V I S I B I L I T Y   O F   R O A D   M A R K I N G S

O N   W E T   R O A D   S U R F A C E S

A LITERATURE STUDY
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PREFACE

On 14 May 1975 a symposium on "Road Markings" was held at the Delft University of Technology, organised by the Studie Centrum Wegenbouw SCW (Study Centre for Road Construction) in collaboration with the Studiecentrum Verkeerstechniek SVT (Study Centre for Traffic Engineering) and the Delft University's Civil Engineering Department.
The purpose of the symposium was to publicly catalogue all the problems of producing, applying and maintaining road markings, of their national and international standardisation and uniformity in their use.
The forum at the symposium subsequently evaluated the complex of questions put before them and reached the conclusion that it was advisable, inter alia, to set up a working party which would aim at improving the visibility of road markings in conditions unfavourable to road users.

This wish was met by working party E9 on "Visibility of road markings on wet surfaces". It was set up on 2 June 1977 and its members are:
G.A. Brevoord
D. Hogervorst
G.J. Blaauw
C.H.M. van Giessen
P. de Groot
A. Lesterhuis
J.M. Boone
D.A. Schreuder
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Its terms of reference can be summarised as: to indicate measures resulting in an improvement of the visibility of road markings to road users, especially motorists, after dark on wet surfaces and outside built-up areas, the latter with the implication that the roads are often unlit.

E9 works under the auspices of both the Studie Centrum Wegenbouw SCW and the Studiecentrum Verkeerstechniek SVT; administration support is given by F. van Gorkum of the SCW Bureau.

The first action the working party had to take was to make an extensive literature study in order to take stock of the present situation in this area of research. Instructions to this effect were given to the Institute for Road Safety Research SWOV. They were carried out by Dr. D.A. Schreuder. The fruits of his labour are embodied in this report: an extensive review of what the world has published on research into the problems outlined above. The original report was published in the Dutch language in November 1978.

The Studie Centrum Wegenbouw SCW and the Studiecentrum Verkeerstechniek SVT both trust that, on the one hand, this publication will be read as attentively as was the work on which it is based and that, on the other, a similar publication will follow very soon, taking stock of the present position of knowledge gained on that part of the problem area - the visibility of road markings in conditions unfavourable to road users - applying in built-up areas.

Studie Centrum Wegenbouw SCW
Studie Centrum Verkeerstechniek SVT

SUMMARY

Road markings, notably lane markers, are often only poorly visible when the road is wet. This is particularly a problem at night on unlit roads. A study of whether a solution for this problem can be found on the basis of the known published literature has been undertaken. The most important conclusions are:

- precise requirements for the visibility of road markings (lane markers) cannot be given at present;
- raised markers with corner-cube reflectors perform best as regards nighttime visibility on wet, unlit roads, followed by other types of reflectorised raised markers, corrugated lines, thermoplasts and finally road paint;
- for daytime visibility the sequence is more or less reversed.

Further field tests are recommended regarding the perfomance of different types of markings, taking into account the visibility under other circumstances (dry roads, daylight).

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1. INTRODUCTION

Working party E9: "Visibility of road markings on wet surfaces" (set up by the Studie Centrum Wegenbouw SCW (Study Centre for Road Construction) and the Studie Centrum Verkeerstechniek SVT (Study Centre for Traffic Engineering) started work in May 1977. The party's terms of reference were to make recommendations for materials for road markings, especially ones that will remain visible on wet surfaces.

One part of these activities was to make a literature study with the specific object of ascertaining what was known about this subject in published literature. The study concentrates on questions of visibility, while questions of cost, useful life, colour, attachment etc. are not dealt with in detail.

2. THE PROBLEMS

Road markings can be divided into a number of categories. Only the "lane marker" category will be examined. The other categories (stop lines, signs, zebra crossings, lane arrows and so on) are not considered. It is a matter for future research to decide whether the results found for lane markers apply to other road markings as well.

The principal function of lane markers is to assist drivers (especially motorists) in choosing the right lateral position on the road. In this respect, roadway delineators can also be regarded as lane markers.
Other functions - of less relevance in the present study - relate to following the road, especially in bends, and furnishing information on the position of vehicles travelling in the same and opposite directions.

The functional requirements for lane markers (and the materials to be used for them) follow from the need for them to be clearly visible at such a distance from the vehicle that its lateral position can be maintained, or that unintentional deviations from the desired lateral position can be corrected in good time - in bends too. "In time" in this context means so early that the deviation from the desired lateral position still causes no danger to the vehicle itself or to other traffic. For the sake of completeness, it should be added that other road elements - whether or not introduced intentionally - may help to provide the desired information.

On the assumption that deviations of several decimetres from the desirable lateral position are acceptable, and that big lateral accelerations or decelerations must be avoided during correction, it is found to be adequate for road markings to have a visibility distance of some tens of metres - even at normal motorway speeds. It is not possible to state the required distances more precisely at present; but it will be clear from the following that greater accuracy is not necessary for the purposes of this study. It should be pointed out that this greater accuracy may, however, be necessary for markings having other functions, and for other types of markings. These are not dealt with in the present study.

Road markings of the type needed for maintaining lateral position need not therefore be visible a great distance away. But on the other hand it is understandable, because of the evident need for reasonably maintaining the lateral position, that road markings must be very clearly visible at close range and in all conditions that may arise. The principal factors determining these conditions are lighting and weather. Many markings now current are poorly visible when roads are wet, especially at night on unlit roads.

The present study deals first of all with this unfavourable combination. The study is further limited by the fact that primarily the motorway situation is examined. This limitation is based on practical considerations. Consequently, the study can be limited to lane markers, and there is less need to allow for glare caused by oncoming vehicles. The description "unlit roads" automatically leads to a further limitation, i.e. motorways outside built-up areas.

Lastly, it follows from these restrictions that only lighting with low-beam headlamps needs to be allowed for: high beams are not suitable on the usually busy motorways. Low beams reach some tens of metres; this corresponds to the distance for which markings have to be visible in order to be functional. The question is thus reduced to: what is the visibility of various road-marking materials on wet surfaces with low-beam headlamps?

3. THE MATERIAL

A literature study was felt to be necessary, since the problems outlined before occur in practically all countries, and research is known to have been carried out in many places.
The study was confined to three groups of publications:

- The IRRD (International Road Research Documentation, a documentation system set up under OECD auspices).
- SWOV's documentation system relating to material held by SWOV recorded since 1972.
- Anything learnt of "by chance"; for instance SWOV material recorded before 1972.

The first two groups were approached systematically (not the third one, of course). Use was made of key words. In the case of the IRRD, they were "carriageway marking; night; wet road; headlamp; visibility; perception; measurement". Titles, authors and so on, of the relevant combinations were asked for; for those apparently relevant, at least summaries and, where possible, complete texts were looked up. Where, finally, the publications were found to contain anything relevant to the present study, they were included in the literature list. The same procedure was followed with respect to SWOV's material: the key words were the same, except that a distinction can be made between "visibility" and "visibility distance".

Although the IRRD and SWOV material together cover a large part of the literature, there is no guarantee that it is complete. An endeavour was made to fill any gaps, at least partly, by supplementing the systematic treatment with publications available more or less incidentally (i.e. unsystematically). This procedure, which even in its entirety gives no guarantee of completeness, was regarded as justifiable because the primary purpose of the study was to form a background for the working party's own studies.

4. STUDY SET-UP

The literature was studied in the following way:

- Analysis of the problem, analysis of the driver's task, visual surroundings.
- Visibility of different materials, experimental methods, material characteristics.
- Other material characteristics, cost, attachment, useful life, damage by traffic, snowploughs, salt and so on.
- Norms and standards.

This is followed by conclusions indicating the materials most suitable for further research in The Netherlands.

Lastly a general comment: at first sight there is a huge volume of relevant literature. Closer examination shows that all most studies do is to establish the poor visibility of markings on wet roads, especially at nighttime on unlit roads. This is of course true, but brings us no nearer to a <u>solution</u> of the problem.
Publications confined to such generalities are not, of course, discussed.

One comment regarding terminology. Both nationally and internationally, terminology concerning materials and their application is rather unclear. The Studie Centrum Wegenbouw Working Party E9 will examine this aspect separately. The present report anticipates this in one respect: the phenomenon wrongly described - both optically and linguistically - as "retroreflection" (CIE, 1970) will be described as "reflection" when this cannot cause any confusion. The same applies to the terms derived from this.

5. ANALYSIS OF THE PROBLEM

5.1. Functional requirements for markings as regards visibility

Requirements for visibility of road markings follow from the information needed for following the road and maintaining lateral position. This information is used by drivers in order to take decisions and to act upon the results of these decisions (Newsome, 1975; Taylor et al., 1971; Schreuder, 1974; Asmussen, 1972, 1973; OECD, 1972; Griep, 1971).
These decisions can be allocated to a number of levels (Schreuder, 1973, 1974; Asmussen, 1976; Blaauw, 1977).
Figure 1 shows this classification; Figure 2 elaborates it, with a subdivision of the manoeuvring level.
According to this table, following the road in bends and through discontinuities belongs to the operational level; maintenance of the lateral position to the steering level.
It has already been indicated before in general terms that lane markers are useful in both respects. A quantitative opinion on the relative importance of maintaining lateral position as compared with following the road cannot be given at present for lack of data, and for lack of an objective method of comparison. In spite of this reservation, several general studies will first be discussed.

Gullatt & Calhoun (1967) give a fairly extensive review. Remarkably, it is based on a classification of motorists into two categories: normal people who drive like they live (within the rules, with self-control and lawfully) and those who do not drive like they live. (These drivers take a hostile and uncooperative attitude behind the wheel) (Turfboer, 1967; see also McFarland et al., 1960).
Gullatt & Calhoun's study is focused on people who drive respectably; the starting point appears to be that all people are well-behaved when they are not driving. This comment is important, because no allowance is made for an extra margin for less calm drivers. This appears to be a dubious assumption; there are indications that the margin obtained by better estimation of position on the road due to markings is used to drive faster (Frybourg, 1972; Pfundt, 1968). This, though, is disputed by O'Flaherty (1972a).

