FUNCTIONAL REQUIREMENTS OF ROAD LIGHTING

R-75-3

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Voorburg, 1975

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CONTENTS

1. INTRODUCTION

The function of traffic is to reduce the distance between people who wish to get into contact with one another.

Since this analysis is concerned with motorised road traffic, it is necessary to devise a system of traffic measures in order that the above-mentioned general function can be accomplished. These measures can be more closely defined: - firstly, that the driver should be able to arrive at his final destination in an adequate manner. "Adequate" in this context is taken to mean (i) to drive without incurring any accidents (i.e. the requirement of safety), (ii) to drive at a reasonable speed (i.e. to preserve the fast, uninterrupted flow of traffic) and (iii) to drive without excessive exertion (i.e. the requirement of driving comfort). It goes without saying that all this has to be achieved with the minimum cost. The word "comfort" in connection with driving, should not be associated with its normal meaning of luxury (which could easily be dispensed with): in traffic engineering it is used to relate to two different concepts.

The first concept is in connection with the above-mentioned function of traffic (the socio-economic need for people to get into contact with one another, or to exchange goods or information), and in this respect it is not surprising that "comfort" is found to be related to the more direct socio-economic parameters of travelling time, capacity, road-occupancy; it should also be noted that while a qualitative measure is given in the "Level of Service" (HRB,1965) (and that the "operational speed" (ibid) has a close relationship), a quantative measure is more difficult, (OECD,1972), and consequently its practical application is not possible at this date (NSvV, 1975).

The second concept of the word "comfort" is related to the fact that the normal sense of well-being can be reduced. It may happen that it is considered too expensive to provide a normal standard of well-being (comfort) since the cost has to come out of taxes. But this has to be weighed against the fact that a reduction in comfort may result in indirect harmful effects on the physiological and biological functions of the body, which detract from the optimum capability of the driver.

In relation to non-visual aspects, reference can be made to Broadbent (1958) and in relation to visual aspects to Benz (1966). A more detailed discussion can be found in Schreuder (1975a).

Finally it should be pointed out that while "discomfort" effects may result in poor vision and reduction in other aspects of visual perception, it is of primary importance to establish the fact that "discomfort" effects, which may cause severe exhaustion, cannot be put on the same level as disability effects. (The terms"discomfort" and "disability" are, normally, only used in discussing phenomena of glare (Adrian & Schreuder, 1970; CIE, 1965), but they can also be used in a wider sense.)

One further observation may be made. It is understood, that in traffic engineering, the term "traffic flow" or, in other words "driving speed" is taken to mean a form of driving comfort. The above discussion also proves that costs, however important, will only be treated in the analysis as a dependant variable. This means that the aim should not be, to construct a road at the lowest possible cost, but to build it at the lowest cost while conforming with certain qualitative requirements, which will be discussed later. The terms which are used in this respect, i.e. "expenses" and "benefits" are discussed in detail by Flury (1972).

The focus of this analysis is the driver of the vehicle, which can be defined for this purpose as having a built-in power source (giving movement to the vehicle) and a steering mechanism; with these, the driver can control the speed and the position of the vehicle on the road, according to his judgement. He can also make the decisions which are necessary to arrive at his destination, and these are made from information which he obtains momentarily from his immediate surroundings. In this respect only the driver's visual system is of interest. From this, it can be concluded that the functional requirements of the lighting installations, must comply with, and are derived from, the main requirement for providing the driver with the necessary visual information. These requirements follow from the general function of traffic, in accordance with the desire for travel; it is also possible to derive the visual requirements from the general functional requirements. This results in the requirement for a lighting system, and in particular, for more specific requirements of illumination and technical construction.

The decisions the driver has to take can be classified as being on various levels of importance. To understand the problems of road lighting the method suggested by Asmussen (1972) has been developped further. This is illustrated in Table 1. In general, this representation is self-evident, but it is necessary to make some additional remarks, concerning illumination.

When studying a certain aspect of traffic, not all levels are of equal importance. For example, the levels on which decisions have to be made with regard to the choice of destination, mode of transport, or the route, are not important when considering requirements for road illumination: such decisions require the study of maps (or railway guides) <u>prior to</u> departure.

