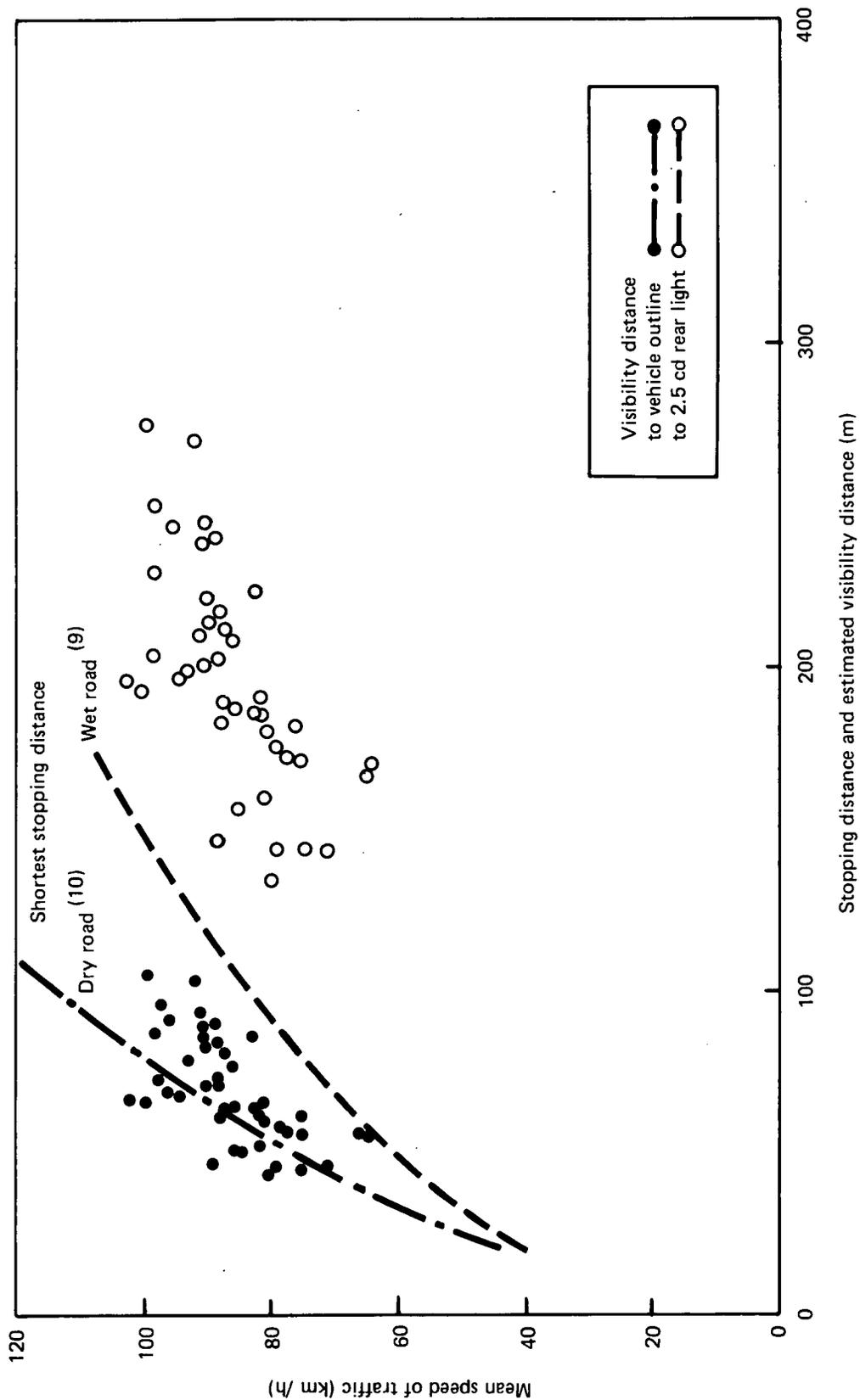


Fig. 9 MEAN OBSERVED SPEED OF TRAFFIC v STOPPING AND ESTIMATED VISIBILITY DISTANCE IN NIGHT-TIME FOG