In describing the visual surroundings on the road, Gullatt & Calhoun (1967) quote a number of conflicting views. According to Gordon (1966) drivers look far ahead. But according to Richards (1961), who refers to Davey (1961) and Waldram (1960, 1961), they look out for objects that are difficult to define. This difference may well be due to differences in experimental methods (Blaauw & Riemersma, 1975).
No clear reference is made to road markings. This is different in the studies by Powers & Solomon (1965), Forbes (1960) and Fryer & Henry (1964) referred to, which indicate that - especially very bright and reflecting - markings are useful in keeping attention concentrated on the road and so that it is not distracted by sources of glare. This is confirmed by Williston (1960).

Fig. 1 (Source: Asmussen, 1972)

Social activities			
Individual behaviour		Sum-total behaviour	
1.	Choice of destination and time of arrival	1.	(a) Trip generation (b) Trip distribution
2.	Choice of vehicle	2.	Modal split, i.e. division between various means of transport
3.	Choice of route and itinerary	3.	Allocation to road networks
4.	Choice of manoeuvre	4.	Traffic flow and traffic operation
Transport and traffic facilities			

Fig. 2 (Source: Schreuder, 1974)

	need leads to		
level	individual behaviour	sum-total behaviour	made of level
1 (a)	choice of trip motive	trip generation	sociological level
1 (b)	choice of destination	trip distribution	planological level
2	choice of vehicle	distribution over means of transport	transportation level
3	choice of route	distribution over road networks	strategic level
4 (a)	choice of compound manoeuvre	traffic operation (4 (a)–4 (c))	operational level
4 (b)	choice of elementary manoeuvre		tactical level
4 (c)	choice of manoeuvre part		steering level

All in all, a weak argument for road markings. Yet markings seem to be useful in reducing nighttime accidents, according to a number of quoted studies. Musick (1960), for instance, says that on marked sections there is a reduction of 19% in nighttime accidents, and a increase of 25% in the control areas. In these areas daytime accidents increase by 19% and 25%, respectively. It was also found that where there were markings, 34% of the accidents occured at night, but 44% in the control area.

Womack (1966) shows that with raised pavements markers there are 27% fewer accidents and 61% fewer accidents with casualties than on a comparable section with ordinary markings. Presumably the noise of driving over raised markers plays a part in this. These figures can be compared with the reduction in accidents for a year after applying reflecting lines (Anon, 1976). For single-vehicle accidents this was 70% and for nighttime accidents 57%. In a more recent study (Charnock & Chessel, 1978) different figures are given, and in this case cover a two-year period. They are 50% and 37% respectively.
The fairly old study by Gullatt & Calhoun (1967) has been discussed here in detail because little is to be found on this subject in a number of other studies where such discussions would be expected (e.g. Rumar & Öst, 1975; Tooke & Hurst, 1975). Other well-known, more general studies on visibility in traffic say hardly anything about this subject. Allen (1970) devotes 18 lines to road markings, Naatanen & Summala (1976) do not mention road markings at all. Böcher (1975) mentions the word a time or two and that is all. Gramberg-Danielsen (1976) merely mentions the importance of markings and other "Leiteinrichtungen". Well-known traffic manuals such as Baerwald (1965), Anon (1965), Davies (1968), Anon (1971), more or less give only marking standards and designs, and even a study discussing in detail all conceivable aspects of road markings confines itself to a number of generalities as far as visibility requirements are concerned (Taylor et al., 1971). Something similar applies to the, otherwise very interesting study by Serres (1975).
Finally, it must be added that many studies discussing signals and markings do not relate to road markings (e.g. Forbes, 1969).

In various places an approach has been prompted which may give a more direct relationship between the (partial) task of driving (maintenance of lateral position) and the standards that road markings should satisfy. Blaauw (1977) broadly outlines the relationship in question, referring to Blaauw (1975) and Blaauw & Riemersma (1974). See also Louis (1977) who makes an interesting comparison between the stopping sight distances used in a number of countries. There are stopping sight distances - which are used in road design - of 80 to 100 metres.

Griep (1972) also made a similar review, with reference to ANWB (1969), Crawford (1963) and Korte (1963). This shows that a long visibility distance (200 to 1000 metres) is needed for overtaking, and hence for marking a no-overtaking section too. For the present study, which is limited to motorways, this is of minor importance, but must be taken into account should the study be extended to markers on two-lane roads. Of great importance is the recent - not yet officially published - study by Allen et al. (1977). Annex I gives part of the Summary and of the conclusions. However this study is particularly important if a more detailed, fundamental study on road markings should be considered.

Also of importance is the study by Macdonald & Hoffmann (1972). Letters 3 metres in size proved to be visible 80 metres away, and letters 1.5 metres about 60 metres away. Whole words, of course, a short distance away, but this is not very important to the present study. In this context, the study by McLean & Hoffmann (1972) is important for two reasons. Firstly, a direct relationship is established between the practical question of lane width on the one hand and the theory of vehicle steering on the other. Reference is made to the studies by Rashevsky (1968, 1970), Leong (1968), McLean & Hoffmann (1971), and those by McRuer & Krendel (1957), Weir & McRuer (1968), Weir & Wojcik (1971). Another important finding by McLean & Hoffmann (1972) is that at high speed in a narrow lane not the heading angle but the direct control of lateral error is the steering input. This suggests that especially at high speeds and relatively narrow lanes, lane markers are very important - on motorways!

A major shortcoming in McLean & Hoffmann (1972) is that the carriageway was always indicated by white marker <u>dots</u> 20 feet apart. Laboratory experiments discussed by Riemersma (1978) show that lane markers are at least as important to perception of course angle (variations) as to lateral position observation, and furthermore that McLean & Hoffmann's conclusions probably cannot be transferred to a normally lined road.

The general requirement has been made above that it is sufficient for road markings to be visible from several tens of metres. Direct observations indicate that lateral position maintenance presents no problems if four to five strips of lane marker are visible at the same time - even at customary motorway speeds. These general observations are largely confirmed by theoretical research (Blaauw, 1975; Blaauw & Riemersma, 1974; Mulder, 1970; Griep, 1971, 1972; Schreuder, 1974, 1977, 1977a) and measurements made in practice (Allen & McRuer, 1977; Bhise et al., 1975; Rockwell et al., 1970).

5.2. <u>Foveal and peripheral perception</u>

<u>Foveal</u> perception can be described as visual observation in which the part of the outside world of interest to the subject is depicted on the fovea - the central part of the retina. If the outside world is depicted on the periphery, one speaks of <u>peripheral</u> perception. In foveal perception, sharpness of vision and colour discrimination are high; in peripheral perception mainly movements are readily recognised.

It is not clear whether perception of lane markers is a matter of foveal or peripheral observation. Cohen & Studach (1977) conclude from their research that "there is a mutual interaction between the pattern of eye movements and the path of driving, whereby visually marked strips play an important role in directing visual attention". In support of this statement, they quote Bhise & Rockwell (1971), Festinger (1971), Schiolborg (1969), Yarbus (1967), Mackworth & Morandi (1967), Antes (1974) and Cohen (1976). This contrasts with the views, among others, of Davey (1961) and Waldram (1960, 1961) that the importance of the periphery must not be underrated. As already indicated, the study by Gullatt & Calhoun (1967) from which the above is taken contains a number of contradictions in this respect.

Lastly, we would mention a number of studies which, though they do not go into much detail themselves, are interesting because they make suggestions for tackling the problems of setting standards for road-marking visibility. O'Flaherty (1972) gives an overall model regarding visual perception in traffic, with reference to Biggs (1966) and Danielson (1957). He also says that markings, besides being useful for classifying roads and routing, see als Griep (1972), are of particular importance in maintaining lateral position, here again referring to Biggs (1966), Waldram (1960a) and Gordon (1966), and to a less extent for estimating speed (Denton, 1966, 1967). A summary of the results is given in O'Flaherty, 1972a.
Smith (1975) also gives a similar review, but in more general terms. A description of the visual input is given in Alexander & Lunenfeld (1975). Lastly, Grieser et al. (1972) may be mentioned. They briefly describe a number of methods with which attempts have been made to improve the poor visibility of wet markings; the statement, of importance to out subject, that 'visibility from 75 to 90 feet ahead is satisfactory for night driving' (ibid. p.48) is taken unclearly from Rockwell et al. (1970).

It can be concluded from the above that the available literature gives a number of useful starting points for further study, but that the elementary question of the distance from which a lane marker must be visible is not answered.
But no indications can be found to make us reject completely the very rough assumption, which is barely supported by objective facts, of 'visibility from a distance of several tens of metres'. We will therefore continue to make use of this assumption.

5.3. Visibility of markings

Another question is how to define the visibility of road markings, how to safeguard it, and why it is often very greatly lessened during rainfall.

The first part of the question is usually answered by stating that there must be sufficient contrast in colour and/or luminance between the road markings and the part of the road immediately around them. Having regard to the materials suitable for road surfaces and markings, and the type of lighting used in nighttime traffic, it proves sufficient in practically all cases to take account of the luminance difference and disregard the colour difference - even with coloured (yellow) markings (Schreuder, 1977a). It is often wrongly stated that the reason for this is that colours cannot be distinguished by nighttime (scotopic) vision.
This is not incorrect in general terms; but this effect hardly exists with the luminances occurring on roads at nighttime, even without road ligthing. Both with road lighting (Westermann, 1967; De Grijs, 1972) and car ligthing (SWOV, 1969) luminance is usually greater than 0.1 cd/m^2. And at 0.1 cd/m^2 there is still only a slight divergence from daylight (photopic) vision; see Schreuder (1975), who quotes the studies by Cakir & Krochmann (1971), Cornsweet (1970), Kokoschka (1971), Wald & Brown (1965) and Walters & Wright (1943).
In addition to the luminance difference (or the luminance contrast) visual perception is influenced by the presentation time and location in

the field of vision. In the case of lane markers, which do not appear suddenly or unexpectedly, this is of minor importance. The effect of the dimensions is another matter. A normal line 3 metres long and 10 cm wide at a distance of 60 metres (at an eye level of 1.1 metre) covers an angle of about 6' in width an 3' in height. These angles are still much greater than the least perceptible dimension, even at 0.1 cd/m^2; however, it is doubtful whether perceptibility under these conditions can be defined solely by contrast.