The analysis is primarily concerned with manoeuvring behaviour, and in view of the importance and the complex nature of this, it has been subdivided into three decision levels: (i) operation level,(ii) tactical level, and (iii) steering level.
Each decision leads to one or more activities. If these activities result in a change of movement of the vehicle in which the driver is sitting, they will be shown as <u>manoeuvring</u>. Manoeuvres, at the operation level are described as "composite manoeuvres". Manoeuvres on tactical level are "elementary manoeuvres", while those at steering level are indicated as "part manoeuvres".

It is interesting to study, which manoeuvres can occur at the various levels. With regard to the functional aspect, is has been attempted to specify the illumination requirements which are necessary to carry out each manoeuvre, or at least for several manoeuvres, in the best possible manner.

For this purpose Tabel 2 contains a summary of the manoeuvres, which can take place on the three levels which are of interest. Efforts have been made to give complete and unequivocal definitions, but this inventory should be taken as a first draft.

There are some additional remarks which should be made concerning the term "just going on": according to the definition no actual manoeuvring occurs, because there is no change in the movement of the vehicle. Since,however, "just going on" can be the result of a decision process, it is regarded as a manoeuvre and is included in Table 2. Moreover, it should be noted that, "to round a bend" is shown at the operation level, and not at the tactical level. It was decided to do this because, when taking a bend in the correct manner, the(lateral)distance of the vehicle from the side of the road remains more or less constant. Furthermore, there is no sub-division given here at the steering level, which considerably simplifies the system.

Finally, "drive off" is not included, because this requires a decision on the strategic level.

The kind of manoeuvres which have to be made (at various levels) depends to a great extent on the road and traffic conditions. It is nearly always possible to define a given situation in terms of objects, which are either present or absent, although the definition of "objects" has to be made in a very broad sense. However, in establishing the functional requirements of road illumination, not only situations and objects which occur on the road but also situations and objects, which can be expected on a given sector of the road, have to be taken into account. As a result of this, a direct relationship is established between the requirements of illumination and the classification of roads. Janssen (1974) proposed a road classification system and use will be made of this later (see Table 3).

2. FUNCTIONAL REQUIREMENTS

In order to establish the functional requirements of illumination,use is made of three basic ideas; these frequently occur in discussions on traffic safety. These basic ideas are concerned with:

1. The standardisation of situations.
2. The prevention of conflict situations.
3. The improvement in the supply of information.

In the following section these basic ideas will be discussed in detail.

1. By standardising the situations, the number and diversity of decisions which the driver has to make, can be reduced.

Based on the criterion of standardising situations, certain requirements can be established for road illumination. It is not desirable to provide different types of lighting installations within one given category of road. In many cases, however, this cannot be avoided, usually because of financial considerations. From this it follows that illumination cannot make a significant contribution to the creation of standardised situations.

The colour of the light, which is sometimes mentioned in this connection, can only be used to a limited extent, particularly since, with the introduction and extended use of high-pressure sodium vapour lamps, the previous clear distinction between yellow and white no longer exists.

2. The prevention of conflict situations does not reduce the diversity of decisions which must be made, neither does it alter the fact that they can occur unexpectedly; but it can be said that the prevention of conflicts does reduce the number of decisions which have to be made. The effect of street lighting on this is limited, however, since illumination does not eliminate the necessity of making decisions.

3. Even if the quality of the information supplied is improved, it will still be necessary to make the same number of decisions. Since,

however, the information mainly concerns the basic data on which decisions have to be made, erroneous or incomplete decisions can be eliminated in part. Furthermore, it is simpler to assess the results of manoeuvres carried out following a decision, (i.e. the feedback is improved). It is evident that in this field, illumination, and in particular street lighting, can offer important contributions. Therefore, when establishing the functional requirements of illumination, this aspect of the improvement in the supply of information will primarily have to be considered. Street lighting has, of course, other uses, such as security for the inhabitants of a city and general aesthetic aspects etc. but these will not be discussed here,(see De Boer ed., 1967).

3. VISUAL REQUIREMENTS

3.1. The room to manoeuvre

The primary function of illumination is to improve the supply of information. More exactly, illumination aims at improving the visibility of "objects". This will be discussed under the heading "visual requirements".

