Vehicle perceptibility

Reflectorized registration plates

and alternative means

Function, design and application

Institute for Road Safety Research SWOV

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Preface

In November 1967 the Minister of Transport and Waterways in the Netherlands asked the Institute for Road Safety Research SWOV to examine the advisable design of reflectorized registration plates from the aspect of perceptibility. Allowance had to be made for the identification of motor vehicles, especially when such plates are photographed by police and tax officials.
This report gives recommendations regarding reflection, diffuse reflection, colour, dimensions of plates and types of letters and figures. Solutions for the problem of photographing the plates are also given.
A number of requirements are not given in this report. These are of a technical nature and relate to resistance to impact, bending, vibration, corrosion and the effects of petrol, and also the requirements regarding adhesion of the reflectorizing coating and securing of the plates.

An interim report on a number of findings from the investigations was completed in May 1968. These findings were elucidated for government authorities during laboratory and road demonstrations, arranged at SWOV's request by the Institute for Perception RVO-TNO (Visuology Department), Soesterberg. The conclusions following the demonstration were:
1. On the basis of present knowledge it is possible to make recommendations for designing reflectorized registration plates.
2. Further research is required into the use of reflectorized registration plates, as compared with alternatives, for:
a. motor vehicles in groups: making them recognizable as to categories of speed, length and width;
b. individual motor vehicles: detection and estimation of differences in speed and distance.

A start has meanwhile been made with preparations for the investigations mentioned in 2.

For the purposes of research into design, KEMA (N.V. tot Keuring van Electrotechnische Materialen) Arnhem, made reflection measurements. A report on these is appended.
The Wassenaar municipal police (Mr. G. J. Boven and Mr. J. J. Flamman) co-operated in examining the possibilities of photographing reflectorized registration plates.

The report was compiled by D. J. Griep (Human Factors Department SWOV), with the co-operation of E. Thoënes (SWOV) as regards photographing of registration plates. Dr. D. A. Schreuder (Basic Research Department SWOV) gave advice on the analytical approach to the visibility distance of reflectorized registration plates.
The calculation of the legibility distance of the characters and also the recommendation of the selected character type and the dimensions of the registration plate were determined by reference to the principles indicated in the (unpublished) SWOV report on Road Traffic Signs. Literature research for this report was undertaken by Miss A. Kranenburg (SWOV).

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Director Institute for Road Safety Research SWOV

I. Summary

1. The use of character type D designed by the American Bureau of Public Roads* on the present type of registration plates in the Netherlands, gives 25% greater legibility distance after dark than the present type.
If this type D were to be used, together with the internationally recommended type face height, on registration plates with the internationally recommended dimensions, legibility distance would increase by a total of 35%.
2. The visibility distance of white reflectorized registration plates when illuminated at night is five to six times that of white enamelled plates.
3. The function of reflectorized registration plates in road safety lies primarily in the increased visibility of motor vehicles whose (rear) lamps are not lighted.
Even when the vehicle's lighting complies with the regulations, reflectorized registration plates can increase visibility. This applies for instance to the visibility of vehicles which, in an unlighted street, are only visible in the dark from their parking lights. It also applies to vehicles parked without lights in poorly lighted streets.
4. Reflectorized registration plates and alternative forms of reflectorized material applied to the rear of motor vehicles are likely to reduce the risk of head-tail collisions between moving vehicles as well.
5. As to increasing the visibility of motor vehicles, alternative forms of reflectorized material may be equal to reflectorized registration plates. The visibility distance is determined by area and reflective power rather than by shape.
6. For detecting and estimating a difference in speed compared with a car ahead (with only one rear lamp lighted), alternative means indicating the width of the vehicle are likely to be more effective.
7. Uncertainty about movement characteristics (especially speed), and about the dimensions of a vehicle ahead, can be reduced by means of information about the category to which the vehicle belongs. An important factor in this is the possibility of distinguishing between two and four-wheeled motor vehicles. Within each such category, however, there may still be big differences.
Four-wheeled vehicles could be classified by indicating the width or a right/left-side distinction (aspects that are lacking for two-wheelers). The registration plate is not one of the best means available for this.
Motor cycles and scooters could be distinguished from mopeds and cycles by—apart from rear light and reflector as at present required—either carrying or precisely *not* carrying any extra configuration in the form of a (white) reflectorized registration plate or a reflectorized (white) rear mudguard. Cycles could then be made distinguishable from other two-wheeled vehicles by a configuration—of reflectors—in the pedals (in addition to the already compulsory configuration of reflector and rear lamp).
The greatest differences within the category occur for four-wheeled vehicles. A closer distinction would therefore have to be made between them. The number of distinctive configurations suitable for this warrants further investigation. The optimum solution, even when the rear lamps are not lighted, might be obtained if the selected configurations consisted of both rear lights and reflectors.

* SWOV furnished two character types to the Netherlands Ministry of Transport and Waterways. The first is the original Bureau of Public Roads D type. The data dealt with in this report relate to this original type. The second is a type D which was made more attractive at the request of the Standardization Committee on Road Traffic Signs in the Netherlands and on the instructions of the Ministry of Transport and Waterways. This was done by Professor G.W. Ovink. This type was standardized some time ago by the Standards Institution of the Netherlands for use on traffic signs.

8. The use of reflectorized registration plates and alternative forms of reflectorized material on the front of vehicles will not notably increase their recognizability as two or four-wheeled (if one of the low-beam headlights is not burning). There will thus be no appreciable decrease in the risk of head-on collisions.
For visible distinction after dark between motor cycles and scooters on the one hand and mopeds and cycles on the other, perhaps the only possibility is a difference in headlamp colour (white and yellow).
In that case headlamp colour can no longer be used to distinguish between two-wheelers and four-wheelers—because a four-wheeler with only one lighted lamp will then be confused with a two-wheeler. But this may be solved by headlamp configuration, for instance by having four-wheelers always keep their *(separately visible)* side lights burning while their low-beam headlights are one. Luminous intensity and positioning of the side lights must be stipulated. (The first is discussed in the SWOV Report 'Side lights and low-beam headlights in built-up areas', 1969.) Even allowing for the possibility of two two-wheelers travelling side by side (for instance yellow-lighted mopeds) being confused with a (yellow-lighted) four-wheeler, it is advisable for the headlamp colour to be prescribed (in this example: white lights for four-wheelers). The risk of any such confusion will however be smaller if, among other things, the four-wheelers headlights are recognizable as a configuration.

II. Conclusions regarding design of reflectorized registration plates

II.1. Perceptibility of reflectorized registration plates

II.1.1. Legibility distance

The maximum distance from which white reflectorized registration plates with dark letters and figures are still readable is not necessarily shorter after dark than during the day. This applies when these plates are illuminated by the low-beam headlights of an approaching vehicle. This could also apply when an electric torch is shone on them, as used by the French police (Estival, 1964). In such situations the legibility distance after dark is about twice that for white enamelled plates.
If the registration plate has the internationally recommended dimensions, the maximum legibility distance is about 40 metres if the optimum type of letters and figures is chosen.

In view of the width/height ratio of the area available for the characters on such registration plates, the most suitable type for obtaining the maximum legibility distance is now one given by the American Bureau of Public Roads (type D). B.P.R. type D moreover has favourable properties in reducing irradiation of the (dark) characters by the reflectorized background. The character type now used on registration plates in the Netherlands is not as suitable as B.P.R. type D in view of the resulting legibility distance (estimated at about 25% less). (See Diagram 1.) This applies even more when the present type is used on reflectorized plates, because of the relatively strong irradiation of the (dark) characters by the light reflectorized background which is then likely.

If the internationally recommended dimensions and the optimum character type are used for registration plates about 35% more legibility distance is likely to be obtained than if the present dimensions and character type are retained on the present plates.

II.1.2. Visibility distance

The distance from which registration plates of the reflectorized design suggested above are visible is over 240 m if illuminated at the rear of a vehicle by the low-beam headlights of a following vehicle.
If the registration plate with the proposed reflective power is observed from the rear by a following driver beside the low-beam headlights of an oncoming vehicle, the visibility distance will usually be about 130 to 200 metres, depending on the distance (d) between the registration plate and the oncoming vehicle's low-beam headlights (for d = 2 and 3 metres; and 2.4 and 3.6 metres). If the registration plate with the proposed reflective power is observed on the front of the car beside a single low-beam headlight, the visibility distance will be about 60 to 130 metres depending on the distance between registration plate and low-beam headlight (50 to 90 cm).

II.2. The effect of reflectorized registration plates on road safety

Reflectorized registration plates may be assumed to have a favourable effect on road safety after dark, especially on the number of collisions with parked cars and the number of head-tail collisions. Indications of this effect, though not completely confirmed, were obtained in American research. In a number of American states such (licence) plates are permitted or compulsory.

Diagram 1. Comparison of the character type used at the present in the Netherlands on models A_1 and B_1 (I) and on models A_2 and B_2 (II) and the recommended type D with internationally recommended dimensions (III). Scale 1:2.

II.3. Possibilities of photographing reflectorized registration plates

The brightness of reflectorized material decreases strongly when the angle of observation is increased. Because of this a simple solution can be found for the problem of over-exposure when reflectorized registration plates are photographed. The Wassenaar municipal police arrived at an acceptable procedure for photographing reflectorized plates on the basis of this principle and choice of the proper photographic procedure. With this procedure non-reflectorized registration plates can also be photographed with acceptable results.

II.4. Recommendations for testing standards

This report contains recommendations for reflection, diffuse reflection and the colour co-ordinates of reflectorized materials for registration plates. Besides reflective properties and colour, efficient reflectorized registration plates must satisfy standards relating to resistance to impact, vibration, bending, corrosion, petrol, water, and to adhesion of the reflectorizing coating and to fixing on the car.

III. Discussion on application of reflectorized registration plates and alternative means

The main aspects of the perceptibility of vehicles are:
a. visibility and conspicuousness, especially in the case of stationary vehicles;
b. recognizability, especially of moving vehicles; a particularly important difference is that between two and four-wheeled vehicles and more generally the length and width, and the vehicle's speed.

III.1. The rear of vehicles

III.1.1. Present compulsory reflectors in the Netherlands

The present requirements regarding dimensions and reflective power of the prescribed reflectors were published in the Official Gazette (Nederlandse Staatscourant) of 18th May 1967, No. 94. They distinguish between the dimensions of motor vehicle reflectors and of triangles indicating the length of trailers and articulated trucks.
In order to ensure an adequate visibility distance for these reflectors and triangles approximately equal to that of a registration plate of the design recommend in this report, the reflective power would have to be greater than indicated by the present regulations (10 cd/m² per lux). A power of 100 cd/m² per lux would about double the visibility distance, even if an approaching driver were troubled by the low-beam headlights of an oncoming vehicle.
The prescribed reflectors on motor vehicles (and the triangles on trailers and articulated trucks) are intended as a means of increasing the visibility of four-wheeled motor vehicles. If only one rear light of such a vehicle is burning and if the driver approaching from the rear is dazzled by the low-beam headlights of an oncoming vehicle, there will be a difference between the right and left reflectors as regards visibility distance. At a given distance only one reflector will then be visible. There will thus be a risk of a driver approaching from behind confusing a four-wheeled vehicle with one of its rear lights not burning and a two-wheeled vehicle.
The risk of such confusion is reduced, however, the more time and opportunity the approaching driver has to adjust his direction and speed from the moment he observes not only one rear light but also a reflector located near the unlighted rear lamp (and hence can recognize the vehicle ahead as a four-wheeler). Such confusion would in fact be eliminated by using reflector configurations revealing the width or the right/left-side distinction. The same applies to the rear lights.

The requirements for dimensions and reflective power of reflectors to make them visible far enough away can be calculated.
They are based on the assumption that glare from oncoming traffic will occur primarily on two-lane roads and that such roads are not wider than 2 × 3 metres. It is also assumed that the distance between the oncoming vehicle's two low-beam headlights is 1.20 m (centre to centre), the distance between the two reflectors on the vehicle ahead is likewise 1.20 m (centre to centre) and the two vehicles are in the middle of their respective lanes. The distance between the left-hand* reflector of the vehicle ahead (seen from the approaching driver's position) and the oncoming vehicle's two low-beam headlights will then be 1.80 m (= d_1) and 3 m (= d_2) respectively. If the left reflector is visible, the right one will be visible too (as the d values of the right reflector are greater). The required visibility distance in most cases is likely to be 130 m to 240 m (see 3.2.1.1.).

* In this report right handed traffic is assumed.

It is then possible to calculate the minimum area (O) and the minimum reflective power (R) required for the (left) reflector to be visible at the required distance (D).
With the minimum reflective power at present required (10 cd/m² per lux) a dimension of 30 minutes of arc would be required when d_1 = 1.80 metres, d_2 = 3 metres and D = 240 metres.

$(R = \frac{L}{I},\ L = 0.02 \times 10 = 0.20\ cd/m^2,\ L_s \approx 10\ cd/m^2;$

Diagram 3 on page 34 (Adrian, 1965) then gives the minimum object size. This is 2.5 times greater than the present permissible maximum.

The present regulations in the Netherlands relate solely to the maximum permissible area. Motor vehicle reflectors must be described in a 200 mm diameter circle.
For this area, a visibility distance of D = 240 metres and the glare conditions referred to above, the reflective power would have to be about 100 cd/m² per lux. For D = 130 metres under these conditions, the present minimum reflective power (10 cd/m² per lux) would suffice for a reflectorized area at least as large as the present permissible maximum.
Making the minimum area as large as the present maximum (and/or increasing the reflective power to about 100 cd/m² per lux) is therefore necessary if the present compulsory rear reflectors are to be effective in reducing the risk of confusion between four-wheeled vehicles with only one rear light burning and two-wheeled motor vehicles driving along unlighted two-lane roads after dark. This applies if these are neared by a motor vehicle with low-beam headlights whose driver is dazzled by an oncoming vehicle's low-beam headlights. If the approaching driver is not dazzled by an oncoming vehicle's low-beam headlight the present minimum reflective power might suffice provided the present permissible maximum is made the compulsory minimum (formula in 3.2.1.2.).