Much research work has been done on this subject. The best known studies are those by Aubert (1865), Simon (1899), Garten (1907) and, more recently, Crozier & Holway (1939), Blackwell (1946), Lamar et al. (1947, 1948), Biersdorf (1955). All these studies, and many more, are quoted by Brown & Muller (1965). But no generally applicable relationship has been found.

The influence of the size of objects on visual detection has received renewed attention more recently in connection with the perceptibility of obstacles in road tunnels.
Schreuder (1964) showed that an object with a side of 28' may have about 20% less contrast than an object of 7' for equal perceptibility.
Blackwell (1955) - in somewhat different experimental conditions - gives a rather higher value, viz. a shift in contrast of 60%. Similar measurements have since been made by Narisada (1972, 1973, 1977) and Narisada & Yoshimura (1977) and Narisada & Yoshikawa (1974).
It is invariably found that the dimensions cannot be disregarded, even with somewhat bigger objects. The change from 28' to 7', according to Schreuder (1964), necessitates a luminance increase of about 40%, and not of four times as would be necessary if $L \times \sqrt{A} = C$ ("Piper's Law").

These considerations apply to ordinary horizontal lines.
Raised pavement markers are usually much smaller. Corner-cube reflectors (studs) usually have dimensions (in vertical projection) of about 1 x 5 cm, i.e. an angular dimension of 0.7' by 3'. Cats' eyes are smaller still; their diameter is usually about 1 cm, corresponding to 0.7' (OECD, 1975; Frédéric, 1972, 1975). Also with photopic vision these dimensions are on the boundary of visual acuity, which is limited by the diffraction images at the pupil on the one hand and the image errors in the eye on the other. These two effects roughly balance each other; with a pupil diameter between 2.5 mm and 5 mm visual acuity changes little (Riggs, 1965, who quotes Lister, 1843; Byram, 1944; Cobb, 1915; and Leibowitz, 1952). This visual acuity is then approximately between 1.3 an 2; this corresponds to angles of approx. 0.8' and 0.5'. Schreuder (1975), quoting De Waart (1946), states that for a 9 mm pupil, a punctiform light source and (monochromatic) light of 400 nm, the diffusion circle on the retina corresponds to an angle of 0.7', for 500 nm to 0.85' and for 700 nm to 1.2'. For this purpose, the data of De Waart, who gives the diameter of the diffusion circle on the retina, were combined with the eye dimensions given by Hollwich (1976, p.2); see also Fry (1965). The diffusion circle is not, therefore, negligible, and there is pronounced colour dependence. This can also be inferred from the findings Schreuder (1975) quotes from Le Grand (1956), i.e. Wald & Griffin (1947), Ivanoff (no year), Moon (1961); see also Bouma (1965).

In short: ordinary road-marking lines can be defined (but not yet very precisely) in terms of luminance contrast. Cats' eyes come within Ricco's Law, i.e. they can be defined in terms of light intensity, or: they can be regarded as punctiform - their dimensions can be disregarded. As to dimensions, corner-cube raised markers are in between; but the most sensible way seems to be to include them under Ricco's Law in the present study, for in rain and splashing water the light diffusion is probably greater than in dry weather.

5.4. Reflection characteristics of marking materials

The contrast between part of a road marking and the part of the road adjacent to it is purely a question of differences in reflection characteristics between the two. At distances relevant to observation of road markings, a few centrimetres difference in location can be neglected when considering the direction of light incidence and of observation.
Very much has been published about the reflective properties of dry road surfaces. A survey is given in Schreuder (1967, 1967a); recent developments are given in Burghout (1977, 1977a, 1978).
Much less has been published on reflection of wet roads (Sørensen & Nielsen, 1974; Frederiksen & Gudum, 1972; Kebschull, 1968; see also Jackett & Fischer, 1975), but reflection can also be defined quite well for wet roads.
Much less is known about road markings, however. Schreuder (1965) made a number of reflection measurements with various materials; but they were new, clean and dry. It was found that in order to prevent the occurrence of regions where the contrast vanishes (i.e. where the white marking and the black road have the same luminance) the marking and the background - i.e. the road - must as nearly as possible have the same texture. This condition is probably quite unfavourable for wet surfaces. It is also found that reflection by white markers - for example bonded sheets - is a multiple of that of black sheets of the same material, and also greater than of a normal road surface. Bonded beaded sheets have much greater luminance when illuminated at night by car headlamps than the same strips unbeaded; see further para. 6.2. Systematic measurements of reflection characteristics of wet markers are scarce. The study by Fosberg & Lavemark (1970), quoted by Rumar & Öst (1975), indicates that reflection can decrease by 75% in the wet state.
Reflection by reflectorised raised pavement markers when illuminated by car headlamps is very much greater than that of horizontal markers. There seems no point here in investigating the contrast between reflector and background. Firstly, because this contrast is too great, owing to the high reflection, to be used as a criterion of perceptibility, and secondly because, owing to the usually very small dimensions of the reflectors, not the luminance but the light intensity is the criterion of perceptibility.
Lastly, it should be indicated why road markings are often poorly visible, especially when the road surface is wet. This applies more particularly to normal horizontal markers (painted lines, bonded sheets and so on). The problem occurs in all lighting conditions, i.e. in daylight, dusk, road lighting, illumination by car headlamps, but the inconvenience is greatest with the last-mentioned type of illumination.

It is questionable whether this fact is due to reflection (or the decrease in this); it is possible that the marker, being invisible in the light from car headlamps, causes more inconvenience because - especially when the road is wet - hardly any further visual support is left to maintain the course.

As already stated, visibility depends on the difference in reflection characteristics as between the marker and the adjacent road. As shown by the measurements of Schreuder (1965), already quoted, this difference may be very considerable in dry conditions. If the road - and the marker - get wet and consequently are covered with a film of water, two things happen: firstly the light is no longer reflected by the surface of the road or marking but the water film, since observation takes place at a very low angle, of about 1° at a distance of 60 metres and eye level of 1.1 metre.
Reflection by the water film makes any differences in colour - or in whiteness - between marking and road surface invisible. All that remains is a difference in texture. If this difference is great, the marking does indeed remain reasonably visible even on a wet road. This fact has been made use of in the corrugated stripes discussed later. But to guarantee good visibility in diffuse light on a dry road surface the difference between marker and surface should be slight! Secondly, minor differences in texture are blurred by the water layer, especially with surfaces with little drainage capacity and a small texture depth.

Beading the marker, which can make such a big difference in its visibility on a dry surface illuminated by car headlamps, hardly helps, if at all, when the surface is wet: in this case, there is hardly any difference between beaded and unbeaded markers, and both are practically invisible. The reason for this again lies in the water film. On a dry surface, the light from car headlamps can penetrate into the almost vertical front surfaces of the beads; after refraction and diffusion, much of the light is reflected back in the direction it came from: 'retro-reflection'.
If there is a film of water on the road, the corners next to the vertical front surfaces are filled up, and the light is reflected without penetrating into the beads. Hence there is no refraction, and the light is not cast back in de direction it came from. This makes it clear why very large beads (about 1 cm) are less affected by rain.
The phenomena dealt with briefly here are described in greater detail in OECD (1975), which devotes an entire Annex to this subject; see also Dray (1977), Rumar & Öst (1974), Frédéric (1972) who quotes Reid & Tyler (1969), Reid et al. (1962), James & Hayward (1960) and Dale (1967).
Further information on the optics of retro-reflecting materials can be found in Eckhardt (1971), Vandange (1952), James & Hayward (1960), Dutruit (1974), Walsh (1965), Chandler & Reid (1958), Serres (1975), Morren et al. (1961). A calculation method for reflectors is given by Cook (1969).
These studies also show that it is not really correct to regard the well-known beaded foils as retro-reflectors.

5.5. Conclusions

The following conclusions can be stated:

- The rule of thumb that lane markers must be visible from a distance of several tens of metres can be retained.
- Both foveal an peripheral perception presumably play a part.
- Perceptibility of lines can largely be described in terms of luminance contrast between line and road surface. Colour does not matter.
- The perceptibility of raised pavement markers, when illuminated by car headlamps (i.e. after dark on unlit roads), can be described in terms of intensity of the reflected light.
- On a wet road surface light reflection is determined by the surface water film.
- On a wet road surface visibility is governed mainly by the difference in texture between road markers and road surfaces.

6. VISIBILITY OF VARIOUS MATERIALS

6.1. Inventory

The following materials are suitable for road markings (based on OECD, 1975; and Frédéric, 1972):

A. Horizontal markings

- Paint.
  evaporation of solvent
  evaporation + polymerisation
  two or more components
- Hot-applied materials (thermoplasts)
  on the road; embedded in the road
- Cold-applied materials.
- Bonded sheets.
- Other markings.
  corrugated stripes
  thin preformed marker strips
  aluminium marker strips
  surface treatment
  concrete slabs, coloured paving bricks
  coloured asphaltic concrete
  coloured cement concrete
  grooved road surfaces

NOTE 1.

Most horizontal markers can be made retro-reflective or not. Paint and thermoplastic materials applied hot can be made retro-reflective by pre-mixing the beads or by spraying them on the newly laid surface layer.

NOTE 2.

Frédéric gives a tabular review of all current horizontal markers, with the most common composition, and their various properties.

B. Raised pavement markers

- Non-reflective.
  metal
  plastic
  ceramic
- Reflective.
  beads
  small plastic lenses
  corner-cubes
  cats' eyes
  plastic lens backed with reflective foil

(NOTE The various designs are described in detail in OECD (1975)).

- Large beads (marbles) fixed in groups, as described by Dale (1970).

C. Shoulder posts and shoulder reflectors (delineators)

These play only a minor part in lane marking, and will hardly be discussed any further in this report. They are often very important for other types of markings. They are dealt with in detail in OECD (1975). A review of markings of special importance in urban areas is given by Wendt (1969).