The term "object" may have different meanings. In each of the three levels in which manoeuvring behaviour has been classified, there are a number of related manoeuvres, each in turn, concerning specific relevant objects. In this way it is possible to determine, for each relevant object, the manner and the time in which it must become visible. In this connection the terms "available moving-space to manoeuvre" and "necessary moving-space to manoeuvre" introduced by Griep (1970), can be taken into consideration, thus making it possible to indicate, for each relevant object the "available" and "necessary" room to manoeuvre in time and space or in both. These concepts depend on the type of object in question, the level on which the decision to carry out a manoeuvre has been made, and the kind of manoeuvre resulting from this decision.

Firstly, the photometric and geometric categories which correspond to these requirements must be investigated.

The translation of the visual requirements into photometric terms is, in theory, quite simple, and a more detailed discussion will be given later on.

It is assumed that a journey requires, in the first place, that a road should be followed; therefore the design of lighting installations which meets the requirements, must conform to visual and/or optical guidance. Up to now, however, no clearly defined quantative standards have been established for this purpose. A qualitative analysis of the problem showed that the standards can be improved, if they are expressed in terms of the above-mentioned levels. The first steps in this direction were given by Schreuder (1970, 1972) (see also NSvV, 1975).

The second general aspect concerns the avoidance of obstacles. Elsewhere it is pointed out that the International Standard Object presents a reasonable compromise having regard to the variety of objects (sometimes very large and sometimes very small) which a car driver may encounter on the road (Schreuder,1975b). However, it can be stated that with increasing levels of illumination the ease with objects can be perceived increases. This holds for all sizes or contrasts of the objects. Since in most cases the required level of illumination can adequately be described by the road-surface luminance, the second photometric parameter can be obtained. The third relates to the fact that small objects should not disappear in dark sectors of the road, and this forms a basis for determining the permissible variations in the luminance: the uniformity.

Finally, the fourth criterion concerns glare. It is evident that good driving conditions ensured by appropriate visual guidance, lighting level and uniformity should not be nullified by excessive glare.

In the following section these criteria will be discussed in detail. However, one further observation must be made. From the above statements, it might be expected that there would be at least two independant groups of criteria i.e. one group concerning traffic safety and one relating to driving comfort, (including the smooth flow of traffic and individual's driving speed). However, this is only partly possible: as a matter of fact, one of the most urgent problems concerning public lighting is, that there are not enough data to show what is the minimum lighting level for safety, and what is required for capacity, travelling time and comfort. Having concern solely for how much money can be saved on public lighting is, however, a wrong approach!

3.2. The effect of adaptation to road surface luminance

It has been found that particularly in the luminance-ranges prevalent in night time driving, there exists a distinct, positive correlation between adaptation to luminance levels and visual performance.

This relationship is not linear, and moreover, it is not the same for each basic function of visual performance. Practical experience has shown that in general, the following four basic functions are of importance with regard to road traffic -(in order of decreasing importance):

1. Detection of movement
2. Detection of small differences in luminance (contrast sensitivity)
3. Detection of small details (visual acuity)
4. Detection of small colour differences (colour sensitivity)

1. Detection of movement takes place mainly at the periphery of the field of vision. However, the physiological aspects of the processes involved are not yet properly understood. Moreover, the nature of the dependence of detection of movement on the position of the object within the field of vision, the adaptation luminance, and the contrast and size of the test object, etc. are not yet known with any certainty.

2. and 3. The detection of small differences in luminance and the detection of (small details)of objects, show certain similarities. Detection depends to a great extent on the adaptation luminance, and it is related to the way in which the rods and cones in the retina of the eye function. This dependence, however, is not a simple one, since at high levels of luminance (e.g. above 10 cd/m^2)detection reaches a maximum. when <u>all</u> cones, and <u>only</u> the cones, are functioning. At low levels (less than about 0.01 cd/m^2), only the rods are functioning, and detection in the area of the fovea is not possible (or only very slightly so), and is dependent on the luminance at the periphery of the field of vision. At intermediate levels both rods and cones are functioning. Practice proves that at a level of luminance of 0.1 cd/m^2 detection still has much in common with detection by rods, while at about 1.0 cd/m^2 the situation is more

nearly equivalent to detection under daylight conditions. These findings are of the utmost importance for practical purposes: it seems that for detecting small contrasts and small objects it is not really necessary to provide a light-level much greater than about 1 cd/m^2. Practice also proved that while the ease of detection improves considerably (in a subjective manner), at a luminance of 2 to 3 cd/m^2, it is not necessary to provide levels approximating to daylight (1000 to 10,000 cd/m^2). However, at a lower luminance (in the region of 0,1 cd/m^2) the situation deteriorates, mainly in relation to the detection of small objects. Under such conditions detection is only slightly better than ordinary night vision.