III.1.2. Reflectorized strips

The same drawbacks apply to additional reflectorized materials on the rear of vehicles as to compulsory reflectors. There is a difference in visibility distance and hence a risk of two and four-wheeled vehicles being confused if the approaching driver is dazzled by oncoming vehicles' low-beam headlights.
Here again the risk of confusion will be lessened by using reflectorized material across the vehicle's entire width and/or configurations revealing the left/right difference.

III.1.3. Reflectorized registration plates

A reflectorized registration plate can equal the methods mentioned in III.1.1. and III.1.2. in visibility distance but *not* in detecting differences in distance and speed.
This applies on the assumption that as regards the latter perceptive process an estimate of the apparent width of the visible parts of the vehicle—the registration plate, a strip across the entire width or (the distance between) the two (configurations of) reflectors—is of some importance (the registration plate is narrow).

III.1.4. Separate arrangements for two and four-wheeled motor vehicles

In order to increase the possibilities of distinguishing between two and four-wheeled motor vehicles, especially if one of the compulsory (configuration of) four-wheeled motor vehicle's rear lamps is not lighted, the use of the same reflector configuration on four-wheeled motor vehicles might be considered. The (configuration with the) reflectorized registration plate could then be reserved entirely for two-wheeled motor vehicles (motor cycles and scooters). Two-wheeled motor vehicles moreover have few other possibilities of increasing their visibility if the rear lamp is not lighted.

The area of the registration plate of two-wheeled motor vehicles is smaller by a factor of 1.5 than that of four-wheeled vehicles. In order to retain the required visibility distance, therefore, its reflective power would have to be (about 1.5 times) higher.

It must, however, be pointed out that this solution gives no information on the perhaps equally important distinction between two-wheeled vehicles as such, especially motor cycles and scooters on the one hand and mopeds and bicycles on the other.

III.1.5. Classifying vehicles according to dimensions and movement characteristics

The necessary distinction between two and four-wheeled vehicles can be obtained by indicating the width or a left/right distinction in designing the rear lights or with reflectorized objects on four-wheeled vehicles.
Respective kinds of two-wheeled vehicles might be distinguished by using extra configurations of reflectorized objects, for instance cycles with reflectors in the pedals, mopeds (or motor cycles, scooters) with (white) reflective mudguards or registration plates. The motor cycle scooter (or moped) will then be recognizable from its rear light or reflector as at present required. Other two-wheeled vehicles from the combination of rear light, reflector and the additional (reflectorized) objects mentioned.
These measures regarding possible confusion are not enough, however. They do not provide road users with sufficient information on movement characteristics (location, speed) of individual vehicles.
The greatest individual differences occur with four-wheeled vehicles. Greater distinction is thus necessary especially in this category. Determination of the number of required distinguishing features and the suitable configurations needs further research. The optimum solution would be obtained if the configurations consisted of both rear lights and reflectors. Only in that event is a definite distinction possible, even when the rear lamps are not lighted.

III.2. The front of vehicles

If only one of the headlamps of a four-wheeled motor vehicle is lighted, an oncoming driver may confuse it with a two-wheeled vehicle. Such confusion could be reduced by observation of the registration plate or other forms of reflectorized material.
The statements in III.1 regarding glare apply even more under these conditions, because in this case the distance between the glaring light source and the object perceived (the registration plate, or strips) is shorter. The required visibility distance, however, will be greater.

III.2.1. Reflectorized registration plates and strips

To obtain the required visibility distance it would be advisable to prescribe a very high reflective power and/or a larger area for the registration plate or strips on the front of vehicles. This might, however, cause more glare for oncoming drivers. They would certainly be able to recognize the four-wheeled vehicle as such far enough away, but the means provided for them to do so might prevent them from observing the road ahead.
Material suitable for this which also satisfies the requirements of resistance to fracture etc. is not at present supplied by the industry, however (maximum reflective power ca. 55 cd/m² per lux for flat reflective sheeting).
Besides being doubtful in theory, therefore, this method is impossible in practice. An additional possibility might be to stipulate a minimum distance between headlights and the reflectorized material in order to reduce the influence of the low-beam headlight.

A uniform distance will, however, be difficult to achieve because of the different distances (wide and narrow) vehicles have between headlamps, and the differences vehicles have as regards the places where reflectorized material can be applied.

III.2.2. Reflectorized material in headlamps

There seem to be fewer possibilities of uniformity in applying reflectorized material at places still further from the headlamps, in view of the differences in car design.
At present the most suitable place is apparently the headlamp itself, but differences in distance between these continue to be a source of error. Such a solution has been advocated in the U.S.A. (Hanson and Palmquist, 1967).
Reflectorized material in the headlamps has obvious advantages compared with applying it on the outside, say around the lamps (for instance as regards wear of the coating and dirtying).
Hanson and Palmquist found that specially developed reflectorized material (no high-temperature evaporation) with a reflective power of about 70 cd/m² per lux had a visibility distance of about 140 m (when a 'single-lamped' four-wheeler [low-beam headlights] is approached by an oncoming vehicle with low-beam headlights, and the distance between lit and unlit lamps is 1.40 m).
It may be added that European vehicles often have shorter distances between their headlamps and the visibility distance will also be (much) shorter. (A rule of thumb is that a 50% shorter distance between these lamps halves the visibility distance. Ten times greater reflective power would be needed to retain the original visibility distance.)
This solution is fundamentally the most correct because the headlamp configuration is repeated by the reflectors. By having a constant distance between headlamps, and a higher reflective power of the material, the practical value of this solution would be increased for moving vehicles. But it would mean that the optical system of European headlamps would have to be changed.

III.2.3. Distinction between two and four-wheeled motor vehciles

A. Headlamp colour

A more effective way of preventing confusion between two and four-wheeled motor vehicles, in the event of a four-wheeled vehicle with only one headlamp lighted, might be to prescribe two distinctive coloured lights, for instance white for four-wheeled vehicles and yellow for two-wheeled ones. This way of diminating the confusion between two and four-wheeled vehicles, however, would also sacrifice an important, perhaps the only effective possibility of distinguishing after dark between two-wheeled vehicles as such, bicycles and mopeds on the one hand and motor cycles and scooters on the other.

B. Lamp configuration

Allowing for the possibility of distinguishing within the two-wheeled vehicle category according to headlamp colour, confusion between 'single lamped' four-wheelers and two-wheeled vehicles would have to be eliminated by other means than headlamp colour. A possibility might be to make four-wheeled vehicles recognizable not only by low-beam headlights but also by their separately visible side lights.
This solution for preventing confusion between two and four-wheeled motor vehicles (in the event of one of a four-wheeled motor vehicle's headlamps not working) will be ineffective if side lights and low-beam headlights are too close together (and the differences in intensity are too great) for the lights to be observed separately from the required distance.

Should this solution not be considered and that of differently coloured lights be reserved for eliminating the confusion between two-wheeled vehicles as such, for instance yellow for mopeds and bicycles and white for motor cycles and scooters, the possibility must be allowed for of two (side-by-side) mopeds or bicycles being confused with a yellow headlighted car. It would then be advisable to permit only yellow (or white) lights for mopeds and bicycles and only white (or yellow) lights for cars.
Such a regulation, however, would still not end the risk of confusing a four-wheeled motor vehicle with side-by-side scooters and/or motor cycles (since both categories would have the same colours of lights).
Even if the shape and design of the (2 × 2) headlamps of four-wheeled motor vehicles does satisfy the requirements, one type of confusion is not prevented: that between mopeds and bicycles, and motor cycles and scooters, which both have headlamps radiating the same (white) light.

It is thus certain that the suggested solutions are not entirely adequate. They will, however, be an improvement on the present situation as regards making a visible distinction after dark between different categories of vehicles. A distinction in headlamp configuration and colour will, of course, be ineffective for parked vehicles.
To find a solution for this, additional reflectorized material could be used, for instance white reflectorized material in the headlamps.

Research

1. The function of reflectorized registration plates

Reflectorized material reflects light in the direction from which it comes. This effect is obtained with a system of (semi-)circular or prismatic elements.
The visibility distance of the material on motor vehicles is determined not only by its area and reflective power, but also by the illumination on the material from the direction of the approaching vehicle, and by the brightness of the surroundings. As the intensity produced by the reflectorized material is less than that of the ambient light sources the visibility distance of the reflectorized material will decrease. This means that reflectorized material on motor vehicles may be especially effective on roads and in streets without public lighting. It is effective for an approaching driver only if illuminated by his vehicle's high-beam or low-beam headlights. Outside built-up areas this will usually be the case; within them not always.

1.1. Motor vehicle visibility

The present enamelled registration plates in the Netherlands* serve primarily to establish the identity of motor vehicles. The visibility of motor vehicles is known to be insufficiently guaranteed by these plates, even if the registration plate lighting is burning after dark.
After dark, on roads with inadequate street-lighting or none at all, reflectorized registration plates might improve the visibility of motor vehicles. This applies especially to motor vehicles with non-functioning lighting. Even if the vehicle's lights are working, reflectorized registration plates may contribute to vehicle visibility. This may apply to motor vehicles parked without lights in a poorly-lighted street and to those with only parking lights in unlighted streets after dark.

1.2. Recognizability of motor vehicles as two or four-wheeled

Reflectorized registration plates may improve the recognizability of motor vehicles, especially in distinguishing between two and four-wheeled vehicles. This is of major importance during overtaking. A four-wheeled motor vehicle with only one headlamp or rear lamp lighted is easily confused with a two-wheeled motor vehicle on a poorly lit or unlighted road after dark. The risk of confusion can be reduced if the approaching driver has additional indications for distinguishing between two or four-wheeled motor vehicles. Observation of a reflectorized registration plate beside the headlamp or the rear lamp might help to solve this problem.

1.3. Estimation of position, speed and distance

Visibility and recognizability of a motor vehicle still tells the approaching driver nothing about its position, distance and difference in speed compared with his own. A faulty estimate of position, speed and distance may be a cause of rear end and head-on collisions.

1.4. Identification of motor vehicles

The registration plate is indispensable for identifying motor vehicles. In the case of moving motor vehicles the distance from which the plate can be read or photographed is decisive. The use of reflectorized material will increase the legibility distance after dark when the plate is illuminated.
An increase in identification distance is primarily of importance in tracing traffic offenders.
But one is not dependent solely on a reflectorized registration plate for improving visibility and recognizability of motor vehicles and for estimating speed and distance.

* Blue plates with white characters.

2. The effect of reflectorized registration plates on accident frequency

Research in other countries indicates that reflectorized registration plates have a positive effect on road safety.

2.1. Research in the State of Maine, U.S.A.

In the State of Maine, U.S.A., reflectorized license plates have been compulsory since 1950 (See Table 1).

There are indications that in this American state the number of (fatal) collisions with parked cars after dark outside built-up areas has decreased since the introduction of reflectorized license plates. It is not known, however, whether and if so to what extent a similar decrease occurred in other states where reflectorized license plates were *not* compulsory in the same period. Furthermore, the numbers of fatal accidents and collisions with parked vehicles are too small for reliable conclusions to be drawn.

2.2. Research in the State of Minnesota, U.S.A.

Reflectorized license plates have been compulsory in the State of Minnesota, U.S.A., since 1956.

Research was carried out into the number of fatalities from head tail collisions with parked cars after dark outside built-up areas, before and after 1956. It showed a percentage decrease in the number of accidents outside built-up areas after dark.
Nor are these figures quite definite, because the number of fatal accidents increases from year to year less than the total number of accidents. The number of fatal accidents as a percentage of total accidents will therefore decrease from year to year. It is not known whether the decrease has been greater since the introduction of reflectorized license plates.

2.3. Research in Polk County, Iowa, U.S.A.

In 1959, the number of motor vehicles registered in Polk County, Iowa, U.S.A., was 99,831; 60% of these had reflectorized license plates.

Table 2 shows the number of collisions with parked motor vehicles, according to severity and vehicle involved, after dark in 1959.
Of the number of parked cars run into, 78, i.e. 24% of the total (326) had reflectorized license plates. Of the total motor vehicle population, 60% had reflectorized license plates.
It might therefore be concluded that there is comparatively less risk of parked cars with reflectorized license plates being run into after dark. This conclusion would be warranted if 60% of all cars parked after dark had reflectorized license plates and 40% did not. Whether this was so is not known.

There are indications, therefore, that reflectorized registration plates have a favourable effect on road safety. But these indications are not definite. Further accident studies may be advisable.
The same conclusion can be drawn from a recent before and after study in the State of California (Campbell and Rouse, 1968).

Annual average number of accidents outside built-up areas	Period 1945–1949	Period 1950–1963
Total	2363	6023
After dark	968	2070
With parked vehicles	142	121
After dark	87	37
Fatal after dark	39	42
With parked motor vehicles	3.8	1.6

Table 1. Number of accidents, type and severity outside built-up areas after dark, before and after 1.1.1950 in the State of Maine, U.S.A.

	Fatal	Non-fatal (including car damage only)	Total
Cars with reflectorized license plates	—	78	78
Cars without reflectorized license plates	2	246	248
Total	2	324	326

Table 2. Number of collisions after dark with parked cars, with and without reflectorized license plates in Polk County, Iowa, U.S.A., 1959.