6.2. Visibility assessment

The visibility of many of the materials listed above has been assessed. This was usually based on subjective evaluation, comparing various materials, and often in different conditions. There was a choice of three weather conditons: dry/moist/wet road surface; and five illumination conditions: daylight/road lighting/road lighting with low-beam headlamps/low-beam headlamps/high-beam headlamps. "Fog" and "glare from oncoming vehicles" are sometimes added.
Almost invariably, a selection of all these variations was tested. As stated earlier, this study is concerned primarily with moist (and/or wet) conditions and low-beam headlamp illumination (possibly combined with glare from oncoming vehicles).
The most complete study, which also contains the most directly applicable data, is that by Tooke & Hurst (1975).
Eleven materials were tested extensively on the road.
They were:
1. White paint (as a control).
2. Beaded thermoplasts.
3. As 2 - corrugated.
4. As 3, broken line.
5. Surface treatment with beaded paint.
6. Surface treatment with "Sinopal" (Reg.).
7. Raised markers, exposed bead type.
8. Corner-cube markers.
9. Cats' eye markers.
10. Raised markers, enclosed bead type.
11. Spray-applied thermoplasts.

Laboratory tests were also made with:
12. Corner-cube markers.
13. Ditto for steel base.
14. Immounted bars (enclosed sheeting).
15. Retro-reflecting foil, low intensity.
16. As 15, high intensity.
17. Road paint (as a control).

Further details and specifications are given in the mentioned report. It also contains very detailed studies of the materials in different conditions. To measure reflection on the road, use was made of photographic densitometry and telephotometry, in addition to visual assessment.

Detailed measurements were also made of strength, useful life, adhesion and so on.

The conclusions from this research of principal importance to the present study are:

- At night, in dry weather, all the systems investigated provided reasonable visibility. The synthetic white aggregate "Sinopal" was much inferior to all the others.
- At night, in wet weather, all normal lines were practically invisible. Raised markers, however, remain very clearly visible, while corrugated stripes are better, but still not visible enough.
- Among raised markers, the corner-cube type are much more visible than any of the others.
- In daytime (presumably in dry weather, though this is not stated) raised markers have very poor visibility.

The conclusions and recommendations in the report are attached as Annex II. No clear recommendation is made. But if the various conclusions are combined, the following suggestions can easily be inferred:

- From considerations of visibility in different weather and lighting conditions, the most satisfactory method is a combination of thermoplastic stripes (possibly corrugated) with corner-cube raised markers. This agrees with one of the recommendations in Anon (1965, p. 387).

Another important study is that by Taylor et al. (1971). This report discusses the entire problem of road markings in detail. The emphasis is on actual marker designs for various geometrical situations, primarily for administrative bodies. A special procedure for driver task analysis was developed for this purpose.
The research is not focused on marker visibility, nor specifically on nighttime visibility on wet roads. The general conclusions and recommendations seem important enough, however, to include them as Annex III.
The principal conclusions are:

- The greatest contribution markers make to road safety is in their wide application at places where this has not yet been done. The quality of the marker itself is then of minor importance. "Provision of any "good, standard" treatment will provide virtually all the benefits obtainable from delineation."
- The choice between variants is made on other than safety grounds. This should be based on subjective assessment.
- Raised pavement markers provide good visibility during rainfall and after dark, the most difficult conditions for reflective markers. Study was still considered necessary in 1971 for raised markers for use in areas with snowfalls (snowploughs, studded tyres). See also Section 7.

Here, too, the recommendations are not in fact very clear.
On the one hand it is suggested that improvements on every day practice are not really necessary, but on the other hand it is clearly stated that raised markers - which are not everyday things - (can) guarantee good visibility, precisely in the most difficult conditions. The comparison

made in Annex J to the report by Taylor et al. (1971) between the various materials is rather sketchy. Reference is made to a study by Rowan (1969) where a number of materials are compared during rainfall, when there are oncoming vehicles and they are illuminated by low-beam headlamps. The loss during tests with rain is roughly half the visibility distance. Rain and fog together caused a reduction in reflection of 75%, i.e. similar to the figure quoted by Rumar & Öst (1975). Yu (1969) also found that rain reduced visibility by half. Finally, the study by Taylor et al. (1971) is worth mentioning because of this very detailed, often annotated, bibliography.

The study by Gullatt & Calhoun (1967) was concerned with plans for research that was apparently never carried out. The plans - Stage I - are themselves interesting. The review of the visual information required, and the role markers may play in this, have already been mentioned. The conclusions and recommendations are appended to this report as Annex IV.

The prinicipal conclusion is that effective lane markers contribute to safety and driving comfort, especially where (reflecting or non-reflecting) raised markers are used as well. It is also proposed that visual effectiveness should be expressed as the "visibility level". This suggestion is supported with references to studies by Guth et al. (1953), Simmons (1962), Blackwell (1964) and Huber (1962). This idea is fully in keeping with modern developments. The problem is, however, that determining the "visibility level" or preferably "conspicuity level" as introduced by Schreuder (1977b), is not at present possible in practice. As emphasised at the Karlsruhe symposium in July 1977 there is neither theoretical knowledge nor measurement data, especially on more detailed analysis of driver behaviour and driver tasks. The symposium did, however, represent a clear step forward, especially by introducing the concepts of necessary and available information. In this respect, the papers by Blackwell & Blackwell (1977), Economopoulos (1977), Enzmann & Adrian (1977), Gallagher et al. (1977), Hall & Fisher (1977), Schreuder (1977b) are of particular importance.
As already stated, Frédéric (1972) and OECD (1975) include many details of various types of road-marking materials.
As regards visibility, however, all that they give is very general, commonly known findings such as "good", "moderate", and so on. These findings are based on practical experience, but not on the results of scientific research.
Rumar & Öst (1975) made a comparison between various degrees of dirtying of the same road-marking material (presumably beaded thermoplast, though this is not stated in the report). Reflection capacity is also measured. As already stated, a slight relationship was found between the visibility distance of rows of marker lines and reflection capacity. Reflection capacity also differed slightly as between dry and wet conditions. It might seem therefore that it was not measured properly, but the report does not give enough details to express an opinion about this.

Grieser et al. (1972) describe the preparatory studies for developing a retro-reflecting road marker effective especially at night on wet roads, but so low and robust that snowploughs cause no problems. The markers would have to last about eight years, just like a road surface (Chaiken, 1969). As an introduction, a number of studies are quoted which examined

the problem of nighttime visibility of markers on wet roads. Reference is made to Anon (1968, 1970) for the well-known fact that beads are very effective on dry roads, but not on wet ones. A solution is indicated by Cahoon (1970) who made grooves in the road for better drainage. The results were not very good. This agrees with the findings of Shelly et al. (1972).
The use of and good results with corner-cube markers are of course mentioned, with reference to Rooney & Shelly (1968). The drawback of damage by snowploughs is also mentioned. Mention is also made of the tests with very large beads (about 1 cm), with a reference to Dale (1967). But it is also stated that Dale (1970) found these beads are damaged by snowploughs. These comments give an incorrect picture of the interesting experiments by Dale (1970); see next paragraph. Lastly, tests are reported in which raised markers are armoured or made so cheaply that they can easily be replaced. As stated, the actual investigations are concentrated on a marker that can withstand snowploughs. Damage by snowploughs - meanwhile satisfactorily solved; see Section 7 - was apparently the only drawback of raised pavement markers!

Dale's publication (1970) is important because it describes a well-planned, thorough study of a type of road marker hitherto uncommon. Beads (marbles) about 6 mm in size are found to remain effective during rain even though they are more than half enclosed in the binder. The study relates to the dimensions, the refractive index, preparation of the beads, and also field tests.
As regards visibility, the results are described as exceptionally good. Further research is still advisable, especially into the question whether acrylic beads are strong enough. In view of the importance of the study and its results, the conclusions and recommendations for research are attached as Annex V to this report. Nothing more has been heard of this principle in recent years, however. Perhaps it was disappointing after all!.

Shelly et al. (1972) has already been mentioned. This is a study in which longitudinal grooves were made in the road with normal road paint on them (in them). The grooves are to drain the line. The results were unfavourable, as shown by the conclusions given as Annex VI. This contrasts with the study by Allison & Gurney (1975), who included corner-cube reflectors in the grooves.
These grooves must not be confused with transverse ripples in the marker itself. The 'corrugated reflex line' is an improvement on normal thermoplastic marker materials (Jonker, 1972). The rumble effect is described as an additional advantage (De Groot, 1974; Visser, 1977). Tooke & Hurst (1975) also state that corrugated stripes are the best of all lines tested. Still on wet roads they are far less visible than raised markers.

Schram (1968) describes experiments with which lines of road paint can be tested in practice. A method for using subjective assessments of nighttime visibility is indicated. The determination of nighttime visibility, and hence the results of assessment described in the article, however, relate to dry conditions only.

The advantages of beads as such are known. References have already been made in several places to literature on this subject. Two more or less special applications may also be mentioned: Fiorentini (1972) describes beads specially treated so that they are less affected by water, and Fisher (1974) describes the addition of "flotation beads" specially for yellow markers.

Lastly, reference may be made to the contributions by Stigre (1977) and Hoebanx (1977) to the OECD Group on "Improving road safety at night", especially as regards the uses of markers in various countries.

Another problem is the skidding resistance of markers. Many horizontal markers have a fairly low resistance, particularly when worn, and especially the cold-hardening materials; see OECD (1975). Many countries therefore have standards or directives for skidding resistance; see Section 8. In this context, the potential danger to motorcyclists riding over raised pavement markers should be mentioned. The literature says nothing about this; even the official accident statistics give no decisive information. The study by Blaauw & Godthelp (1978) mentioned by Blaauw (1977) suggests that this is not a major problem. Further study is considered necessary, however, and is in course of preparation.

This section closes with a brief enumeration of a number of alternative - perhaps attractive - methods of lane marking, about which too little is known, for more detailed discussion.
Vedam & Shuler (1975) describe tests with hemispherical beads, without otherwise stating exactly how they work. They are expected to continue functioning as retro-reflectors on wet roads. The degree to which beads of various dimensions can stand up to traffic and snowploughs was investigated.
Hopkins & Marshall (1974) describe a number of possible versions of self-luminous road markers, using bio-luminescence and chemo-luminescence. This development is obviously still in its initial stages.
Lake & Tyler (1967) describe a road delineation system using reflective concrete slabs. High nighttime visibility, even in rain, is reported; see also Anon (1965). This was apparently not a great success.
A number of variants on embedded markers are described by Graves (1973). He also describes a number of detail improvements for painted lines. The study relates mainly to roads where snowploughs are used.