These data can also be considered from another aspect. If it is required to ensure that the traffic facilities can be used (at least for some sectors of the road system) with the same ease, and can provide the same supply of information and consequent behaviour patterns, as when used for daytime situations, then the lighting system must create an environment, closely simulating the daytime situation, for the road user. For this purpose it seems necessary to provide a road-surface luminance of at least 1 cd/m^2.

3.3. Visibility of objects; the distribution of the luminance

In the perception of small objects or small details of large objects, the luminance of the road surface is also important for another reason. Usually, such objects are visible because they are contrasted against their immediate background; this background is, as a rule, the road surface (including the shoulders, side-walks etc.). Since most relevant objects are dark, with a diffuse reflection, they form a dark silhouette against a relatively lighter background. Thus, a high road-surface luminance is desirable not only to provide a high level of adaptation (thus ensuring a relatively high visual acuity) but also, for creating a bright background for the darker objects. Ideally, it should be ensured that the road surface has a lighter colour, (for example by applying white aggregates), while the object remains dark (for example by installing cut-off streetlighting lanterns and by restricting the use of vehicle head-lights as far as possible: this latter requirement is also important from the point of view of minimising glare).

However, other considerations have to be taken into account. Not only must the average road-surface luminance be high so that small objects shall be visible, but since the road surface also functions as a visual background, it is very important that no dark areas occur on the road, in which certain objects can become hidden ("camouflage zones"). On dry roads and with adequate lighting systems these dark areas generally can be avoided. However, both the choice of the road surface, (with respect to its reflective characteristics) and the design of the lighting system must be studied very carefully, to prevent the possibility of "camouflage zones" in wet conditions (see Fisher, 1968; Hentschel, 1971; Frederiksen & Gudum, 1972).

3.4. Disturbing factors: Glare

The visual performance can be reduced by various disturbances. In the following discussion we shall confine ourselves to the effect of glare. When areas (or light sources) are present within the field of vision, which have a higher luminance than the adaptation level and/or the luminance of the objects to be perceived, the phenomenon of glare occurs. Glare reduces the ability to distinguish the object to be perceived, because of the fact that, among other reasons, part of the light entering the eye is scattered. In serious cases, perception can become completely impossible. This physiological blindness or "disability glare" can be described as a (hypothetical) veil drawn across the field of vision, including the objects which it is required to perceive. The (equivalent) luminance L_{seq} of this veil can be defined numerically, by means of the well-known relationship of Holladay (Adrian & Schreuder, 1970).

Physiological glare is reduced when the intensity of the light source is reduced. However, even when glare is so weak that it does not affect the visual performence appreciably, considerable disturbance will sometimes be noticed. Since the extent of such disturbance is assessed by psychological methods, this kind of glare is described as "psychological" or discomfort glare.

Discomfort glare can be defined by a rather complicated relationship (De Boer & Schreuder, 1967; Adrian & Schreuder, 1972). Two observations are important here: - firstly, that the colour of the light has some effect, (though this is not the case with disability glare), and secondly, that the adaptation level does not influence it greatly. In relation to road lighting, these observations mean that in case of a low level of illumination the disability glare is prevalent, while, in the case of "adequate" illumination, even if observable disability glare is absent, discomfort glare can still cause a considerable degree of disturbance.

3.5. Following the road; visual guidance

Following the run of the road, i.e. maintaining the correct transverse position on the road, is mentioned several times in the patterns of manoeuvring at various levels. On the basis of the requirements established for satisfactory steering, it is possible to define certain visual requirements for various traffic installations and systems, such as road lighting and road markings, and also to some extent, for route indications etc.

4. LIGHTING REQUIREMENTS

In the preceding sections it has been shown how visual requirements can be derived from functional requirements. In the following section an attempt will be made to give more detailed information concerning photometric and geometric requirements (indicated as lighting requirements) based on the premise of road classification.