3. Perceptibility of reflectorized registration plates

3.1. Symbol legibility

3.1.1. Conditions influencing legibility distance

The legibility characteristics of registration plate characters are affected by a number of circumstances, for instance by brightness and contrasts in brightness of the surroundings.

3.1.2. Choice of character type and typical features

A. The legibility distance of letters and figures is influenced, inter alia, by:
1. type face height;
2. type face width;
3. (average) stroke width;
4. spacing;
5. design details;
6. absolute brightness level (and colour) of the characters, of the registration plate and of the surroundings (for instance car, road surface, sky, traffic);
7. contrast in brightness (and colour) of the characters compared with that of plate;
8. contrast in brightness (and colour) of registration plate as a whole compared with that of the surroundings (for instance the car, road surface, sky, traffic).

The precise contribution to the legibility distance for each of these factors and combinations of them is not yet properly known.
It may be assumed, however—apart from brightness and colour (contrasts)—that type face height and type face width (described below as type height and (average) type width *) and stroke-width and spacing are factors of primary importance as regards legibility distance. Design details can be regarded as of secondary importance.

On this assumption character types could be characterized by their average width/height ratio and their stroke-width and spacing.

Choice of letter and numerals can thus be determined from:
a. the area available per character expressed as the average width/height ratio (x);
b. the average width/height ratio of a number of available character types (w/h);
c. the legibility distance of a number of character types, expressed as metres per cm type face height (l).

B. Thus the problem is, subject to efficiency (area required as compared with legibility distance), to indicate the use of different character types according to differences in the width/height ratio of the available area. Bearing this efficiency in mind, four character types are suitable. These are American Bureau of Public Roads types C, D, E and F.
Table 3 lists the average width/height ratio ** and the (average) legibility distance per cm type height (l). The l values apply to dark characters on a non-reflectorized light background (Kneebone, 1964).

* Type height in this context means the height of capital letters (only capitals are used on registration plates). The width (of capital letters) differs per character type for a number of groups of characters. But as all possible combinations of letters and figures may occur on registration plates, the average type width per character type has been taken as a basis for general rules for choosing the appropriate type.

** The average width/height ratio has been calculated inclusive of the spacing.

B.P.R. type	Average width/ height ratio	Average legibility distance per cm type height for dark characters on a light background
C	0.61	4.7 m
D	0.73	5.8 m
E	0.88	6.2 m
F	0.98	6.6 m

Table 3. Average width/height ratio and average legibility distance of the four B.P.R. types.

If $x \geqq (w/h)_F$ all four types could be used. In that case, however, type F would be preferable owing to its greater legibility distance. The problem, then, is to indicate transitional values for types E, D and C for the range when $x < (w/h)_F$.
Type E can be used when $(w/h)_F > x > (w/h)_E$. The available text area would not then be fully utilized, however.

In order to use the wider type F, h_F would have to satisfy:

$$h_F = \frac{x}{(w/h)_F} \cdot h_E \qquad (1)$$

The choice of F instead of E, however, only has any purpose if
$L_F > L_E$, i.e. $l_F \cdot h_F > l_E \cdot h_E$ (2)

Substitution of (1) and (2) gives:

$$l_F \cdot \frac{x}{(w/h)_F} \cdot h_E > l_E \cdot h_E$$

$$l_F \cdot \frac{x}{(w/h)_F} > l_E$$

$$x > \frac{l_E}{l_F} \cdot (w/h)_F$$

$$x > \frac{6.2}{6.6} \cdot 0.98 \rightarrow x > 0.92$$

The use of type F is therefore indicated when $x > 0.92$.

Similarly it can be calculated from $L_E > L_D$ that type E is indicated instead of type D when $x > 0.82$. Type E is therefore indicated for $0.92 \geqq x > 0.82$.

Analogous calculation gives $x > 0.59$ for using type D. This is even less than the value for $(w/h)_C$.
For $x \leqq 0.82$, therefore, type D is indicated.

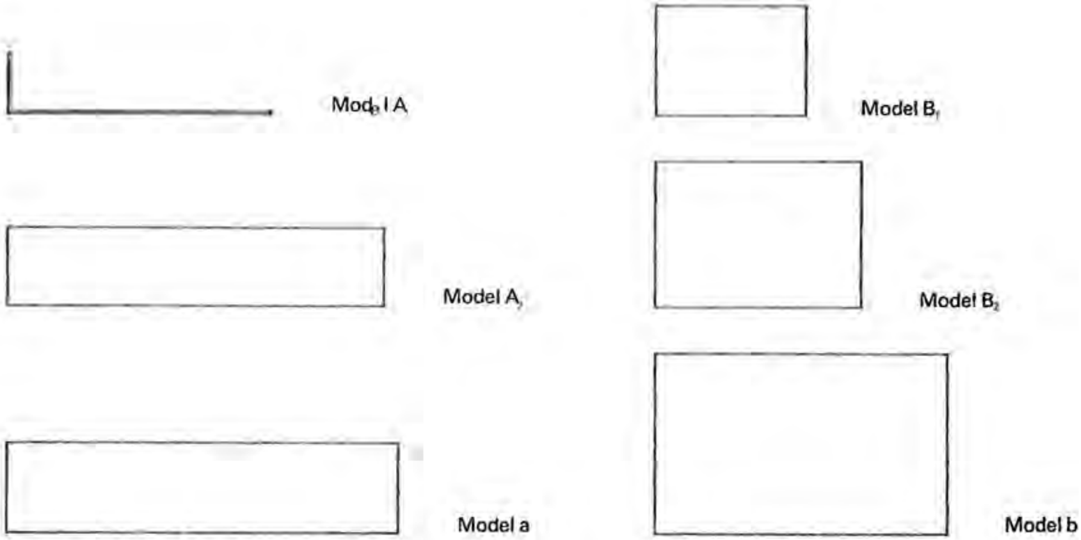


Diagram 2. Comparison of the dimensions of registration plates as determined for the Netherlands (model A_1, A_2, B_1, B_2) and as internationally recommended (models a and b). Scale 1:10

Type C should be used only with a fixed type height; the available text area is too narrow to use a different type in view of the number of characters.

Note: In order to use the various types, the value of x need not be equal to the (w/h)-value of the chosen type. This may lead to differences in calculating type height and width. To avoid difficulties in spacing, the starting point is:
type width when $x < (w/h)$-type;
type height when $x < (w/h)$-type.

C. The character type to be used on registration plates can now be determined as follows: The dimensions of registration plates are internationally recommended, (E.C.E., 1967) (See Diagram 2), as:
Model a: 520 × 120 mm
Model b: 340 × 240 mm

Model a

On *model a* registration plates a text width of 470 mm is available if the horizontal distance between the text on the plate and the edge of the plate as customary for (American) traffic signs is equal to twice the stroke-width of the character type used (2 × 2 × 1.25 – 5 cm for B.P.R. type D) *. The type face height is internationally fixed at 8 cm.
The available text area is therefore 470 × 80 mm.

Registration plates used in the Netherlands have eight symbols (six letters and/or figures and two hyphens). The average width/height ratio of the area available per symbol is $x = 0.73$. This satisfies $x \leqq 0.82$, so that B.P.R. type D is indicated. Table 4 shows the required text width and the resulting legibility distance for an eight-symbol text 8 cm high, in cases where type D or types C, E or F would be used.

B.P.R. type	Required text width	Resulting legibility distance
C	8 × 0.61 × 8 = 39 cm	8 × 4.7 = 37.6 m
D	8 × 0.73 × 8 = 46.7 cm	8 × 5.8 = 46.4 m
E	8 × 0.88 × 8 = 56.3 cm	8 × 6.2 = 49.6 m
F	8 × 0.98 × 8 = 62.7 cm	8 × 6.6 = 52.8 m

Table 4. Required text width and resulting legibility distance per B.P.R. type for registration plates of the internationally recommended dimensions (Model a).

Even if a type face height less than 8 cm should be chosen for types E and F, with a legibility distance per cm type height greater than type D (and type C), the legibility distance would be shorter. This can be seen from equations (1) and (2) in this section. (For type E a type height of 6.7 cm would result ,with a legibility distance of 41.5 m; for type F: h_F = 6 cm, L_F = 39.6 m; for type C: h_C – 9 cm, L_C = 42.3 m.)

Model b

Registration plates as per *model b* with the internationally recommended dimensions contain two lines of text.
The first (or second) line of the registration plates, used in the Netherlands, contains five symbols (four figures and one hyphen). The width/height ratio available per symbol is 0.72 This satisfies $x \leqq 0.82$, and hence type D is indicated.
The second (or first) line contains two symbols (two letters). The available width/height ratio per symbol indicates type F.
The overall legibility of the registration plate is determined by the line of symbols with the smallest (w/h)-ratio. Therefore, the same character type, i.e. D, is advisable on model b for both lines.

It should be noted that this is based on legibility distances per cm type height for datyime observation and dark characters on a light background (See Kneebone, 1964.) For observation after dark with reflectorized material such data are inadequate. Characters with the optimum legibility distance for daytime observation may, when observed after dark with reflectorized material as the background, have a shorter legibility distance (owing to relatively smaller stroke-width, greater brightness contrast and more possibility of being irradiated). For dark characters on a light (reflectorized) background this effect can be counteracted, for instance by using larger stroke-width.

With B.P.R. type D the risk of irradiation will be comparatively slight because of the characteristics which are favourable for use on a reflectorized background.

3.1.3. Dimensions, character type and legibility distance of present registration plates in the Netherlands

A. In 1950 the Standard Institution of the Netherlands laid down standard registration plate dimensions.
Standard sheets N 1147 and N 1148 give the following (see also Diagram 2):

* This value does not influence the determination of the character type. Even with a available text width of 520 mm, the character type indicated would be the same.

For two-wheeled motor vehicles with or without sidecar:
Model A_1: 350 (maximum) × 80 mm
Model B_1: 200 (maximum) × 145 mm.
The character type height laid down in these standard sheets, including lead, is 60 mm; the type width averages 31.5 mm, including spacing.

For motor with more than two wheels:
Model A_2: 500 (maximum × 105 mm)
Model B_2: 275 (maximum × 195 mm).
The character type height is 90 mm, including lead; the type width averages 47 mm, including spacing.

Not enough is known about the legibility distance per cm type height of the characters used at the present in the Netherlands. In view of the width/height and type height/stroke-width ratios of the characters at present prescribed, it might be the same as for B.P.R. type C (4.7 m per cm type height).

For the present registration plates and the prescribed characters, and based on an actual type height of 48 mm (for models A_1 and B_1), and 72 mm (for models A_2 and B_2), a legibility distance could be obtaining corresponding to that for B.P.R. type C, of 4.8 × 4.7 = 22 m and 7.2 × 4.7 = 34 m, for dark characters on a light background. This distance will not, however, be obtainable if the registration plate is reflectorized, owing to irradiation because of the smaller stroke-width of the character type used at the present (type height/stroke-width ratio 8:1).

B. If the present registration plate dimensions should be kept, with the actual prescribed type heights of 48 mm (for models A_1 and B_1) and 72 mm (for models A_2 and B_2), the appropriate character type can be determined as follows.

Models A_1 and A_2, B_1 and B_2 are specified in the standard sheets as:
Area:

A_1: 350 × 80 mm	B_1: 200 × 145 mm
A_2: 500 × 105 mm	B_2: 275 × 195 mm

Available text width:

A_1: 350—24 = 326 mm	B_1: 200—24 = 176 mm
A_2: 500—24 = 476 mm	B_2: 275—24 = 251 mm

Actual type height:
A_1 = 48 mm
A_2 = 72 mm

The area available per symbol, expressed as width/height ratio, is thus:

$$x_{A_1} = \frac{326}{8 \times 48} = 0.85 \qquad x_{B_1} = \frac{176}{5 \times 48} = 0.73 \text{ (first line)}; \quad x_{B_1}' = \frac{176}{2 \times 48} = 1.83 \text{ (second line)}$$

$$x_{A_2} = \frac{476}{8 \times 72} = 0.83 \qquad x_{B_2} = \frac{251}{5 \times 72} = 0.70 \text{ (first line)}; \quad x_{B_2}' = \frac{251}{2 \times 72} = 1.74 \text{ (second line)}$$

The appropriate character type can then be determined as:
For x_{A_1} and x_{A_2}, $0.92 \geqq x > 0.82$ is satisfied, indicating type E. But x_{A_1} and x_{A_2} are less than $(w/h)_E$ (= 0.88). The basis must then be type width and not type height.
Use of type E would then give a type height less than that prescribed. For such cases, therefore, type D is advisable.

Model	Required text width	Resulting legibility distance
A_1	8 × 0.73 × 48 = 280 mm	4.8 × 5.8 = 27.8 m
A_2	8 × 0.73 × 72 = 420 mm	7.2 × 5.8 = 41.8 m
B_1 (first line)	5 × 0.73 × 48 = 175 mm	4.8 × 5.8 = 27.8 m
(second line)	2 × 0.73 × 48 = 70 mm	4.8 × 5.8 = 27.8 m
B_2 (first line)	5 × 0.73 × 72 = 263 mm	7.2 × 5.8 = 41.8 m
(second line)	2 × 0.73 × 72 = 105 mm	7.2 × 5.8 = 41.8 m

Table 5. Required text width and resulting legibility distance of present registration plates in the Netherlands, using type D.

For x_{B_1} and x_{B_2}, $x \leq 0.82$ is satisfied, indicating type D.
For x_{B_2}, however, $x_{B_2} < (w/h)_D$, and type C should be used or, with type D, less spacing. The latter solution is preferable in this special case.