6.3. Conclusions

- Of all the possible variants in materials, and in weather and lighting conditions, few have been investigated experimentally.
- Although most authors express themselves cautiously, the general conclusion seems to be justified that from the viewpoint of nighttime visibility on wet roads, by far the greatest preference is for corner-cube surface reflectors; cats' eyes also work well. Well after these come other types of retro-reflecting raised markers; then corrigated stripes and after these horizontal markers. In daytime, the order is just about the reverse. The optimum would therefore seem to be a combination of corner-cube markers and corrigated or flat thermoplastic marker materials.

The drawback that raised markers may be damaged by snowploughs does not seem insuperable in The Netherlands. Also the drawback that raised markers may be dangerous to motorcyclists is not as great as it seems, especially if they can be used - as in a combination - a good distance, say several metres, apart.

- Markers with large beads (marbles) have interesting properties. Further study is advisable, especially as regards their quality as compared with other marking materials.
- No advanced measuring methods are available for the visual effectiveness of markers. For the time being it would seem advisable to continue using subjective, visual assessment on the road, preferably under traffic conditions. Only Blaauw (1977) makes a suggestion for objective measurement, but this still has to be elaborated. Photometric measurements produce useful information regarding reflecting properties, but not always regarding visual effectiveness. A contour measuring method (Anon, 1975c) does not seem very useful (Blaauw, 1977; Blaauw & Riemersma, 1974).

7. OTHER CHARACTERISTICS OF MARKING MATERIALS

The present literature study concerns nighttime visibility of lane markers on wet, unlit roads. In studying the literature on this subject, other characteristics were obviously noted as well. Although they are not strictly within the range of this study, a number of interesting items of information are enumerated here. The idea is that they may be useful for another part of the programme of SCW Working party E9. As there has been no systematic research on other subjects besides visibility, the following section is in no way complete. It is better to regard it as a collection of marginal notes come across by chance. They relate to skidding resistance, fixing and cost.

The skidding resistance of road markings is described in connection with the relevant test specifications (see, for instance, Schram & Clee, 1971; Hiersche 1970, 1972).
An extensive series of skidding resistance measurements of marker materials ('Dickschichtmarkierungen') is described by Hiersche (1970). Two conclusions from the study will be mentioned. Firstly: thermoplastic material has about the same resistance as the road surface; cold applied material has less, and foil less still. Secondly, no correlation can be demonstrated between skidding resistance and other quality criteria (daytime and nighttime visibility, durability).

Fixing marker materials on the road has been the subject of much research. Adhesion may be a problem, especially with raised pavement markers which are so good as regards nighttime visibility on wet roads. This is particularly the case in countries or regions with heavy snowfalls, especially when snow is normally cleared with snowploughs. As stated above, the consideration that raised markers may be damaged or even ripped out by snowploughs was the reason for seeking alternative forms of road markers. Some of these seemed very promising (Grieser et al., 1972), but others proves unsatisfactory (Shelly et al., 1972).
But it is also possible to adapt snowploughs, for instance by fitting rubber edges on the blades. Anderson (1971) says this is an effective solution except when the temperature is constantly below freezing point. This result is based on wide experience gained in the State of Washington, U.S.A., with its frequent snowfalls. Reference is made to Stackhouse (1967), Anon (1969b) and Cody (1967) giving further details of the study. According to McNaught & Capelli (1975) even steel blades can be used if certain precautions are taken.

In The Netherlands, using salt is kept to a minimum; this means that in the future snowploughs will be used more frequently than in the past. In experiments on National Highway A 12 in December 1976 to January 1977, experience was gained in using hot air snowploughs, travelling at about 50 km/h. These are expected to replace every other kind of snowplough very soon. The blade is made of a special plastic which can follow all the unevennesses in the road surface, even at speeds up to 50 or 60 km/h. The conclusion is that 'snowplough operations have had no significant adverse effect on raised pavement markers' (Hogervorst & Clee, 1977, pp. 3-4; see also Anon, 1978a).

Gullatt & Calhoun (1967) say that fixing markers needs no longer be a serious problem if they are secured with epoxy resin. It is stated that mechanisation can greatly reduce the high cost (in 1967 about $ 0.50 per button, chiefly labour).
According to Holman (1971), markers with drop-on beads are more visible at night but have a shorter life than reflectorised paint.
In Louisiana - a subtropical region - raised markers only came off through variations in the road surface. The reflection of the markings dropped immediately after fixing to about half the figure when new (Calhoun, 1970).

As to the cost of suitable markings and marking materials little can be said on the whole. Dutch data quickly become out of date, and it is impracticable to apply other countries' figures to The Netherlands. Only a few remarks follow below.
Griep (1972) reports several factors of importance for cost/effectiveness comparisons. As to cost, reference is made to the studies by Taylor et al. (1971), James & Reid (1969), Dale (1970) an Frédéric (1972). As to effectiveness, reference is made to O'Flaherty (1972) as regards accidents and to Mulder (1970) as regards course maintenance; but there are no quantitative data.
Jobson (1976) gives the cost of raised pavement markers. Big differences are stated for different types and for different countries. The cost ranges from $0.50 to $6. Reference is made to Cillie & Nicoll (1975), O'Flaherty (1972), Pigman & Agent (1974), Taylor et al. (1971), Taylor (1974).
A comparison of material costs specifically relating to use in urban areas is given by Wendt (1969).
Flanikin (1975) and Azar & Lacinak (1975) give data on the better cost/effectiveness of thermoplast as compared with road paint.

8. STANDARDS AND SPECIFICATIONS

Most countries have standards for fitting and designing road markings, and most also have specifications for the materials. This section deals with a number of these standards and specifications, especially where they are of direct importance to nighttime visibility of markings on wet roads. This section does not claim to be complete either. The principal international standards relating to road markings are those of the Vienna Convention.

Most states in the U.S.A. have their own standards, which may differ very greatly. The "Manual of uniform traffic control devices" (Anon, 1971) attempts to achieve greater uniformity in these standards. The part on road markings relates almost exclusively to design (dimensions, colour, and so on) of markings for specific locations. The data, in fact, are very much like those given by Baerwald (ed.) (1965).
Australia apparently has only a general standard: "Rules for the design, location, erection and use of road traffic signs and signals" (Anon, 1960), as quoted by MacDonald & Hoffmann (1972). There may have been some changes since this was published.
British practice is given in Anon (1965a). Davies (1968, p.187) refers to this as follows: "Comprehensive descriptions of the approved signs and markings are contained in the Traffic Signs Manual". British markings are reviewed by Kennard (1969). Here again, the present position is not known.

A general review of a number of national standards and EEC proposals is given by Griep (1972; see also Stieg, 1972) who is particularly opposed to the use of yellow markings, but also makes suggestions for an alternative geometry. O'Flaherty (1972, 1972a), too, gives extensive reviews of the standards and specifications in various European countries; see also Stigre (1977), Hoebanx (1977) and especially OECD (1975).

Anon (1965) also includes a review of the most important standards in Great Britain. Of greater importance, however, is a suggestion for supplementing marker standards especially with a view to nighttime visibility on wet roads. Five variants are mentioned (concrete slabs with calcinated flint, surface treatment with calcinated flint, lines combined with road-surface reflectors, curbs with reflectors, curbs without reflectors). The first three were found to be quite visible on wet roads. As to the second, this clashes with the results of Tooke & Hurst (1975) and as to the third it agrees with them. See also Christie (1961) and Christie et al. (1963).

Wendt (1969) reports a number of standards for various materials. The statements are not clear however.

In 1973, a review was published in France of specifications for paint for road structures and road markings (Anon, 1973). In particular, the chemical and physical specifications for paint are described in detail. The status of the document is not clear; it resembles a draft for test specifications.

Specifications for test lines of retro-reflective road paint are given in Schram (1968). Reflection must be at least 1.5 measured with a Hunter meter (ASTM, 1964).
Quality is determined subjectively from appearance. This method was taken from an American report (Anon, no year).

Next, a number of inspections based on laboratory tests were described. The methods have since been partly overtaken by events; see for instance Schram (1975), Anon (1975a, 1975b), Anon (1976a, 1978). Schram & Clee (1971) describe a similar arrangement for testing durable materials. Measurements of skidding resistance (with Leroux's apparatus), appearance, resistance to wear, and nighttime visibility were made on the road.

Baerwald (ed.) (1965) reviews a number of testing methods used in America. Reference is made to reports where these methods are discussed in greater detail (Anon, 1960a, 1960b, 1962; Volk, 1959; see also ASTM, 1969).

In Japan, specifications for road paint have been issued by the Japanese Standardisation Institute (Anon, 1969). The requirements relate to the chemical and physical aspects of paint; visibility requirements go no further than measuring directional reflection by vertical observation and incident light at 45° (the well-known 45° - 0° measurement). For a description of this and other reflection measurements see Anon (1974).

The Bundesanstalt für Strassenwesen (BASt) in Germany has issued directives for road-marking materials (Anon, 1970a, 1972). The status of these documents is not completely clear, especially of Anon (1970a). It looks like an unofficial English summary of another document. A new version is in course of preparation (Anon, 1977a). Hiersche (1972) reviews the various regulations and the tests described there in.
The results are also given of a large series of measurements made in Germany in 1971, in which five factors were investigated:

1. Daytime visibility.
   For this, the colour point is determined and reflection by the 45° - 0° method. The measuring method is described in DIN 6171.
2. Nighttime visibility
   This is determined with the aid of measuring equipment as per Schreiber (DIN 67 520).
3. Durability in traffic conditions
   It is estimated how much of the original area of the markings still exists after a given time.
4. Layer thickness and constancy
5. Skidding resistance
   This is determined with the SRT (Skid Resistance Tester). The surface texture is also measured with Moore's flow meter.

It is striking that wet-surface visibility is not examined.

The contrast between road markings and light (concrete) road surfaces was studied by Meseberg (1977). Here again, the principal question is the minimum permissible reflection (and retro-reflection) values of marker materials when dry; and it is only stated that the luminance of both road and marker may be very slight at night on a wet road. Lists of approved products are drawn up on the basis of the experiments.