In Table 2 a general representation is given of the elementary manoeuvres, which can be executed during various types of composite manoeuvres. In Table 4, the composite manoeuvres which have to be carried out, are set out against the road categories, (as indicated in Table 3). From a combination of these data, it can be established that, when confrontations with stationary traffic-(J), and confrontations with obstructions-(L) can be avoided, the elementary manoeuvre of stopping "e",may be expected to occur only at "Journey Completed-(M)", on all roads with right-of-way; it may also occur at "avoid conflicts with slow traffic (K3)". Thus, "e" may be expected on roads in categories IX and X, resp. VI to X only. For these roads stringent speed-limits are usually enforced. If, however, stationary traffic and obstructions are taken into account, it is evident that the elementary manoeuvre "e" is necessary on all roads including motorways, where much higher speeds are permitted. In order to clarify this problem, Table 5 sets out the distance required for the manoeuvre "stop" related to driving speed, the time necessary for recognition and perception etc., and braking.
For this purpose, the well known formula has been used:

$$S = t_r V_o + \frac{V_o^2}{2a}$$

where: S = the stopping distance: (in this case equal to the required and to the available distance)

t_r = the reaction time

V_o = the initial speed

a = the rate of deceleration

In this equation the following values may be substituted:

V_o = 10, 20, 30, & 40 m/sec

a = 2.0 m/sec^2 (gentle braking)

= 3.5 m/sec^2 (hard braking)

= 5.0 m/sec^2 (emergency stop)

and t_r = 0.3 sec (for an expected event)

= 1.0 sec (for a normal event)

= 3.0 sec (for an unexpected event)

As shown in Table 5 it is found that the stopping distance varies between 13 m and 520 m, (the distance decreases with decreasing values of V_o, decreasing values of t_r and increasing values of a). It is generally assumed that unlighted objects, which are not reflectorized, become visibile to an oncoming car, (being illuminated by the car's own low-beam head-lights) at a distance of between 40 and 50 m, if such objects are expected (although their actual position and the moment when they may appear are not known beforehand) (Schreuder, 1971; De Boer & Vermeulen, 1951).
When it is considered what the reaction time t_r actually means, it seems reasonable to define the experimental situation by taking t_r = 2.0 sec, and because an emergency stop (a = 5.0 m/sec^2) usually is impossible (for example on wet roads),we come to the conclusion that in order to make the manoeuvre "stop" possible, either dual carriageways must be provided with public lighting systems (so that the visibility range of such objects can be greater than 50 m) or the speed has to be restricted to about 50-60 km/h. For one way roads and also for many motorways the situation is different, because in these cases glare occurs less frequently.

The specification for lighting systems, and more particularly, questions as to whether a road should be lit or not, have been based on safety considerations. However, it has already been pointed out that it is important to differentiate, as to whether requirements should be laid down from the point of view of safe driving, or from the point of view of maintaining a smooth traffic flow, or driving comfort. In the first place it must be stated that a certain degree of safety is an indispensable condition for smooth traffic flow and for driving comfort. It is self-evident that an accident is not conducive to smooth traffic flow or to driving comfort, not only for the persons directly involved, but also for those in the vicinity (for example piling-up behind a collision). Thus, safety requirements can be regarded as minimum requirements; the requirements established for the purpose of the smooth flow of traffic and for the comfort of driving, are, as a rule, more stringent, but essentially, they are always concerned with the visual perception of objects. Consequently, these requirements, although more stringent, belong to the same type as safety requirements. Naturally, at high speeds the braking-distance is increased and the car travels a considerable distance during the time in which a decision is made, as to which manoeuvre to carry out. Traffic must also be safe at low speeds: consequently the requirements of visibility become more stringent when the traffic is flowing smoothly and fast. For driving at higher speeds, with a certain degree of comfort, it is desirable that the strain should be less than the maximum acceptable level. All this requires a longer period of time for perception, making decisions etc. Moreover, hard braking is found to be uncomfortable, consequently the braking-distance tends to become extended. For the above cases therefore, the requirements can be expressed in terms of perceptibility distances, but the value of these is dependent on whether the requirements are related to safety, to smooth traffic flow or to driving comfort. Requirements for smooth traffic flow are more stringent than those for safety. Avoidance manoeuvres, as an emergency measure at high speeds, are difficult to perform with most cars, but not impossible. They are, however, definitely not compatible with either comfortable traffic or with traffic that is both fast and comfortable. This latter traffic condition requires continuous concentration by the driver, which must not be relaxed for a moment. It is evident that a comfortable flow of traffic cannot exist under these conditions, quite apart from the question as to whether these conditions can be regarded as safe.