For x_{B_1}' and x_{B_2}', type F is indicated.

Since overall legibility of the registration plate is determined by the line of characters with the least (w/h)-ratio, however, type D is indicated for both lines in models B_1 and B_2.
Table 5 gives a summary.

Conclusions:

For use on registration plates in the Netherlands (whether enamelled or reflectorized), type D is suitable in view of the required and available text width.
The resulting legibility distance is 27.8 metres for models A_1 and B_1 and 41.8 metres for models A_2 and B_2. This is about 25% more than can be expected with the character type used at the present in the Netherlands.

If, in addition to the indicated B.P.R. type D, the internationally recommended type height and registration plate dimensions are chosen, the total legibility distance would increase by 35% compared with models A_2 and B_2.
For models A_1 and B_1 the increase would exceed 100%. The use of registration plates of such large dimensions for two-wheeled vehicles, however, might have drawbacks in practice.

3.1.4. Empirical legibility distances for registration plates

The legibility distance of texts on enamelled registration plates and of reflectorized registration plates was investigated by Rumar (1965) and Herrington (1960).

Rumar used a character type with a type height/stroke-width ratio of 5:1 (about equal to B.P.R. type F), and a width/height ratio of 0.6 (about the same as B.P.R. type C).
He investigated the legibility distance of dark characters (7½ cm type height) on white reflective sheeting and on a white enamelled background. The registration plates were in all cases illuminated by the low-beam headlights of an approaching vehicle, in which the observer was seated.
His findings are summarized in Table 6.

Rumar's findings agree with expectations based on reflectorized material properties. With focused illumination (by a low-beam headlight) the legibility distance of texts on reflectorized registration plates is greater than that of enamelled ones. With diffuse illumination (in daytime, and after dark by means of the registration plate lamps), no differences are found.

Conditions	Enamelled plates	Reflective sheeting	% gain on enamelled plates
Daylight	40 m	40 m	—
After dark			
License plate lighted	25 m	25 m	—
License plate lighted —illuminated by low-beam headlights	28 m	36 m	+ 30%
License plate unlighted —illuminated by low-beam headlights	19 m	36 m	+ 90%
License plate between two low-beam headlights—illuminated by low-beam headlights	13 m	33 m	+ 150%

Table 6 Legibility distances for dark texts on white enamelled plates and on white reflectorized background (Rumar, 1965).

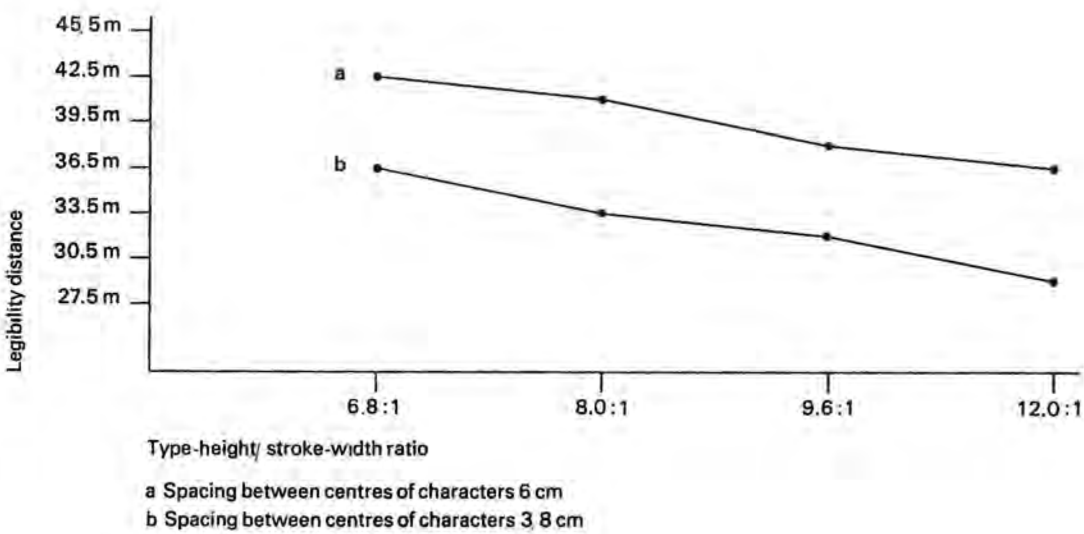


Table 7. Legibility distances for dark texts on white reflectorized background as a function of spacing and type height/stroke-width ratio (Herrington, 1960).

Herrington investigated the legibility distance with illumination with (American) low-beam headlights in unlighted surroundings with texts 7½ cm high. The character type, however, was different from that used by Rumar, i.e. B.P.R. type C.
The choice of this is indicated by the width/height ratio of American license plates. This is less than that of the internationally standardized registration plates. Herrinton varied the stroke-width and the spacing of this type. For dark (blue) characters on a white reflectorized background a type height/stroke-width ratio of 6.8:1 was used. This is almost the same as the type height/stroke-width ratio of B.P.R. type C, viz. 7:1. The spacing (between the centres of the characters) was 3.8 and 6 cm. Table 7 shows the results.

Herrington's data show that the legibility distance increases as the type height/stroke-width ratio decreases, and also as the spacing increases. Compared with B.P.R. type C, type D has relatively more stroke width and has more spacing. B.P.R. type D is therefore indicated for registration plates with the internationally recommended dimensions. In view of the width/height ratio available per symbol, however, B.P.R. type C, especially as regards stroke-width and spacing, is indicated for American license plates.

The theoretically too low value (See 3.1) found by Rumar can be explained by the character type which is comparatively unfavourable as regards irradiation. As regards type height/stroke-width ratio, this character type is equivalent to B.P.R. type C; its average width/height ratio and spacing are greater than B.P.R. type C, but less than B.P.R. type D.

It follows from the foregoing that of the character types now available, B.P.R. type D is the optimum for use on registration plates, also when these are reflectorized. This applies both to registration plates with the internationally recommended dimensions and the present plates in the Netherlands.

3.2. Visibility distance

3.2.1. Analysis

3.2.1.1. Visibility distance and braking distance

A. If the visibility distance—the maximum distance at which the registration plate is still visible—must be greater than the braking distance—the distance in which the driver can stop—a vehicle with a speed of 120 km/h must have a visibility distance of at least 240 metres. This applies with an assumed reaction time for driver and vehicle of RT = 3 secs, and a deceleration of the vehicle on wet road surfaces of a = 4 m/sec². A visibility distance of 240 m can then be regarded as a necessary minimum for reflectorized registration plates.

B. This visibility distance applies if the driver is confronted with a stationary motor vehicle in his lane. On roads outside built-up areas, however, stationary motor vehicles will be recognizable as such right away from a warning triangle. Motor vehicles travelling very slowly, however, have no special warning sign. On motorways, in the Netherlands only vehicles are permitted which can and may drive faster than 40 km/h. On the whole there are no maximum speeds on motorways in the Netherlands. Based on measurements on motorways, differences in speed of 80 km/h are no exception. With such a difference in speed and RT = 3 sec, a = 4 m/sec², the necessary braking distance is about 130 metres. This would necessitate a visibility distance of at least 130 metres.

C. Visibility of a motor vehicle, though necessary, is not sufficient for observing its movement characteristics, especially its speed. A driver approaching a stationary or moving vehicle in his own lane must detect a difference in speed. Among other things, moreover, he must estimate this difference before he can take appropriate action. Speeds (and distances), however, are usually underestimated, the more so the higher the speed is. As regards driving behaviour, such as slowing down in time for a vehicle ahead, little is yet known in terms of (the accuracy of) assessing one's own speed and position, difference in speed compared with and distance from the vehicle ahead, and the necessary deceleration. This applies particularly to the part that may be played by reflectorized registration plates. It is not possible, therefore, to lay down hard and fast rules for the required visibility distance of such plates. A reasonably acceptable estimate is that the visibility distance required for registration plates will mostly be between 130 metres upon approaching a vehicle travelling ahead and 240 metres upon approaching a stationary vehicle.

3.2.1.2. Visibility distance and reflective power

With very great contrast in luminance between object and surroundings, and a given threshhold visibility, a relation can be found as follows between visibility distance D (in metres) and reflective power R (in cd/m² per lux) of objects:

The illumination on the reflectorized area is $E = I/D^2$, when I is the luminous intensity of the light source(s) and D the distance between the light source(s) and the registration plate. Luminance L of the area is $L = R \cdot E$ when R is the reflective power. If the area of the registration plate is O, the luminous intensity of the plate is:

$$I_p = L.O = R.E.O = \frac{R.I.O}{D^2}.$$

The illumination E_o in the plane of the observer's eye is therefore:

$$E_o = \frac{I_p}{D^2} = \frac{R.I.O}{D^4}.$$

When $E_o = 2.10^{-7}$ lux (threshold value for signal lights), $I = 1200$ cd (two low-beam headlights) and $O = 0.05$ m² it follows for distance D, which is identical with visibility distance that $D = 131 \sqrt[4]{R}$.

This inference assumes:
a. that the headlamps form a point and are in line with the observer;
b. that the reflective power is independent of the luminance of the light source;
c. that the reflectorized registration plate can be considered to form a point;
d. that the threshold value of the illumination E_o is independent of lighting conditions.

A visibility distance of 240 metres would require R to be about 11.3 cd/m² per lux.

3.2.1.3. The effect of glare

The glare effect can be described as the occurrence of an extra veil in the observer's field of vision. The equivalent veiling luminance (L_v) for a single light source can be determined as

$$L_v = \frac{K \cdot E_o}{\theta^n}$$

in which:

E_0 is the illumination on the eye supplied by the glaring light source (lux),
K is related for instance to θ and the observer's age,
n is an exponent related to θ,
θ is the angle between the glaring light source and the observed object (in degrees), expressed in radians $\theta = 180/\pi \cdot d/D$, for d < D, in which d is the lateral distance between the registration plate and the glaring light source and D is the distal distance between the observer and the object.

On the assumption that glare from oncoming traffic occurs mainly on undivided roads and that such roads are often no wider than about 3 metres per lane, then if four-wheeled motor vehicles are 1.5 metres wide and are driving approximately in the middle of their lanes, the distance d_1 between the centre of the registration plate and the centre of the oncoming vehicle's right low-beam headlight (seen from the approaching driver's side in right handed traffic) will be about 2.4 metres.

The distance d_2 to the centre of the left low-beam headlight will then be about 3.6 m. For wider (oncoming) four-wheeled motor vehicles d_1 will be less and d_2 greater than the above figures. The effect of glare will then be greater owing to the greater contribution to this by the right low-beam headlight as compared with the left one, since it is closer to the registration plate that has to be observed.

The angle θ between the glaring light source (i.e. the oncoming vehicle's right low-beam headlight) and the middle of the registration plate, with a distal distance of 240 metres, is about 30'. At a distance of 130 metres θ is about 1°.
When $0.25° < \theta < 1.5°$, n = 3.5 and K = 50 ± 6; when $\theta > 1.5°$, n = 2 and K = 17.7 ± 2.6 (Hartmann and Moser, 1968).

Applied to the situation of the registration plate this gives (when D = 240 m, I = 600 cd per lamp; d_1 = 2.4 metres; d_2 = 3.6 metres) an average equivalent veiling luminance L_v:

$$L_v = L_{v_1} + L_{v_2} = \frac{50 \cdot 600}{240^2 \cdot (0.57)^{3.5}} + \frac{50 \cdot 600}{240^2 \cdot (0.86)^{3.5}} = 4.54 \text{ cd/m}^2.$$

The minimum luminance difference required between the registration plate and the surroundings can be assessed from Diagram 3 (Adrian, 1965). It must be remembered that the veil extends both over the registration plate and over the immediate surroundings. This means that luminances of registration plate and surroundings as seen by the observer are both L_v higher than the intrinsic luminance actually existing at the location of the objects. Under the described conditions the intrinsic luminance of the surroundings can be taken as nil, and therefore the luminance difference between plate and surroundings is equivalent to the registration plate's intrinsic luminance caused by the car's own low-beam headlights.
The dimension α (as an angle measurement) of the registration plate is taken as the diameter of a circle with the same area as the registration plate (about 0.05 m²). When D = 240 this gives: α = 3.5'.
It follows from Diagram 3 that the luminance difference between the registration plate and the surroundings should be at least 1 cd/m².
The illumination on the registration plate at 240 metres is about 0.02 lux.
The reflective power of the registration plate needed for a visibility distance of 240 metres, when the observer is dazzled by an oncoming vehicle's low-beam headlights 2.4 metres and 3.6 metres respectively beside the middle of the registration plate would then have to be about 1/0.02 = 50 cd/m² per lux, because the luminance of the surroundings has been taken as nil.