Serres (1976) describes a unit with which the reflection of retro-reflective road marking materials can be determined on the road. It is not stated whether measurements can be made on wet roads too. In view of the dimensions of the field of measurement (10 x 8 cm^2) the reflection properties of road surface reflectors apparently cannot be determined. The unit can be used in daylight; positioning and beam correspond to illumination by low-beam headlamps from a short distance (beam 86°30', observation 85°30').
A comparison was made between this unit (Ecolux) and Optronik's reflection meter. For calibration, a measuring circuit comprising a Massart-Schréder luminance meter was used. A very close correlation is found to exist between the measurement results obtained with the two units. The reproducibility of the two therefore appears to be good. Little can be said as to accuracy, because direct calibration was not possible (difference in construction of the units, which in turn differed from the calibrating assembly). Measurements relative to a white standard gave the same result for both instruments. The Ecolux unit apparently has advantages in zero setting, easy handling and other practical aspects. This measuring set up closely resembles that described by Burghout (1971). This is in fact used mainly for measuring the reflection of ordinary road surfaces. For the results of such measurements see Anon (1974); see also Serres (1975).
In this connection, and also in relation to practice in The Netherlands, the observation by Frank (1968) is interesting: "Measurement of night visibility using the Hunter Night Visibility Meter does not appear to be satisfactory, because of difficulties in maintaining calibration and in adjusting to the changing geometrical requirements for each field measurement". It is interesting to investigate whether the Ecolux unit described by Serres (1976) is better in this respect.
Frank (1968) himself proposes a photographic method with which densitometric determinations were made with projected colour slides. This does not seem very accurate, and such a method is therefore not to be recommended.

Testing marker materials on test sections is, of course, a normal procedure. Van Vechten (1974) gives a number of practical directions for such tests. An important finding is that it is difficult to determine the life of markings from the extrapolation of brief tests. An example of testing raised pavement markers in the field is given by Rushing et al. (1971). The experiments led to a test procedure for reflection, and adaptation of the specifications of raised markers.
Another example comparing various paints is given by Hnojewyj & Rheneck (1971). Something similar is described by Elkin & Balensiefer (1971), visual inspection being supplemented by photometric analysis based on photos. Suggestions for practical tests are given in Anon (1969c).

9. CONCLUSIONS

- The standards of road-marker visibility (lane delineation) cannot be determined by reference to the published literature.
- It is not readily possible, from the published literature, to indicate a type of marking material which, on the one hand, can quarantee good nighttime visibility on a wet road and, on the other, is the optimum answer to other requirements.
- From the available data a number of current types of road markings can be classified in order of decreasing nighttime visibility on wet roads. They are:
  - corner-cube raised pavement markers
  - other raised pavement markers
  - corrigates stripes
  - thermoplasts
  - painted lines
- The order sometimes differs greatly in different lighting and weather conditions.
- A good compromise might be: a combination of thermoplastic lines and corner-cube raised markers.
- The literature gives answers to other problems (adhesion, snow-ploughs, motorcyclists, water accumulation, cost).
- At present there are no generally usable, accurate, reproducible measuring methods for determining (nighttime) visibility. It is, in fact, questionable whether such a method is really necessary.
- Objective, reproducible measurement of the reflection of marking materials is possible with certain types of current photometers.

10. RECOMMENDATIONS

- Further research into the relative merits of various types of marking materials is advisable, allowing for visibility in other conditions (dry road, daylight).
- This research should cover various types of corner-cube raised pavement markers.
- It is advisable to include the use of large beads (marbles) in this research.
- The research can be carried out by making test markings on roads in normal use. Laboratory research for the development of new products does not appear necessary at present.
- In such experiments visibility can be determined on the basis of subjective assessments.
- Development of an objective measuring method for determining visibility of markers (even very small ones, for instance cats' eyes) on wet roads is necessary. It should be investigated whether normal commercial apparatus (photometers) can be used for this purpose.
- More detailed theoretical study of the function of road markings (lane markers, bends) is necessary. There are no reasons following directly from the literature study, however, which suggest that this subject should be given high priority.

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Annex I Allen et al (1977)

EXECUTIVE SUMMARY

The overall purpose of this multiphased research study was to establish visibility requirements for roadway delineation that can be used as an element in the determination of the cost-effectiveness of a variety of delineation treatments. Given the visibility requirements developed here and subsequent cost/benefit analysis, a rational approach can be taken for the development, design, and maintenance of roadway delineation.

EFFECTS OF CONTRAST AND CONFIGURATION ON DRIVER PERFORMANCE AND BEHAVIOR (VOLUME 1)

Background and Objectives

Two issues are addressed in this volume:
1. the human factors requirements for adequate delineation visibility under adverse visual conditions of night, rain, and fog; and
2. the development of functional specifications for a methodology to assess highway marking contrast. The research on the above issues documented in Volume I of this report will provide some guidance for delineation design and maintenance and quantification of driver performance and can be used in subsequent cost/benefit analysis studies.

The specific objectives addressed in this first volume are as follows:

- Develop dependent variables sensitive to roadway delineation treatments.
- Establish visibility requirements for roadway delineation.
- Determine luminance-contrast requirements for delineation.
- Develop functional specifications for a practical test methodology suitable for assessing roadway marking contrast.

Theory. A theory for delineation visibility was developed based on human visual characteristics, atmospheric visibility properties, and the photometric properties of light sources and road surface conditions. Driver visual characteristics require minimum (i.e., threshold) contrast levels for detecting delineation targets (e.g. line segments). Delineation visual range is limited under adverse visibility conditions due to increasing contrast thresholds with distance and decreasing apparent contrast due to environmental effects. Perceptual theory and past research indicate that driver's require a minimum visual range for adequate steering control, and the visibility theory developed here quantifies the manner in which various adverse visibility factors limit this visual range.

Simulation. A driving simulation experiment was conducted to establish the relationship between performance, visual range, and delineation configuration. The simulation study resulted in the derivation of a configuration visibility parameter which is able to quantify the combined effect of limited visual range and delineation configuration (i.e., line segment and gap size) on driver steering control.

Field Test. In-vehicle tests on the open highway employed an instrumented van. These tests measured driver performance capabilities in an actual driving scenario over a range of adverse visibility and delineation conditions. Driver steering performance was established as a function of road marking contrast under clear night driving conditions. Under night rain conditions the efficacy of raised pavement markers on driver performance was also demonstrated.

Conclusions and Recommendations

The simulation and field test results were compared and connected analytically through the use of the visibility theory developed earlier. A model was developed to quantify steering performance in terms of delineation contrast and configuration, and conclusions and recommendations resulting from the research and analysis were as follows.*

Combinations of reduced visibility and delineation configuration (i.e., intermittent dashed or dotted lines) tend to induce increased time delay in the driver and impair his perception of road curvature.
The above effects appear to be related to the apparent intermittent or sampled nature of delineation under reduced visibility conditions. Driver time delay increases at slower speeds, due to decreased sampling frequency, even though vehicle dynamic lags decrease with speed.

Visibility Requirements for Roadway Delineation. The driver's ability to steer his vehicle along a delineated pathway is dependent on the visual range and configuration of the delineation, vehicle speed, and road geometry. Delineation provides the visual perceptual input for driver steering control actions. Driver steering performance depends on the quality and extent of the perceptual input. Steering performance degrades with decreased visual range. Steering performance also degrades as the segment-to-gap ratio of delineation is reduced, and the cycle length is increased.

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*It should be noted that these results relate primarily to the driver's ability to laterally control his vehicle along a delineated pathway (steering control), as opposed to speed control and/or stopping which is primarily evoked by signing, signals, traffic and other obstacles on the roadway.

Under adverse visibility conditions of night and/or fog, steering performance can be improved by increasing delineation contrast to achieve a longer visual range, and by improving the quality of the delineation configuration by increasing segment-to-gap ratio and decreasing the segment cycle lenght. Adding a solid right edge lines give a rather dramatic improvement in performance under adverse visibility conditions.

Steering performance also is affected by roadway geometry. In some cases delineation visual range may be restricted simply by roadway curvature, and in these cases, combined with prevalent adverse visibility conditions, high quality delineation configuration (i.e., higher segment-to-gap ratios and shorter cycle lenghts) is indicated.

Rain effectively obscures painted delineation, and raised pavement markers which penetrate the water surface provide the only effective countermeasures.

Annex II Tooke & Hurst (1975) p. 121-129

CONCLUSIONS AND RECOMMENDATIONS

A. Summary Characterization of Delination Systems

A summary of performance data on the eleven test systems is shown in Table XIX. Pertinent conclusion which can be drawn from the complete body of test data are given below.

1. Nighttime visibility
*a. Dry conditions.*Under dry conditions, retroreflective stripings or buttons provided generally acceptable visibility levels, although Sinopal aggregate was considerably lower in retroreflectance than the other ten systems.
b. Wet conditions. Under wet conditions, no form of striping studied is satisfactory or competitive with buttons, which exhibit excellent delineation performance. With one exception, the wet night performance of all stripe delineators was about the same as or worse than Sinopal aggregate under dry conditions.
*c. Surface treatments.*Textured or corrugated surface treatments do impart some improvement in wet night visibility, but line delineators treated in this manner were still unsatisfactory.

2. Daytime visibility
*a. Button delineators.*In general, retroreflective buttons are almost invisibly under daytime conditions. Even at night, overhead lighting diminishes their effectiveness. Since the requirements of effective nighttime retroreflectance and daytime diffuse reflectance are mutually exclusive, efforts to compromise these functions on single buttons are likely to be contraproductive. The use of separate diffuse-reflecting buttons as presently practiced by GDOT appears to be a better solution if an all-button system is to be employed.
b. Line delineators. The most highly reflecting night-visible striping tends to be dull or greyish in appearance as compared with beaded lines in the daytime. With few exceptions, traffic engineers will opt for maximum night visibility as yielding the greater return in safe and comfortable driving conditions since day-time brilliance may be more cosmetic than functional.