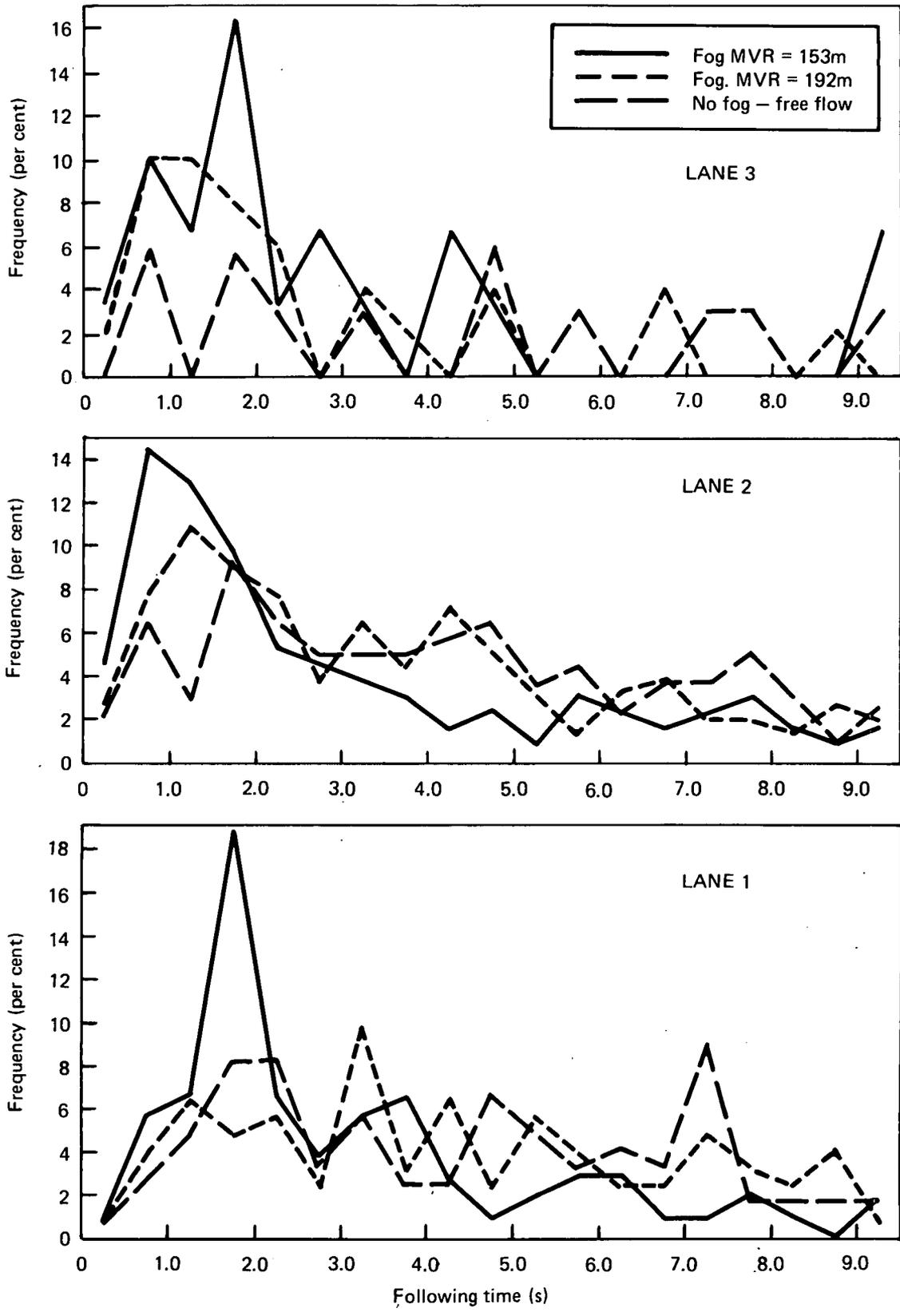


Fig. 10 DISTRIBUTION OF VEHICLES IN 1/2 SEC FOLLOWING TIME INTERVALS (Day-time)