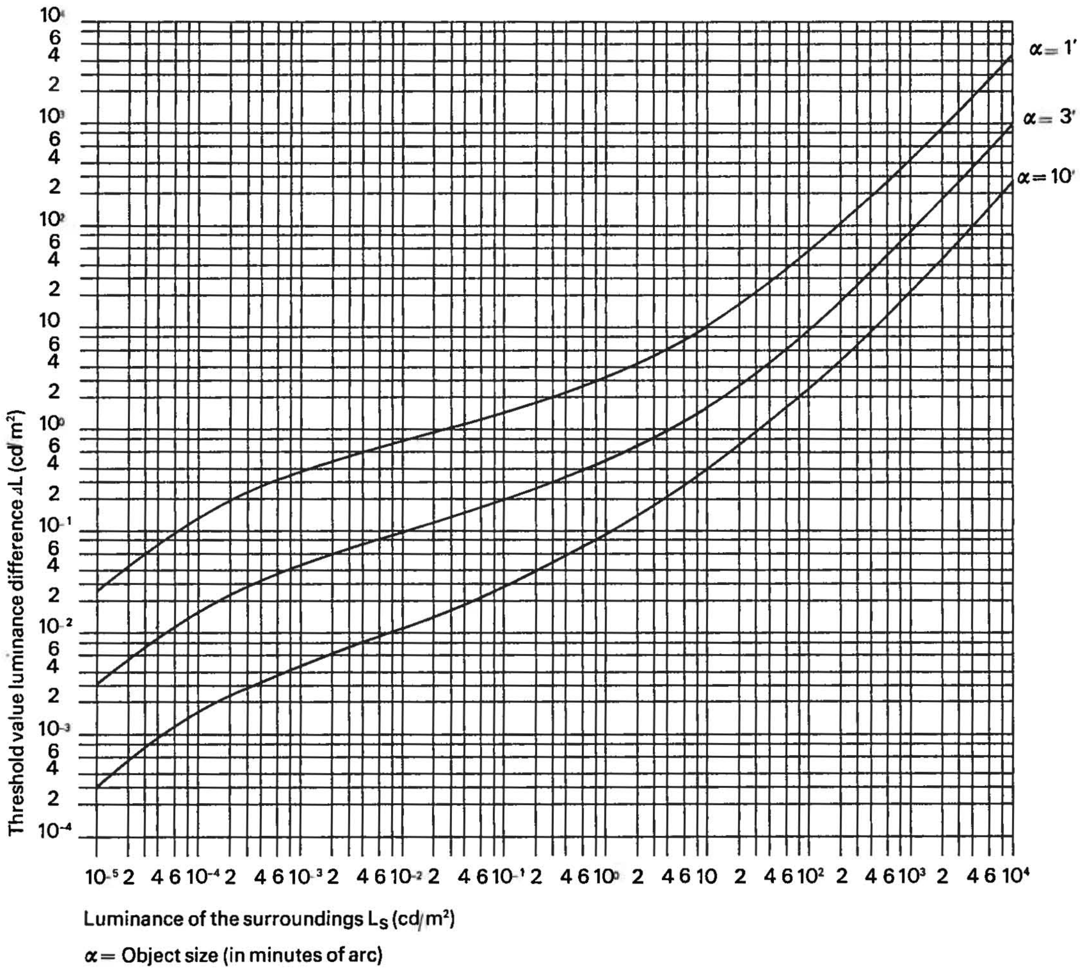


Diagram 3. Threshold value of luminance difference as a function of the luminance of the surroundings with various object sizes (Adrian, 1965).

For a visibility distance of 130 metres, the equivalent veiling luminance L_v under these conditions can be calculated at 1.91 cd/m².
When $\alpha = 6'$, $E = 0.075$ lux, then $L = 0.3$ cd/m²; and a reflective power of 0.3/0.075, or 4 cd/m² per lux.

The reflective power required for visibility is closely related to the d_1 and d_2 values. For a visibility distance of 240 metres, when $d_1 = 2$ and $d_2 = 3$, the equivalent veiling luminance L_v can be calculated at about 10 cd/m². The reflective power would then have to be about 90 cd/m² per lux.

3.2.1.4. Visibility of four-wheeled oncoming vehicles' registration plates

If the front registration plate is observed beside one lighted low-beam headlamp, the distance between (the middle of) the registration plate and (the centre of) the low-beam headlight can be about 50 cm for a narrow vehicle and about 90 cm for a wide vehicle.

A. Narrow four-wheeled motor vehicles.
If D = 240 metres, $\theta = 7'$. If $\theta < 0.25°$ no formulae are known for arriving at the equivalent veiling luminance L_v.
With Hartmann and Moser's approximation for $0.25° < \theta < 1.5°$ no more than a rough estimate will be obtainable of the required reflective power.

$$L_v = \frac{50 \cdot 600}{240^2 \cdot (0.12)^{3.5}} = 866 \text{ cd/m}^2 \text{ per lux.}$$

If $\alpha = 3.5'$, $\Delta L = 60$ cd/m².

$E_{240\,m} = 0.02$ lux.

$$R = \frac{60}{0.02} = 3000 \text{ cd/m}^2 \text{ per lux.}$$

If D = 130 metres, the equivalent veiling luminance $L_v = 256$ cd/m².
If $\alpha = 6'$, ΔL should be 20 cd/m².
$E_{130\,m} = 0.075$ lux.

$$R = \frac{20}{0.075} = 266 \text{ cd/m}^2 \text{ per lux.}$$

(Always assuming that L_v is equal to the adaptation level).

B. Wide four-wheeled motor vehicles.
If d = 0.90 metres and D = 240 metres, the equivalent veiling luminance L_v can be estimated at 113 cd/m².
If $\alpha = 3.5'$ then ΔL would be 8 cd/m².

The reflective power R would then be $\frac{8}{0.02} = 400$ cd/m² per lux.

If D = 130 metres, the equivalent veiling luminance L_v would then be 45 cd/m².
If $\alpha = 6'$, then ΔL would be 2.5 cd/m².

R would then be $\frac{2.5}{0.075} = 33$ cd/m² per lux.

(Always assuming that L_v is equal to the adaptation level).

Conclusions:

1. Estimates of the reflective power of a registration plate required for a given visibility distance if it is observed beside one lighted low-beam headlamp and is illuminated by the low-beam headlights of an approaching driver, are largely determined by the distance between the registration plate and the glaring low-beam headlight. For distances of 0.5 and 0.9 metres respectively the difference in reflective power required for the visibility distance is already a factor of 10!
A prescribed minimum distance between registration plate and headlamps would thus be advisable in order to give some guarantee of visibility of an oncoming four-wheeled motor vehicle one of whose low-beam headlamps is not lighted.

2. The reflective power needed for visibility of registration plates on the rear of motor vehicles if the approaching driver is dazzled by an oncoming vehicle's low-beam headlights is likewise determined by the d values, though to a less extent as the absolute d values are then higher. A decrease in the distance between the middle of the registration plate and the centre of the oncoming vehicle's left low-beam headlight from 3.6 metres to 3 metres already requires twice as much reflective power for a visibility distance of 240 metres. In bends d may have considerably lower values than those used above.

3. Reflectorized registration plates will not make a motor vehicle with defective lighting visible at the required distance under all conditions. This applies especially on (narrow) two-lane roads.

3.2.2. Empirical visibility distances

Rumar (1965) investigated the visibility distances after dark of white enamelled plates and of plates with a white reflectorized background. Table 8 summarizes his results.

The conclusion is that reflectorized plates are visible at much greater distances than enamelled plates, even under critical glare conditions (registration plate beside one lighted low-beam headlamp).
The material Rumar examined for visibility distance was Scotchlite Silver No. 3270. Its reflective power is about 55 cd/m² per lux. (See KEMA measurements in the Annex).
This value is much greater than that inferred in 3.2.1.2 as required for 240 m visibility distance if the registration plate on the rear of the four-wheeled motor vehicle is illuminated by (the scattered light of) the low-beam headlights of an approaching car.
In these conditions the actual visibility distance of the material examined by Rumar will therefore far exceed 240 metres.
Rumar's report does not state the d value in the case of the registration plate was observed beside one lighted low-beam headlamp. It is therefore not possible to check a calculated value against the observed reflective power in this case. For a reflective power of 55 cd/m² per lux, the visibility distance is stated by Rumar to average 120 metres. In 3.2.1.4 a reflective power of 266, and 33 cd/m² per lux was calculated with a visibility distance of 130 metres and d = 0.5 and 0.9 metres. The distance applied by Rumar between the glaring low-beam headlight and the registration plate can be assessed by interpolation at about 80 cm. Such a distance does not seem to be an unrealistic one.

Visibility conditions	Visibility distance	
	Enamelled plates	Reflectorized plates
Unlighted rear license plate illuminated by an approaching vehicle's low-beam headlights	60 m	greater than 250 m
Front license plate beside one lighted low-beam headlamp, illuminated by an oncoming vehicle's low-beam headlights	20 m	120 m

Table 8. Visibility distances of white enamelled plates and of plates with white reflectorized background (Rumar, 1965).

$$\frac{\Delta\alpha}{\Delta t} = \frac{p.v}{p^2 + q^2 - q.v.\Delta t}$$

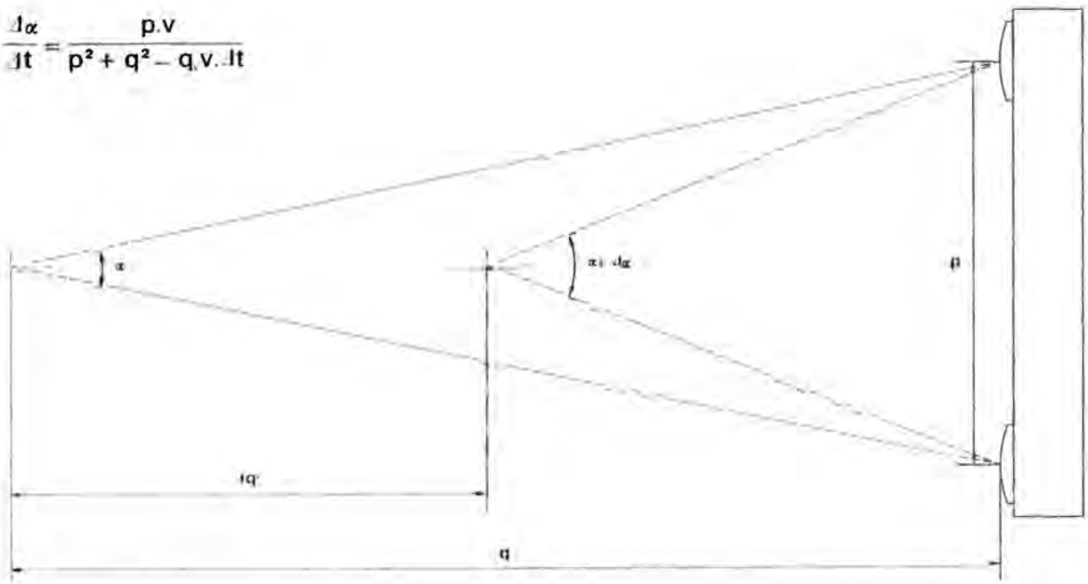


Diagram 4. Detection of differences in speed by assessing the change in apparent obstacle size.

3.3. Assessing speed and distance

A. In the literature—Rumar (1965) reviews this—it is expected that reflectorized registration plates will be an effective aid in estimating differences in speed and distance, especially at high speeds. The risk of head-tail collisions and collisions with parked motor vehicles might then be reduced.

B. On the assumption that the observation of a difference between a motor vehicle's and an approaching driver's speeds can be described as a function of the apparent enlargement seen by the approaching driver of (the distance between the rear lights and/or reflectorized material and/or reflectors of) the vehicle ahead (See Diagram 4), a relationship can be inferred between the detection distance and the difference in speed, in which:

q is the detection distance, i.e. the distance at which a difference in speed can be detected (metres),
p is the width of the motor vehicle ahead (m),
v is the difference in speed (m/sec),
α is the image angle of the motor vehicle ahead (of which only the rear lights and/or reflectorized material and/or reflectors are visible) (radians),
Δq is the displacement of the approaching motor vehicle in a time Δt,
$\Delta\alpha$ is the change in the image angle with a displacement of Δq,
Δt is the observation time.

As p is very small compared with q and hence α and $\Delta\alpha$ also have very low values, an approximation is: $tg\,\alpha = \alpha$ and $tg(\alpha + \Delta\alpha) = \alpha + \Delta\alpha$

$$\Delta\alpha = \frac{p}{q - \Delta q} - \frac{p}{q} = \frac{p \cdot \Delta q}{q^2 - q\Delta q}$$

If the speed of each vehicle is constant, then:

$$\frac{\Delta\alpha}{\Delta t} = \frac{p \cdot v}{q^2 - q \cdot v \Delta t}$$

The width of the registration plate (50 cm) is—depending upon the vehicle's width—three to four times smaller than the distance between the rear lights and/or the reflectorized material and/or reflectors. Thus the detection distance will likewise change: a p value three times less gives a detection distance also three times less.

C. It is not impossible, however, that approaching drivers do not use, or use to a much smaller extent, the apparent enlargement of the area of reflectorized registration plates in estimating differences in speed and distance, but do use, or use to a greater extent, the change in brightness of the reflectorized registration plate, which increases as the distance between light source (an approaching motor vehicle's low-beam headlights) and object decreases. In this event observation of the reflectorized registration plate might already give a reliable of differences in speed and distance much further away.

D. If it is entirely or substantially this observed change in brightness which drivers use to detect and interpret a difference in speed and/or distance, this detection distance would be no less (or would be greater) with reflectorized registration plates than with alternative forms of reflectorized material, provided the reflective power and the area are the same.

E. If, besides perceived changes in brightness, changes in the observed width of the visible parts of the vehicle are of importance in assessing speeds and distances compared with this vehicle, reflectorized materials across the entire width of the vehicle and/or at the location of the rear lights (or a reflectorized rear bumper) may be more effective than reflectorized plates.
Empiric research for verifying this assumption is, however, necessary before the ultimate choice can be made from these two alternatives.

F. It can be concluded without further research that any contribution towards correct assessment of speeds and distances will be greater for reflectorized registration plates than for enamelled ones, in view of the difference in the distance at which the two types of plates are visible.
It can also be concluded that if area, form and shape are the same, this contribution will increase as the reflective power is greater.