3. Economic evaluation
As a group, buttons cost more to install and maintain than the line type delineators. The conventional painted striping is by far the most economical system to apply in the field, with the thermoplastics lying between the paint

Table XIX Summary of performance data on eleven highway delination test systems

	Dry Retroreflectance			Wet Retroreflectance			Unit Cost[1] Concrete		Dry Service Life (Units of CAE x 10^6) Concrete		Asphalt		Wet Service Life (Units of CAE x 10^{-6}) Concrete		Asphalt	
Rank	System	Type	cp/fc	System	Type	cp/fc	System	Cost	System	CAE x 10^6	System	CAE x 10^{-6}	System	CAE x 10^{-6}	System	Cae x 10^{-6}
1		Button	3.1	8	Button	3.10	1	.037	3	150	2	150	8	>300	10	>300
2	8	Button	0.38	10	Button	0.38	5	.237	4	150	4	150	10	>300	8	252
3	9	Button	0.25	9	Button	0.35	6	.309	8	87	3	67	1	200	2	200
4	7	Button	0.210	7	Button	0.061	4	.645	11	81	7	65	9	180	1	200
5	3	Plastic	0.120	5	Agg	0.38	3	.649	2	81	11	58	3	150	7	155
6	5	Agg	.090	3	Plastic	.033	2	.649	10	77	1	50	2	110	3	150
7	11	Plastic	.080	2	Plastic	.025	9	.724	1	50	8	46	7	110	9	120
8	1	Paint	.070	11	Plastic	.018	11	.750	9	27	10	21	4	53	4	30
9	2	Plastic	.055	4	Plastic	.016	7	1.111	5	10	5	10	11	42	5	10
10	4	Plastic	.038	1	Paint	.010	8	1.206	6	< 1	6	< 1	5	< 10	11	< 1
11	6	Agg	.016	6	Agg	.008	10	1.289	7	< 1	9	< 1	6	< 1	6	< 1

[1] Unit costs are given in terms of dollars per standard unit of 1 button or 3 feet of 4 inch line

and the buttons in application cost. Economic evaluation, however, cannot be restricted to application cost, since hazards resulting from nighttime visibility problems might limit the candidate systems to those having retroreflective performance levels greater than that obtainable from the line systems. For those applications, the methodology developed in Section V will have to be applied.

4. Service life

a. Button delineators. Maintenance studies have shown that the service life of button delineators is lower as a group than some of the line delineators, but is nevertheless satisfactory for most highway applications. All the button delineators retained at least 100 percent of the new wet night visibility performance for standard paint at a traffic volume > $100x10^6$ Cumulative Axle Equivalent (CAE) on both concrete and asphalt surfaces. The dry service life performance of the exposed bead type (system no. 7) and the complex lane type (system no. 9) was found to be very low on asphalt due to smudging by tire impact. One factor is not apparent from Table XIX is the loss of button units which resulted from wheel impact at highway speeds. Over the three year field test period, losses of 59 percent were recorded for the lens type buttons, while losses of 4 percent were observed for the buttons employing exposed beads.

b. Bonding and 'Shape Factor'. The loss by impact was shown to depend primarily on the adhesion bond strength and the "shape factor". The probalility of impact loss was found to be proportional to the shear component of force resulting from initial impact of the tire with the button. This factor can be reduced by lowering the button's profile or by reducing the angle of the face of the button. The three buttons with the highest adhesion strength were No. 8 (prism), No. 7 (exposed beads), and No. 10 (enclosed beads) in decreasing order. Of these three, No. 7 had the smallest "shape factor" and also, predictably, recorded the smallest number of losses due to tire impact. The remaining button system, No. 9 (lens), had a low shape factor, but also had an adhesion strength which was about a factor of ten less than that of the other three buttons. In was, therefore, not surprising that button No.9 recorded more losses due to impact than the other three.

c. Thermoplastic line delineators. The service life of the four thermoplastic lines was as a group, very high on concrete but notably lower on asphalt; however, with the exception of the Prismo system all the thermoplastic lines had a wet service life > 30×10^6 CAE on both concrete and asphalt surface for wet and dry night conditions.

d. Other line delineators. The dry service life of the conventional white, beaded traffic line paint (Ga. Spec.874.01) was high on concrete (50×10^6 CAE) and good (40×10^6 CAE) on asphalt. Under wet night conditions, the service life was 200×10^6 CAE on both surfaces. One must remember, however, that the initial retroreflectance of the button delineators is much greater than for the white traffic line paint. For example, the retroreflectance of the button delineators at the end of their service life period is about the same as the initial of the aggregate line systems was unacceptable for any surface or night visibility condition.

e. Effects of snow removal. None of the test systems were resistant to destruction by steel-tipped snowplows. In general, the lower the profile of the system, the less the snowplow damage. Thus decreasing order of damage would be buttons, hot thermoplastic, and paint. No satisfactory solution to the wet night visibility problem was found for highways requiring snowplowing.

B. *Implementation of Findings*

1. Highway planning and design

The methodology developed in Section VI for selection of delineation systems to optimize cost and performance features for a given application can be employed in planning and design for new roadways, and improvement of existing roadways. Area meteorological data, type of roadway surface, restrictions on vehicle speed, impact of frequent maintenance on traffic conditions, and special wet night visibility problems revealed by accident statistics can be factored into the selection process. In this manner a delineation system providing enhanced driver safety can be specified at the lowest possible cost for any existing or proposed highway section.

2. Specifications and acceptance criteria for delineation systems

It is recommended that the laboratory photometric range developed during this program be set up and maintained at the appropiate facility within GDOT. This range, which to our knowledge, is the only one of its kind in existence could be employed in the following manner:

a. To generate specifications to serve as guidelines in the procurement of new delination systems,
b. To perform acceptance tests on new delineation systems,
c. To evaluate and compare new delineation system designs submitted by manufacturers to existing systems, and
d. To evaluate failure modes in existing delineation systems, and to apply this analysis tot the prediction of maintenance problems to be expected in new systems employing similar design features.

For these purposes, the laboratory would not need to be fully automated as it was set up for this program's measurements. Instead, it could be operated in a simplified mode with only an x-y recorder such as Houston Omnigraphics Instrument Model HR-101 or equivalent required in addition to the photometric equipment delivered to GDOT at the termination of the measurement phase of this program. Housing requirements for the indoor photometric range could be satisfied in an adequate dark room with dimensions of about 15′ x 25′. In addition to the equipment requirements, a short period of instruction should be given by EES personnel to the technician at GDOT who would be designated as the primary operator of the range.

3. Instrumentation for maintenance evaluation

It is also recommended that the telephotometry instrumentation developed for field testing during this program be adapted for routine use by GDOT. The field telephotometers could be used for systematic roadway inspection and the development of maintenance schedules based on actual performance deterioration of delineation systems along specific sections of roadway. Data obtained during routine inspections would thus allow maintenance schedules to be developed which would optimize both driver safety and maintenance cost. The field photometric instrumentation was delivered intact along with calibration standards. This equipment could be easily installed on a GDOT vehicle with only minor modifications required. The telephotometric responses could be observed on a meter or recorded while the vehicle is in motion if a permanent record is desired. Data taken over a period of time could then be analyzed and displayed in graphical form in the same manner as the regression analysis data of Figures 29-31 and 42-49. From these data, projections of delineation system lifetime could be obtained by determining the intersection of the characteristic performance curve with a line representing 50% of the new dry response for Georgia Specification white traffic line paint (0.035) which was suggested as a performance standard in Section IV.E.5. This technique was used to determine the performance parameters which were presented in Table XVIII. Any interested engineer or technician could assemble, align, and operate this equipment with a minimum of instruction from EES personnel.

C. Follow-On Research and Development

The results of this investigation suggest that few vendors (or users) of highway delineation materials have directed consistent attention to the rational design of roadway night visibility systems. A more concentrated applied research and development effort directed explicitly at the roadway illumination problem now appears to be particularly appropiate as an important contribution to highway safety. Integration of individual concepts into a total system design is needed. Some specific recommendations follow:

1. Retroreflector unit design

We recommend that the fundamental design parameters of various retroreflectors be examined with a view towards optimizing desired characteristics. For example, it may be possible to slightly raise the axis of the 'cone of divergence' of a retroreflector to place maximum response at an optimal level. It may also be possible to 'flatten' the divergence response to gain more uniform brightness at all ranges. Plastics and glass (transparent ceramics) should be studied in the materials design aspects of the problem.

2. Illuminator design

We recommend that headlamp units be studied from the point-of-view of the specific illumination problem. For example, is the present light pattern optimum in horizontal and vertical distribution? Should headlamps be articulated to the front wheel steering angle? What advantages (or disadvantages) might result from positioning headlamps differently?

3. Systems study

The total driver-lighting-highway-retroreflector system complex requires study to establish overall optimum designs for the various conditions that must be met. In particular, the relationship of retroreflector intensity to visual noise (glare) should be established, and glare should be defined and surveyed in relation to roadway design so that design decisions for retroreflector system placement could be made on an objective basis. The system study should endeavor to develop a mathematical model that would be capable of correlating the significant variables so that both existing and novel ideas for lighting, retroreflectors and other parameters could be computed for guidance in design or development.

4. Wet night evaluation

We recommend that the 'water spray truck' concept be revised to provide 'vehicle in motion' drenching of buttons or lines with a large volume of water, so that mobile field telephotometers may dynamically measure wet night visibility without stopping.

5. Button 'Shape Factor'

We recommend that a device be designed to measure button 'shape factor'. This device is conceived as a highly instrumented 'fifth wheel' to be mounted on a highway test vehicle, and caused to impact on buttons at highway driving velocities.

Annex III Taylor et al (1971) p. 101-104

CONCLUSIONS AND SUGGESTED RESEARCH

Specific conclusions from the various study phases of this project have been summarized in Chapter Two, *Findings;* the studies themselves are included in the Appendixes. Chapter Four, *Applications,* reflects the project staff conclusions regarding the application of specific delineation treatments in the 'classical's situations. More general conclusions, based on an overview of the total project, are presented in this Chapter.