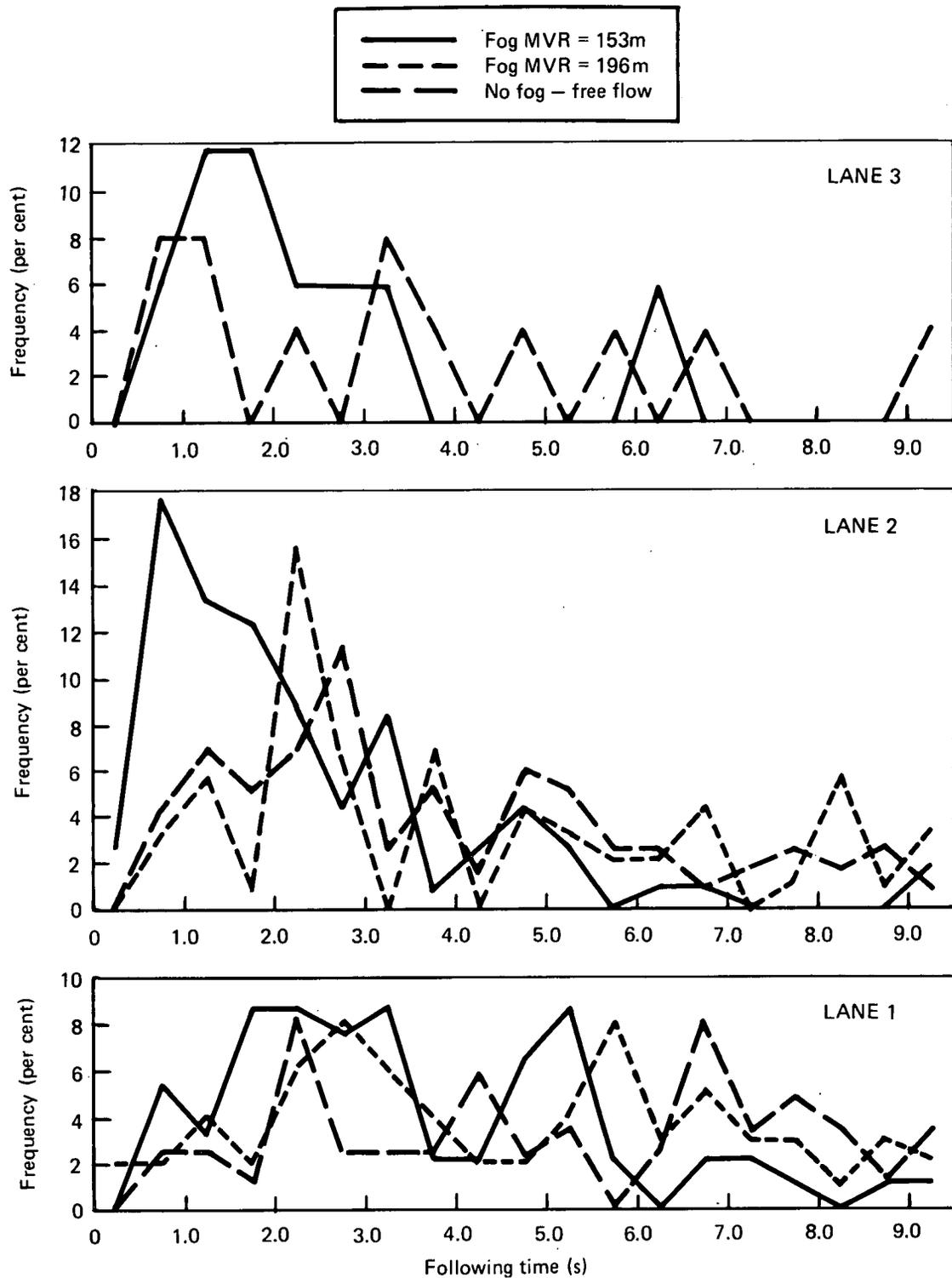


Fig. 11 DISTRIBUTION OF VEHICLES IN 1/2 sec. FOLLOWING TIME INTERVALS (Night-time)

ABSTRACT

Some aspects of motorway traffic behaviour in fog: M E WHITE and D J JEFFERY:
Department of the Environment Department of Transport, TRRL Laboratory Report 958:
Crowthorne, 1980 (Transport and Road Research Laboratory). This report describes an
experiment to determine the effect of fog on the speed and spacing of traffic on the M4
motorway.

A discussion of visual range in day and night-time fogs is included to show that these
two conditions should be considered separately.

In the range of day-light fogs tested (visibility down to 150m) the relations between
mean traffic speed and visibility are well defined and remain substantially unaffected until
the driver's visibility distance, as given by a measure of the meteorological visual range,
falls below about 200m. In a similar range of night-time fogs mean traffic speeds are more
variable, but the trend is similar to day-time if the driver's visibility distance is taken as the
maximum distance at which a vehicle rear light of about 2 candela intensity can be seen
through a dipped headlamp beam.

In conditions where the visibility distance does not fall below about 150m, average
traffic speeds are generally sufficiently low to enable most drivers to stop within their
visibility distance, but the reduction in speed with reducing visibility is accompanied by an
increase in close following causing an overall increase in risk. Around one-third of all
vehicles follow within a 2 second inter-vehicle time gap when driver visibility distances are
reduced to 150m in day or night-time fog conditions.

ISSN 0305-1293

ABSTRACT

Some aspects of motorway traffic behaviour in fog: M E WHITE and D J JEFFERY:
Department of the Environment Department of Transport, TRRL Laboratory Report 958:
Crowthorne, 1980 (Transport and Road Research Laboratory). This report describes an
experiment to determine the effect of fog on the speed and spacing of traffic on the M4
motorway.

A discussion of visual range in day and night-time fogs is included to show that these
two conditions should be considered separately.

In the range of day-light fogs tested (visibility down to 150m) the relations between
mean traffic speed and visibility are well defined and remain substantially unaffected until
the driver's visibility distance, as given by a measure of the meteorological visual range,
falls below about 200m. In a similar range of night-time fogs mean traffic speeds are more
variable, but the trend is similar to day-time if the driver's visibility distance is taken as the
maximum distance at which a vehicle rear light of about 2 candela intensity can be seen,
through a dipped headlamp beam.

In conditions where the visibility distance does not fall below about 150m, average
traffic speeds are generally sufficiently low to enable most drivers to stop within their
visibility distance, but the reduction in speed with reducing visibility is accompanied by an
increase in close following causing an overall increase in risk. Around one-third of all
vehicles follow within a 2 second inter-vehicle time gap when driver visibility distances are
reduced to 150m in day or night-time fog conditions.

ISSN 0305-1293