4. Recommended reflection properties and colour of reflectorized registration plates on four-wheeled motor vehicles

4.1. Minimum reflection values

In Britain the standards for reflective power of material for use on registration plates (in cd/m² per lux) (BS AU 145, 1967) include the following. (The angle of observation is defined as the angle between the directions of incident light and of observation. The angle of orientation indicates the direction of incident light relative to the perpendicular on the illuminated surface.)

Colour	Angle of observation	Reflective power	
		Angle of orientation (horizontal) approx. 5°	approx. 30°
White	0.2°	35	18
	2°	3.5	2
Yellow	0.2°	18	7
	2°	2	0.75

The values in the U.S.A. (LS-300, 1965):

Colour	Angle of observation	Reflective power	
		Angle of orientation (horizontal) approx. 5°	approx. 30°
White	0.2°	35	18
	0.5°	20	10
	2°	4	2.2
Yellow	0.2°	25	9
	0.5°	10	4
	2°	2.2	1.0

Western Germany has minimum standards for white and yellow reflectorized materials (RAL-F7) which are the same as the American standards, at angles of observation of 0.2°, 0.5° and 2°. Furthermore the German standard gives requirements for the angle of observation of 0.33° customarily used by the inspecting authorities in the Netherlands. These are (in cd/m² per lux):

Colour	Angle of observation	Angle of orientation (horizontal) approx. 5°	approx. 30°
White	0.33°	28	14
Yellow	0.33°	17	7

By increasing the minimum requirement by 10% for inspection in dry conditions, the German standard allows for a reduction of 10% in reflective power in wet conditions. It seems not unreasonable to recommend the German standards for the time being for use in the Netherlands; at least as regards white reflectorized material. (See Notes, B.)

Notes on reflective power recommended for registration plates

Firstly, the reflection standards mentioned are based solely on (an approximation of) the corresponding visibility distance under optimum conditions of observation. Visibility of a registration plate under these optimum conditions does not, however, mean that the plate will be visible under all traffic conditions.
In 3.2.1.2., in assuming that the headlights are in line with the observer, that is to say the angle of observation = 0, it was inferred that a reflective power of about 11 cd/m² lux is required for a visibility distance of 240 metres. The intensity of reflected light is largely determined by the angle of observation. The greater this angle is, the greater the decrease in measured reflective power will be. Not enough is known about this decrease with angles of observation less than 0.2°. It is not known, therefore, what value measured at 0.2° or 0.33° angle of observation, as customarily applied by inspecting authorities, the reflective power as inferred in 3.2.1.2. corresponds with. It can, however, be said that this value will be greater than that inferred in that paragraph.
The proposed reflective power figures should therefore be interpreted as minimum standards.

A. Angle of orientation
It was inferred in 3.2.1.2. that 240 metres visibility distance requires a reflective power of about 11 cd/m² per lux (with an angle of observation of about 0°). Registration plates made of material with at least this reflective power will usually be visible at this distance when the angle of orientation is about 0°.

At 240 metres, the angle of orientation for vehicles parked parallel on the road will often be no greater than 0.5 to 1°. This angle may, however, be greater in bends and for motor vehicles not parked parallel on straight roads. It would therefore be desirable to set standards for reflective power for bigger angles of orientation.

B. Yellow and white
The values given in the British, American and German standards for yellow are not adequate at an angle of orientation of 30° for 240 metres visibility distance. Owing to this, higher values should be required for yellow, or a single colour should be recommended for fronts and rears of vehicles. A drawback of the latter might be a diminishing of the visible distinction between front and rear after dark. From 240 metres the colour impact of a (yellow) registration plate will be very slight; the approaching driver will therefore usually be unable to gain sufficient information from this colour impact. If yellow should nevertheless be stipulated for the rear, a higher reflective power would have to be required than present standards abroad (7 cd/m² per lux, See RAL-F7). Yellow reflective materials satisfying this requirement, however, are not in the present (European) range of production.

C. Visibility of registration plate in oncoming vehicles' glare
The reflective power required with a given visibility distance is largely determined by the distance between the oncoming vehicle's low-beam headlights, and also the distance between the registration plate and these low-beam headlights. No systematic records of these distances are available. Glare from oncoming cars will occur mainly in two-lane roads. Assuming that such roads will often be no wider than about 2 × 3 metres, and assuming that the distance between (the centres of) the low-beam headlights will usually be about 1 to 1.20 metre, a visibility distance of about 130 to 200 metres can be obtained for a registration plate with the proposed reflective power, and with a distance between (the centre of) the registration plate and these low-beam headlights of 2 to 2.40 metres or 3 to 3.60 metres. By approximation

a minimum distance of 130 metres might be required for avoiding a head-tail collision between two motor vehicles travelling in the same direction with a difference in speed of 80 km/h. In order to obtain a greater visibility distance, the reflective power would have to increase greatly. A rule of thumb is that for twice the visibility distance about ten times more reflective power is required. White reflectorized material suitable for use on registration plates at present commercially available has a maximum reflective power of 55 cd/m² per lux at an angle of observation of 0.33° and an angle of orientation of about 5°. Use of material with a reflective power of 55 cd/m² per lux instead of 28 cd/m² per lux would increase the registration plate visibility distance in this case to 145–225 metres instead 130–200 metres.

D. Visibility of registration plate beside one lighted low-beam headlamp
When the registration plate at the front of a car with one lighted low-beam headlamp is observed, the visibility distance will be largely determined by the distance between (the centre of) the low-beam headlight and (the middle of) the registration plate. If the registration plate is fixed 50–90 cm from the low-beam headlight, the proposed reflective power will correspond to a visibility distance of 60–130 metres. This distance will usually be too short for swerving aside.
Assuming that swerving aside requires at least 3 secs, then, if two cars are approaching each other with a difference in speed of 200 km/h, the visibility distance would have to be at least 165 metres. With 50 cm between registration plate and low-beam headlight, this visibility distance would need about 15 times the reflective power at present proposed.
Material with this reflective power, which also satisfies other requirements for registration plates (especially resistance to fracture, vibration and shock) is not commercially available. It can therefore be expected that the contribution of reflectorized registration plates towards increased recognizability of four-wheeled motor vehicles with one low-beam headlamp not lighted will be inadequate.
The function of reflectorized registration plates (and alternative forms of reflectorized material) in reducing the risk of head-on collisions, by increasing the recognizability of motor vehicles as two-wheeled or four-wheeled (if one of the low-beam headlamps is not lighted) will thus be slight or non-existent.

4.2. Maximum reflection values

Maximum permitted reflection values for registration plates are not mentioned in regulations in other countries. It would be advisable to lay down such standards because a driver approaching a motor vehicle runs the risk of interpreting a relatively slight reflectorizing registration plate as comparatively far away. This might happen if the driver is not troubled by the (low-beam) headlights of oncoming vehicles (there is hardly any question of this in case of glare by oncoming vehicles: see 4.1 Notes, C). In practice this confusion through a difference in reflective power will, however, be negligible: the greatest reflective power of the registration plates could be about 55 cd/m² per lux, bearing in mind the material at present available. About 10% more visibility distance would then be obtainable.

4.3. Diffuse reflection

The diffuse reflection standards for white reflectorized materials are identical in Western Germany and U.S.A.
These minimum standards can also be recommended for the Netherlands.

	LS-300	RAL-F7
White	37	37

4.4. Colour co-ordinates

The co-ordinates for white reflectorized materials given in the American (and German) standards are:

	1		2		3		4	
	x	y	x	y	x	y	x	y
White	0.309	0.308	0.337	0.343	0.323	0.354	0.295	0.322

The colour range is defined by the colour co-ordinates of the intersecting points of the lines bordering this range.

4.5. Retention of reflective power

This is shown by British research (Rutley, 1966) to be comparatively slight. A decrease in reflective power of 24% was found in one year.
The material, however, had a rough surface and collected a lot of dirt. Materials are also commercially available with a protective coating (flat reflective sheeting) which collect much less dirt and withstand cleaning agents well. The reduction in reflection is caused by the top coating being attacked by dust, sand, water, wind and cleaning agents.
In the U.S.A. e.g. standards apply for the maximum permitted reduction in the reflective power of reflectorized material. Standard LS-300 requires that the reflective power must not have decreased by more than 30% after two or three years' use. Such a requirement for reflectorized registration plates is difficult to check on in practice. It is, however, possible to lay down requirements for the resistance of the top coating while new to dust, sand, cleaning agents etc. and to verify these with an accelerated aging test.

5. Recommended reflection properties and colour of reflectorized registration plates on two-wheeled motor vehicles

As regards reflective power, American and German standards e.g. do not distinguish between registration plates required for two and four-wheeled motor vehicles.
The area of plates for these two categories does differ, however (by a factor of about 1.5). To retain the required visibility distance a higher reflective power (about 1.5 times higher) would then be needed. The *minimum* reflection values to be recommended could then be the existing (and identical) American and German standards for silver white reflectorized material. With an angle of observation of 0.33° and angles of orientation of about 5° and about 30° respectively these are (in cd/m² per lux):

Colour	Angle of observation	Reflective power	
		Angle of orientation (horizontal) approx. 5°	approx. 30°
Silver white	0.33°	35	18

For *diffuse reflection* the American (and German) standards apply the same value for white and silver white.

For the *colour co-ordinates* for silver white the American (and German) standards give the following values:

	1		2		3		4	
	x	y	x	y	x	y	x	y
Silver white	0.309	0.308	0.350	0.359	0.338	0.371	0.295	0.322

6. Possibilities and recommendations for night-time photography of vehicles fitted with reflectorized registration plates

6.1. Introductory

The reflective power of reflectorized registration plates results in difficulties in night-time photography of vehicles fitted with such plates. The difference in luminance between the plate and the remainder of the photograph may be so great that a normal photographic emulsion can no longer reproduce it.

6.2. Analysis of the problem

The amount of contrast that photographic emulsions can record depends on emulsion quality. Film emulsions can record more contrast than paper emulsions. If the differences in brightness of the object are too great to be recorded by an emulsion, the under-exposed emulsion will appear unexposed, while a ring around the over-exposed parts will be blackened (by irradiation). Where such irradiation occurs the photographic image will be blurred or even disappear.

Tests made previously outside the Netherlands with night-time photography of vehicles fitted with reflectorized registration plates show that these plates produce irradiated negatives. It is also found that the image in the irradiated area is blurred but does not disappear. When these negatives are printed, however, the differences in brightness in the image are so great that paper emulsions cannot reproduce it.

Exposure during printing can generally be arranged so that
a. the over-exposed and irradiated parts appear as an image in the photograph, and irradiation occurs on the print in the other parts, making them completely black or almost so;
b. normally exposed parts appear as an image in the photograph, while the over-exposed and irradiated parts of the negative appear on the print as unexposed (i.e. remain white).
By allowing some extra exposure for the over-exposed and irradiated parts on the negative, all the information recorded on the negative can be transferred to the paper emulsion.

Photographs of vehicles using reflectorized registration plates can, if enlarged by hand, be exposed in two stages by using masking plates. This will not usually be possible with automatic printing units. Units for multi-stage exposure (Dodging printers) must be disregarded in view of their cost, similarly to other equipment, which can be assumed to be unavailable to the departments concerned.
If irradiation is slight, the difficulties can be counteracted by choice of film, paper and developer In the first instance, however, it should be counteracted with the correct photographing method.

Blurring of contours by irradiation is inversely proportional at a given focal distance to the distance between camera and registration plate. The irradiation is a function of the angle of observation. If the angle of observation changes from 0.5° to 2°, the reflective power decreases by about 90%*. A further increase in the angle of observation has a progressively decreasing effect on the reduction in reflective power. Using the Netherlands departments' present photographic equipment, the effect of angle of observation and distance on irradiation can be examined first of all.

* See Diagram A1 in the Annex.

If the irradiation is caused by coloured light (coloured registration plates), it may be possible to counteract it by using a suitable colour filter. Colour filters have the property of absorbing certain colours in the spectrum; the filter should absorb the colour causing the irradiation. This can be examined in the second instance.
Basically, vehicle and registration plate could be photographed with two cameras, the diaphragm of one being set for the vehicle and the other for the registration plate. This would seem to be a less effective solution, however, than that indicated above, for technical, financial and legal reasons.

6.3. Research programme

6.3.1. Terms of reference

At the request of the Institute for Road Safety Research SWOV, Mr. G. J. Boven and Mr. J. J. Flamman of Wassenaar municipal police examined the effects of distance, angle of observation and colour filters on irradiation in photographs of vehicles with reflectorized registration plates taken after dark.
A series of forty exposures were taken in combinations of distances of 5, 10, 20 and 40 metres and angles of observations of 0°, 1°, 2°, 3° and 4°, with and without filters. The effect of colour filters was gone into separately. Effects of film and developer were also examined.

6.3.2. Effects of distance and angle of observation

Diagram 5 shows horizontal the distances of object, observation lines are plotted under angles of 1°, 2°, 3° and 4°. These angles of observation are realized by taking the distance flash unit/lens d = v tg w.