1. The literature review, the discussions with other researchers and practicing highway engineers, and the studies conducted within this project all suggest the rather modest conclusion that the major benefits derivable from delineation, in terms of accident reduction potential, can be obtained through the widespread application of the current standard treatments. Data from extensive long-term investigations (outside this project) indicate that statistically significant reductions in accident rates can be obtained through the application of delineation treatments where there were previously none - i.e., presence vs. absence of specific delineation treatments can be related to accident rates. Therefore, if accident reduction is the overriding criterion, the solution is fairly straightforward – provision of any 'good, standard' treatment will provide virtually all the benefits obtainable from delineation.

2. Major changes in delineation treatments in specific situations can produce measurable changes in intermediate effectiveness criteria. The intermediate measures include erratic maneuvers and the means and variances of various traffic performance measures, such as speeds, lateral placements, points of brake application, etc. It is hypothesized that the installation of treatments which reduce the number of erratic maneuvers and/or the variances of the traffic performance measures (indicating more uniform driving performance) will lead to a lower accident frequency. Hence, the relative effectiveness of major alternatives in delineation treatments can be evaluated through these intermediate measures. Almost certainly, however, factors other than safety will also influence the evaluation.

3. The intermediate effectiveness criteria are not sensitive enough to measure the effects of minor variants within treatments (spacings, brightness, most color codes, differences in materials, etc.). Diagnostic teams and driver surveys inherently evaluate factors other than accident reduction (e.g., driver ease and

comfort, message clarity, aesthetics). Thus, it is possible to use these techniques to determine the relative 'effectiveness' in terms of these latter factors, of minor variants in the treatments.

4. In designing and specifying delineation treatments and systems, there should be far greater concern for compliance with a few basic principles than with minor variations in the treatments.
In general, both 'far' and 'near' delineation is required. Far delineation keeps the driver appraised of changing situations; post delineators are the most common form. Near delineation, on the other hand, provides the driver with information he needs to perform adjustive maneuvers and to maintain his desired travel path; pavement markings are the most common form. Raised pavement markers, where they can be used, provide both far and near delineation in a single treatment. This advantage is being recognized, and the use of these markers is growing rapidly where there is no need for snowplowing.
Other principles that deserve consideration include the desirability of two-line vs. single-line systems, the need for minimization of clutter, the need for positive (as opposed to negative) delineation, or at least suppression of negative delineation in the presence of positive delineation, and the need for simple instrinsic codes.

5. Since minor variants in treatments do not measurably affect their effectiveness as accident reduction measures, least-cost solutions can receive more attention. More expensive variants of the treatments must be, and may well be, justified on other bases.

6. Reliance has been and will (and should) remain on subjective evaluation methods, as the accident reduction potential is nearly the same for all treatments in the same class and the non-accident factors are subjective by nature. The lack of a valid, reliable, and data-feasible cost-effective methodology is a further constraint on objective evaluation. Cost-effectiveness techniques can be used as aids in the decision-making process, but it will be difficult to arrive at convincing benefit/cost ratios if only direct 'hard' benefits are included. In general it will be better to use an approach similar to that outlined in Guideline Form III in Chapter Two than to attempt to assign dollar values to the various indirect, intangible benefits.

7. The establishment of a Delineation Task Force, similar to the one in California, is likely to be the single 'best move' by any state highway department in the field of delineation. This Task Force is essentially a diagnostic team, and the advantages and limitations of this approach are outlined in Appendix T.
It is important that this Task Force should include traffic engineering personnel from the divisions as well as the central office. The maintenance, materials testing, and design departments should also be presented. As the functioning of this group is dependent on subjective opinions, it is essential that independent ratings and opinions be obtained, and that no single 'strong' person controlled the group. Structured judgmental decisions, such as those outlined in the Guideline Forms of Chapter Two, are the preferred method, rather than a round-table discussion.

This group should meet at regular intervals, and be continuing in nature. This will permit evaluation of large numbers of diverse test installations and, perhaps most important of all, provide the impetus for continuing study of delineation problems within the state.

8. The major problems in implementing the findings, applications, and recommendations of this report, and in the general improvement of delineation practices are:

- The lack of clear-cut cost effectiveness arguments. Considerable reliance must be placed on subjective evaluations of indirect benefits.
- Institutional constraints. In most states, the districts are relatively independent and may set their own priorities. The authority for design, installation, and maintenance of delineation treatments and systems may be devided among several persons within the agency.

Suggested Research

Research directed toward the evaluation of the accident-reducing potential of minor changes in delineation treatments is not likely to be fruitful – the benefits from these changes will be 'soft' and only subjective evaluations will be possible. However continued research in the following areas is highly desirable, and meaningful advances can be expected.

1. An initial attempt at validating the relationship between intermediate measures and accident rates at horizontal curves is reported in Appendix Q. This work should be extended to other situations and other traffic performance measures.
2. A change in the broken-line patterns used for center lines and lane lines is recommended in Chapter Four, *Applications*. Support for these recommendations was derived from observation of practices of foreign countries (and discussions with traffic researchers there), and a limited amount of field studies be conducted.
3. Subjective evaluations are likely to remain major considerations in arriving at delineation decisions. Hence, studies directed toward the improvement and strengthening of subjective evaluation techniques will be worthwhile.
4. Raised pavement markers provide good visibility on 'rainy nights' – the most severe condition for reflective markings. However, the common markers cannot be used where snowplows operate and studded tires are used. Although a few commercial firms are working on this problem, a totally satisfactory snowplowable marker (cost and performance) is not yet available. Considerable effort in the development of a snowplowable marker is warranted.

In addition, where appropiate, recommendations for the extension of the individual, more specific studies within this project are included in the appropiate Appendixes.

Annex IV Gullatt & Calhoun (1967)

CONCLUSIONS

1. Various studies related to the elements of the roadway visual environment show that a highway lane marking system which is effective, day and night, in bad weather as well as good weather, is needed for added safety and convenience of the driver.

2. The use of reflective and non-reflective raised pavement markers in place of conventional painted traffic striping appears to have real merit.

3. A test program can be conducted to assess the technical and economic feasibility of using raised pavement markers for marking the lanes of highways in urban areas.

4. Raised pavement marker systems of lane marking can be compared with painted traffic stripe marking systems. These comparisons can be made on the basis of durability, effectiveness in delineation of the traffic lane, and cost. A meaningful quantitative measure of effectiveness for comparison purpose is Visibility Level.

5. Driver fatigue may be a problem that should be investigated in connection with lane marking systems involving reflectorized raised pavement markers.

RECOMMENDATIONS

1. The test outlined in this report should be conducted in order to assess the technical and economic feasibility of highway lane marking in urban areas with raised pavement markers.

2. More elaborate tests than those proposed in the test program should be conducted by qualified researchers to assess the effect of lane marking with reflectorized raised pavement markers on the safety and comfort of drivers due to driver fatigue.

Annex V Dale (1970)

CONCLUSIONS

It is concluded that:

1. The basic hardware, equipment, and procedures for applying formed-in-place, wet, reflective markers were successfully developed and field-tested.
2. Formed-in-place markers consisting of a pigmented expoxy base with 0.25-in.-diameter glass bead reflective elements were field-tested and found to perform exceptionally well in snow-free areas of the country.
3. In snowfall areas of the country, the 0.25-in.-diameter glass bead reflective elements in the formed-in-place markers were severely damaged by steel snowplow blades, studded tires, and chains.
4. The damage to the formed-in-place markers and other raised markers by snowplowing with steel blades can be overcome by the use of rubber-tipped snowplow blades.
5. The damage to the 0.25-in.-diameter glass bead reflective elements in the formed-in-place markers by studded tires and chains should be markedly reduced by the use of plastic beads.
6. The formed-in-place marker concept is a means of obtaining night-wet visibility on highways; this concept may be used alone or in conjuction with beaded paint, nonflectorized, raised markers, and thermoplastic markings.
7. More consideration should be given by authorities to balancing their investment in pavement markings to provide day and night, dry and wet visibility.
8. The low cost of the formed-in-place, wet, reflective markers is such that their use should be considered at every location.
9. The formed-in-place, wet, reflective marker concept in in its infant stage and subject to further development that should improve performance and reduce costs.

SUGGESTED RESEARCH

It is recommended that future attention be given to the following points:

1. The development of equipment and procedures for rating the retroreflective characteristics of all types of raised, reflectorized markers.
2. The development of epoxy resin systems that cure more rapidly and at lower temperatures.
3. The optimization of the use of filters, extenders, and diluents in the epoxy resin system used in the formed-in-place makers.

4. The development of 0.25-in.-diameter acrylic beads for use in the formed-in-place markers.
5. The development of reflective elements other than 0.25-in. glass beads for use in the formed-in-place raised markers.
6. The development of economic comparisons between marking materials on the basis of cost per mile per day of useful life per unit of viewing motorist. New marking materials and systems, unlike older systems, no longer have useful lives that relate directly to the traffic density.
7. The development of a field application unit for applying microwave energy to the pavement surface where formed-in-place makers as well as other types of raised markers are to be applied.

Annex VI Shelly et al (1972) p. 3

CONCLUSIONS

1. In mountainous areas, snow plowing, chain traffic, and use of salt and sand results in fast loss of paint. When the paint is intact, sans often fills the grooves and obscures the lines. Grooved stripe performance in these areas is no better than performance of a regular painted line, and is, therefore, of no significant advantage.
2. After two winters of exposure, the grooved lines in the mountain area have been abraded to the point where the original grooved configuration is about one-half its original depth.
3. At lower elevations not subject to snow removal activity, chain traffic, etc., the grooved traffic line is superior to the regular traffic paint line during nighttime wet weather conditions. This is the only advantage of the grooved stripe shown by this study, and the effectiveness in this respect is about equal to nonreflective ceramic markers.
4. The grooved traffic line and regular traffic line are about equal during day and night dry weather conditions, and during daytime wet weather. The grooved line does collect dirt which decreases the white area exposed to the motorist to some extent.
5. Increasing the depth of grooving seems to offer no advantage.
6. The use of high index of refraction beads in the traffic paint does not increase the visibility of the grooved line under any weather conditions.
7. Traffic paint applied to a grooved area does not last significantly longer than the regular traffic line. No economic advantage could be claimed for the grooved line because there was no increase in time between repaintings. Use of a paint which would not flow off the crests might show better durability than a nongrooved section.