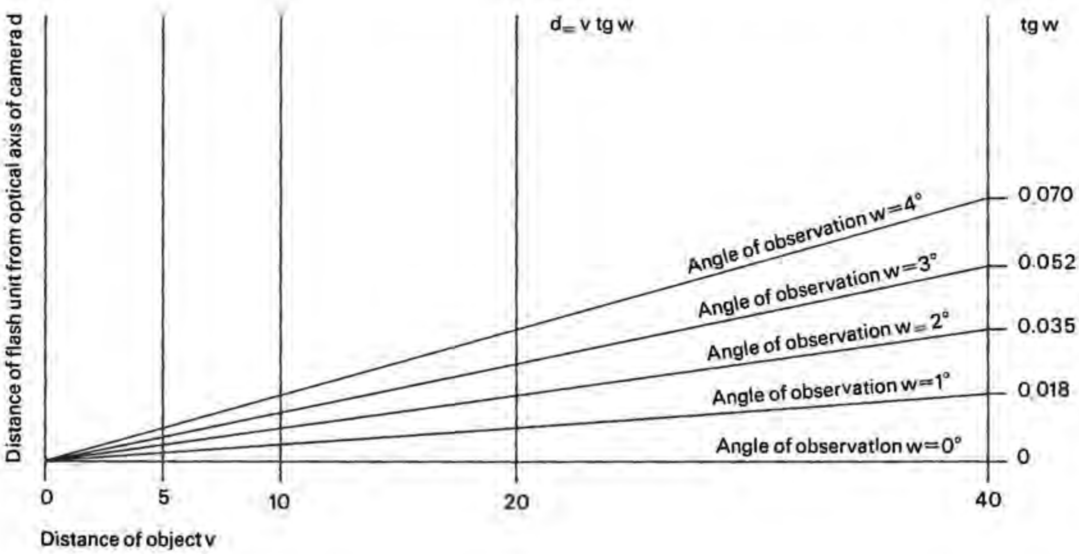


Diagram 5. Camera positions relative to flash unit and object.

At positions corresponding to the intersections of these series of lines, a series of twenty exposures were taken of various types of registration plates. The possible occurrence of irradiation was disregarded in deciding the flash guide number.
The normal quality negative was used and it was developed in the usual way. The twenty negatives were printed out with and without using masking plates, and it was noted how much the irradiated parts had to be over-exposed to obtain a good print.

6.3.3. Effects of colour filter

A similar series of twenty exposures were taken of the same series of registration plates, with filters. The surplus light supplied by the flash unit (the number of stops down compared with full aperture) is a criterion of the maximum permissible absorption factor in using a filter. Further procedure as in 6.3.2.

6.3.4. Effects of film, developer, paper and exposure

A similar series of exposures were taken on a film with a high density range which was two stops under-exposed. It was developed in an appropriate developer. The negatives were printed as in 6.3.2., but the type of enlarging paper and paper developer were regarded as variables.

6.4. Results

The registration plates were legible on the negative in all cases. If the flash unit is on the camera (angle of observation about 0°) all reflectorized registration plates are illegible on the print. Widening the angle of observation and using a colour filter may limit negative irradiation so that the registration plates are legible on the prints. A blue filter is best for suppressing irradiation.
With exposures made at an angle of observation of 0° or more, yellow registration plates are legible on the prints if a blue filter is used. With exposures made at an angle of observation of 1° or more, yellow and gold-coloured plates are legible on the prints if a blue filter is used.
With exposures made at an angle of observation of 2° or more, all registration plates are legible on the prints if a blue filter is used. With exposures made at an angle of observation of 3° or more all registration plates are legible on the print even without a filter.
Owing to the graininess of the picture and the constant irradiation, the legibility of registration plate characters decreases on the photograph as the size of the registration plate decreases. Difficulties may already occur with standard lenses at 40 metres from the object. The maximum distance recommended between the registration plate and the camera is 25 metres. Test photographs showed also that a fine-grain film, developed in normal developer, may have a coarser grain structure than a coarse-grain film developed in fine-grain developer.

6.5. Summary of research

Photographing reflectorized registration plates after dark causes no insurmountable difficulties.
A fast film, about 27 DIN, the correct developer and correct exposure of the photographs will always give legible negatives in spite of irradiation and the negatives can be printed by hand, if necessary with masking plates. The following list shows the combinations of factors with which negatives can or cannot be printed automatically. It includes angle of observation (0°, 1°, 2°, 3° or 4°), colour (DW = diffuse white; RY = reflective yellow; RG = reflective gold; RW = reflective white or silver) and filter (WF = with filter; NF = no filter).

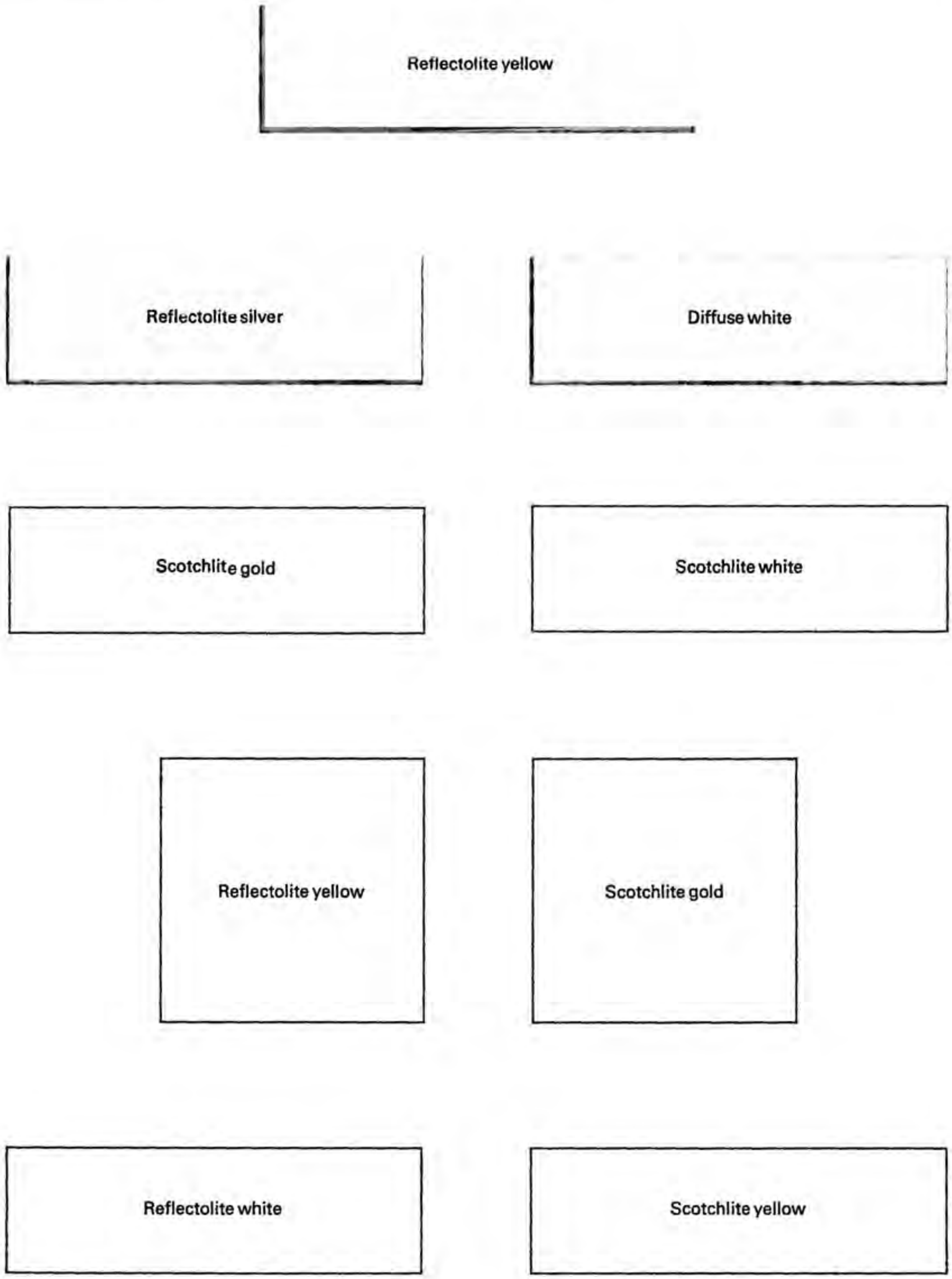
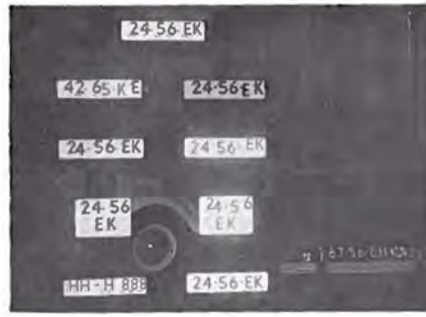


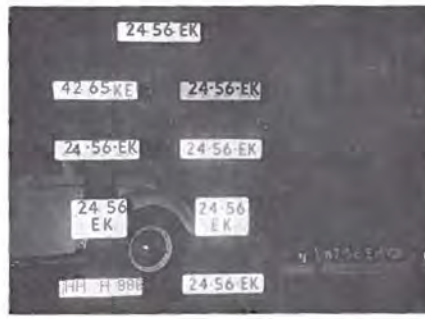
Diagram 6. Position of the various registration plates used for photographic research.

A_1



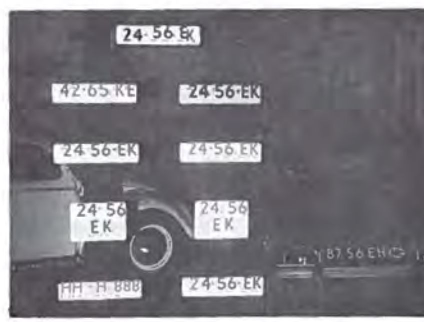
B_1

A_2

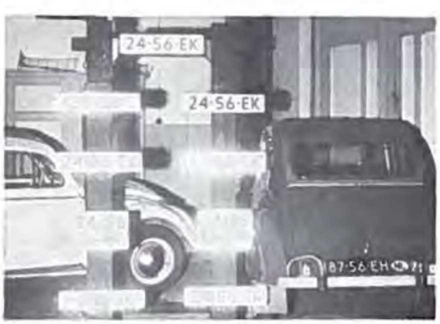


B_2

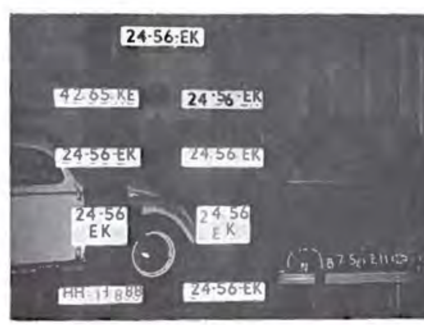
A_3



B_3



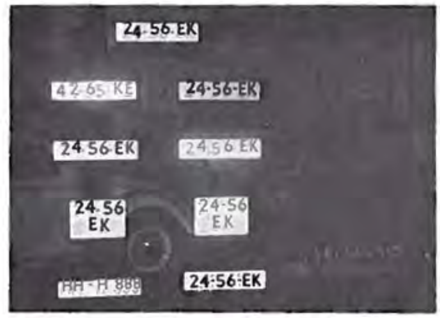
A_4



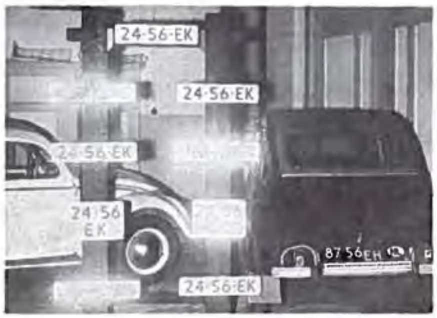
B_4

A_1 to A_4 Prints of a series of exposures made at 5 metres at angles of observation of about 0°, 1°, 2° and 3° respectively. Distance flash unit to lens about 0 cm, 9 cm, 18 cm and 27 cm respectively. Exposure time for prints 4 secs. B_1 to B_4. The same negatives as in A_1 to A_4, exposed to give a legible print. The exposure time for prints was increased as follows: B_1 compared with A_1 ten times; B_2 compared with A_2 eight times; B_3 compared with A_3 six times; B_4 compared with A_4 four times.

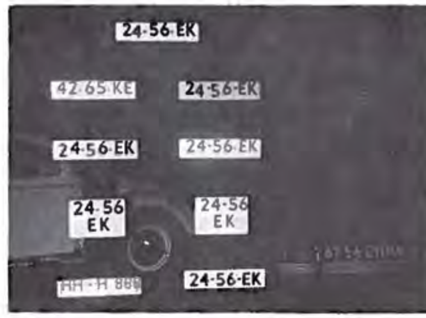
C_1



D_1



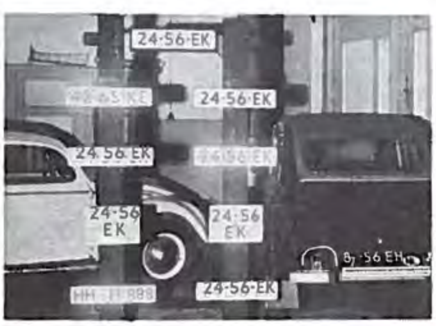
C_2



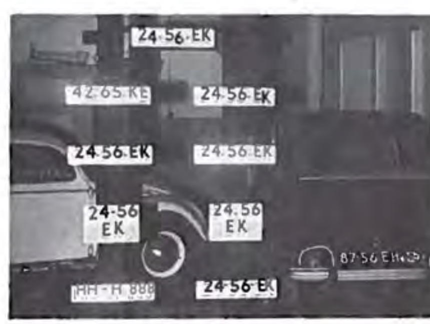
D_2

C_3

D_3



C_4



D_4

C_1 to C_4 Prints of negatives under the same conditions as in A_1 to A_4, with a blue filter and diaphragm one stop up. Exposure time for prints 4 secs. Especially the legibility of yellow registration plates is greatly increased. D_1 to D_4. The same negatives as in C_1 to C_4 exposed to produce a legible print. Exposure time for printing increased as follows: D_1 compared with C_1 five times; D_2 compared with C_2 four times; D_3 compared with C_3 two-and-a-half times; D_4 compared with C_4 twice.

a

b

A slow film in normal developer (a) gives a coarser grain than a fast film in fine-grain developer (b).

The combinations marked + can be printed automatically, those marked — not. It is advisable in all cases to have the greatest possible distance between flash unit and camera, up to a maximum of 7% of the distance from the object. This will not always be possible.

Colour	Filter	Angle of observation				
		0°	1°	2°	3°	4°
DW	WF	+	+	+	+	+
	NF	+	+	+	+	+
RY	WF	+	+	+	+	+
	NF	—	—	—	+	+
RG	WF	—	+	+	+	+
	NF	—	—	—	+	+
RW	WF	—	—	+	+	+
	NF	—	—	—	+	+

6.6. Recommendations

The following possibilities exist according to the various requirements.

6.6.1. For accident records (short-distance)

By having the flash unit/lens distance at least equal to 5% of the distance from the object (25 cm for an object distance of 5 metres) negatives are obtained which can be printed automatically or by hand without using masking plates.
If the flashunit is fitted on the camera, the negatives must be printed by hand with a masking plate. Use of a blue filter when taking the photograph simplifies printing out but is not essential.

6.6.2. For stationary speed checks

For stationary speed checks the equipment is set up in two ways:
a. flash unit on camera;
b. separate flash unit.
In the Netherlands, on the whole, only the negatives will be examined. If prints are required they will be made by hand.
Negatives of yellow reflectorized registration plates can always be printed automatically if a blue filter is used, or by hand without a masking plate. With gold reflectorized registration plates, and using a blue filter, the flash unit/lens distance should be at least 2% of the object distance (50 cm at 25 metres).
For stationary speed checks with a separate flash unit, the flash unit/lens distance should be at least 5% of the object distance in order to dispense with a filter. Negatives taken under other conditions must be printed by hand, using masking plates.

6.6.3. For mobile speed checks

In the Netherlands, on the whole, only the negatives will be examined in these cases. If a print is required it can usually be made by hand. The method is similar to that described in 6.6.2. To obtain negatives that can be printed automatically or without a masking plate by

hand, the object distance must not exceed twenty times the flash unit/lens distance or thirty times this distance if a blue filter is used (for flashunit/lens distance of 70 cm this is 14 metres, and 21 metres respectively; for a flash unit/lens distance of 1.20 metres it is 24 metres and 36 metres respectively).
If the object distance is greater, the photographs must be printed by hand, using a masking plate.

6.6.4. For tax checks

For tax checks, in the Netherlands only the negatives will be examined. If prints are required they are made automatically.
For both mobile and stationary tax checks, automatically printable negatives require a maximum object distance of twenty times the flash unit/lens distance or thirty times this distance if a blue filter is used.
With reflective yellow, negatives can all be printed automatically if a blue filter is used.

Note: For stationary checks from cars the vehicle should as far as possible be parallel to the camera's optical axis.

7. Literature

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Annex to the report Reflectorized registration plates

Report on reflection measurements with ten specimens of reflectorized materials, by KEMA (N.V. tot Keuring van Electrotechnische Materialen) Arnhem, The Netherlands

Introductory

At the request of the Institute for Road Safety Research SWOV, the reflective properties were tested and the colours were determined of ten specimen plates of reflectorized materials received from the Institute.

The tests were made in the following order:
a. Assessment of light dispersing power
b. Assessment of specular reflection
c. Determinations of reflective power, while dry and wet.
d. Determination of effects of the angle of observation on reflective power.
e. Study of the effects of cleaning agents on reflective power.
f. Determination of colour of diffuse reflected light.

In these tests, the Institute's instructions were followed.

a. *Assessment of light dispersing power*

Light dispersing power was assessed by illuminating the measurement area with standard daylight source C. The angle between the average incident light direction and the perpendicular at the measurement area was kept at 45°; the observations were made in the direction of the perpendicular at the measurement area. The measurement area was always the same size, which was slightly smaller than the specimens.
Observations were made with a Weston-Viscorcel about 0.5 metre from the object under test. The equipment was calibrated with a flat surface intensively smoked with magnesium oxide, its size being the same as that mentioned above.

The light dispersing power of the specimens was finally stated as a percentage of the value measured for the magnesium oxide surface (See Table A1).

b. *Assessment of specular reflection*

Specular reflection was determined with the equipment extensively described in Electrotechniek No. 20 for 7th October 1954. (See also under Section c of this report.) The measurement area which had a diameter of 5 cm, was located relatively to the direction of illumination and the direction of observation so that there was maximum reflection in the direction of observation. Specular reflection was ultimately expressed (see Table A1) as a percentage corresponding to the maximum reflection, less the reflective power (see Section c) measured with the same area (ø 5 cm). The slight influence of light dispersing reflection in total reflection was disregarded.

The specular reflection was ultimately expressed (see Table A1) as a percentage of the reflective power of an absolutely diffusely and totally reflecting white surface, corresponding to $10^{-1}/\pi$ mcd/lux per cm² or to $1.96/\pi$ mcd/lux per 19.6 cm² (applicable to an area with a diameter of 5 cm).

c. *Determination of reflective power*

Reflective power was determined with equipment described in detail in Electrotechniek No. 20 for 7th October 1954. This equipment complies fully with 'Règlement nr. 3: Prescription uniformes relatives à l'homologation des dispositifs catadioptriques pour véhicules automobiles' (Commission Economique pour l'Europe des Nations Unies, Genève, 20th March 1958). For completeness it should be noted that these measurements were made by observation at an angle of 0.33° with the average incident light direction and angles of orientation of 0° (or about 0°) about 30° and about 45°. Measurement at 0° (or about 0°) was in all cases just so that the white

Specimen number	Colour	% light dispersing power	% specular reflection
1	red	8.8	36,000
2	red	9.5	53,000
3	white	49.6	—
4	white	46.6	—
5	yellow	31.4	—
6	white	38.0	—
7	yellow	49.5	—
8	yellow	45.9	—
9	white	47.7	—
10	white	65.4	—

Table A1. Light dispersing power and specular reflection of ten specimen plates of reflectorized materials.

Specimen number	Colour	—45°		—30°		0°		+30°		+45°	
		dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
1	red	0.23	0.22	1.53	1.50	6.75	6.50	1.43	1.40	0.22	0.21
2	red	0.20	0.18	1.53	1.40	8.09	7.13	1.50	1.40	0.20	0.20
3	white	1.56	1.39	8.60	7.77	36.82	33.18	8.09	7.58	1.59	1.40
4	white	24.20	23.12	41.21	39.62	57.71	55.54	41.21	39.24	24.65	23.50
5	yellow	12.99	**8.79**	36.31	**27.39**	71.33	59.36	32.80	27.18	11.97	**8.60**
6	white	22.33	**17.77**	73.89	68.15	117.20	117.83	75.16	64.97	20.83	**16.18**
7	yellow	0.41	0.42	0.64	0.64	0.96	0.92	0.63	0.66	0.42	0.34
8	yellow	0.76	**0.61**	1.53	**1.02**	2.07	**1.46**	1.43	1.01	0.74	0.61
9	white	1.02	**0.70**	2.45	**1.40**	10.38	**5.22**	2.36	1.37	1.02	**0.69**
10	white	1.66	**1.07**	2.29	**1.46**	2.71	**1.75**	2.32	1.50	1.69	**1.08**

Table A2. Reflective power with different angles of incidence, both dry and wet (in mcd/20 cm² per lux).
Note: A value in bold type in the 'wet' columns is in all cases equal to or less than 0.8 times the corresponding 'dry' figure.

reflection on the front of the specimen no longer influenced observation, which was verified visually. The entire area of the specimen was included in the measurement, i.e. 104 cm² for specimen No. 4 and 100 cm² for all the others. The colour temperature of the light source was about 2850° K.
The reflective power was again expressed as a percentage of that of a completely diffuse and totally reflecting white surface.

In compliance with the Institute's request the specimens were assessed both dry and wet. The latter condition was obtained by spraying the specimens, held vertically, with a fine spray of water; spraying ended each time immediately the surface under test was completely and almost homogeneously covered with separate water droplets. (Experience had shown that continued spraying was liable to cause the formation of large drops, or to make water run off or dry in places.)
The results of the tests are summarized in Table A2.

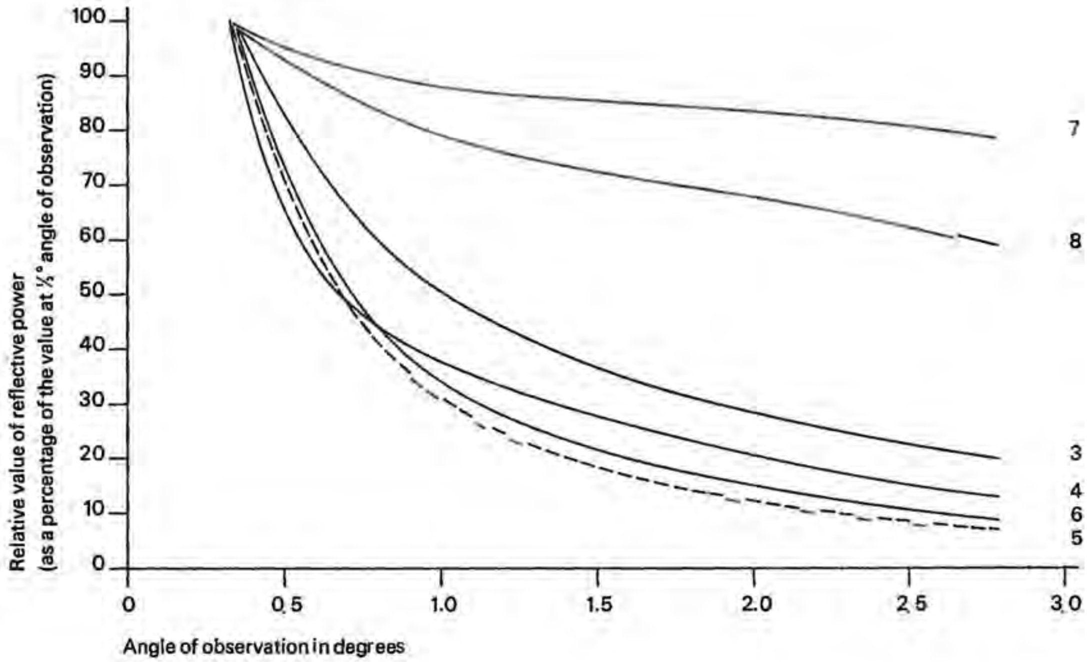

Diagram A1. Effects of the angle of observation on reflective power (angle of orientation approx. 0°; specimen numbers 3–8).

d. *Effects of the angle of observation on reflective power*

These effects were studied with the dry specimens, with the equipment mentioned in Section c; the angle of observation was varied, but the angle of orientation was kept constant at 0° (or practically 0°).
The relative trend of reflective power ultimately calculated in relation to the angle of observation is shown in Diagram A1; the reflective power with an angle of observation of 0.33° (and an angle of orientation of 0° or thereabouts) was taken as 100%.

e. *Effects of cleaning agents on reflective power*

The effects of using a number of cleaning agents were studied with the equipment mentioned in Section c; the angle of observation was in all cases 0.33°, while the angle of orientation was kept constant at + 5°.
The following cleaners were tested in succession:
1. 'Dubro', a synthetic detergent made by De Fenix, Zwolle, 12 cm^3 of which was dissolved in 4 litres of lukewarm water.
2. 'Valma' liquid Auto Was, with Silicones, made by Valma Ltd. Amersfoort.
3. White spirit.

1. 'Dubro' was used by thoroughly washing the front of the speciment with a sponge dipped in the solution; the specimen was then rinsed with running tap water and rubbed dry with a paper towel.

Specimen number	Initial value (%)	Test with Dubro (%)	Test with Valma (%)	Test with white spirit (%)	After repeating white spirit test (%)	After repeating Valma test (%)	After repeating white spirit test (%)
3	100	103	105	97	—	—	—
4	100	94	80(?)	98	—	97	102
5	100	104	107	99.5	—	—	—
6	100	103	104	91.5	93.5	—	—
7	100	96.5	96.5	101	—	—	—
8	100	107	108	115	—	—	—

Table A3. Relative value of reflective power.

Specimen number	x co-ordinate	y co-ordinate
1	0.661	0.328
2	0.654	0.325
3	0.342	0.359
4	0.337	0.358
5	0.511	0.474
6	0.340	0.362
7	0.508	0.466
8	0.497	0.452
9	0.330	0.346
10	0.345	0.362

Table A4. Colour co-ordinates of diffuse light reflected by the specimen illuminated with standard daylight source C.

2. 'Valma' was used by wetting the reflectorized surface thoroughly with a piece of cotton waste soaked in the liquid; after drying for 15 to 20 minutes (and evaporation of the solvent) the surface was wiped with a wollen cloth.
3. White spirit was used by wiping the surface with a woolen cloth soaked in this.

The results of the tests are summarized in Table A3. They show that these cleaning agents had only a slight effect on reflective power. The effect of the first 'Valma' cleaning of specimen No. 4 was quite noticeable, but the decrease was not reproducible after a repeat test; specimen No. 8 was found to reflect noticeably better after the various cleanings, perhaps owing to the successive removal of optically detrimental substances adhering to the surface.

f. *Determination of colour of diffuse reflected light*

The spectral energy distribution in the reflected light was measured for a specimen diffusely illuminated by a light source with a colour temperature T_K of 2850°K. The results permitted the colour co-ordinates to be calculated which would apply for the light that would be reflected by illuminating the specimen with standard daylight source C (T_K = 6500°K). The ultimate results of these tests are summarized in Table A4.

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