A certain "feeling of safety" is an indispensable condition for driving comfort. The driver must be assured that the road indeed is free from obstacles, if he does not actually see them, for driving in a calm and relaxed manner. Consequently, it is required that the manoeuvre of "stopping" can be carried out from the point of view of comfort, even though it might be not required from the point of view of safety and smooth traffic flow. This observation is of importance when considering the question of whether rural trunk roads and motorways should be provided with a continuous public lighting system.

As an example of making decisions on different levels, the requirements for leaving a motorway will be discussed. In this case a decision has to be taken at the operation level, to carry out a composite manoeuvre, in order to leave the motorway. This manoeuvre requires information of a certain kind. For example, it is necessary to indicate that the exit of the motorway is on a particular place, and not elsewhere. On the strategical level, however, it is also necessary to know whether leaving the motorway is to take place in the direction A or in direction B. On planological level it is required to know that leaving the motorway has to be in direction A in order to arrive at the final destination C.
Lower levels than the operation level also play a part. The tactical level refers to the manoeuvres actually necessary for leaving the motorway. For this purpose it is necessary to be able to see the road and its borders in detail, for a short distance ahead. It is more important that the road surface and the road markings are visible rather than the delineators on the shoulder. If the markers reflect the light from the car's own headlights adequately, this can be used to replace the road lighting system quite satisfactorily.

This example proves that the requirements which lighting systems must meet, depend to a great extent on the decision level in question. The "International Standard Object" i.e. a square of dimensions 20 cm x 20 cm which displays a 20 per cent contrast with its direct background and is visible from a distance of 100 m, is adequate for some decisions on the operation level; but this concept does not give enough information to establish lighting requirements at tactical and steering levels (the example is taken from Schreuder, 1974).

5. CONCLUSION

The above example shows the manner in which visual requirements can be established from functional requirements; and in addition, it shows how theoretical lighting requirements can be formulated in accordance with visual requirements. The example also showed that, even for this simple example, quite a lot of theoretical information is also required which is not available at this moment.

In view of the lighting requirements, and especially,in view of technical and structural requirements, use must be made of practical experience, gained from observations and tests which have been made to date. The results of experience and the tests have two draw-backs in common: firstly, they are not systematically classified, according to to the elements and criteria - in general it is not made sufficiently clear whether the observations refer to safety, smooth traffic flow, driving comfort or costs , - since they relate to road lighting generally. Secondly, apart from lighting, other technical data are not considered in any detail, and a further limitation, particularly concerning the factor of experience, is that this can only be obtained from a considerable number of lighting installations. All this results in the fact that the lighting requirements, and the accompanying recommendations yield satisfactory results for "normal" cases (CIE, 1965; NSvV, 1975), although it is known whether the optimum has been established.

It is more important, however, to realise that very little can be said regarding situations or techniques which are still relatively unknown, or which differ for other reasons from the "standard solution".

Finally, it is recommended that more detailed investigations should be carried out, in order that the available scientific data can be applied and used for the preparation of Recommendations for Public Lighting.

Desire leads to:		level	
Individual behaviour	Collective behaviour		
selection of motive	trip generation	sociological level	1a
selection of destination	trip distribution	planological level	1b
selection of mode of transport	modal split	transportation level	2
selection of route	assignment	strategical level	3
selection of composite manoeuvre	traffic flow	operation level	4a
selection of elementary manoeuvre	traffic flow	tactical level	4b
selection of part-manoeuvre	traffic flow	steering level	4c

Table 1

1. Operational level (composite manoeuvres)
   - A just going on
   - B pass a discontinuity
   - C pass an intersection
   - D rounding a bend; a grade
   - E pass change of type of road
   - F turn off at intersection
   - G leave road (turning off + other type of road)
   - H pass car ahead
   - I overtaking and passing
   - J confrontation with stationary traffic
   - K avoid conflicts
     - K1 pedestrian
     - K2 cyclists
     - K3 slow traffic
     - K4 other motor vehicles
   - L confrontation with obstructions
   - M journey completed

2. Tactical level (elementary manoeuvres)
   - a just going on
   - b swerving around an object
   - c pulling out of the lane
   - d adapt speed (mostly reduce)
   - e stop

3. Steering level (part manoeuvres)

Table 2 Classification of manoeuvres

	paved roads			
	dual carriageway		single carriageway	
	rural	urban	rural	urban
Motorway	I design speed 120 km/h	II 100 km/h	-	-
Highway for motor vehicles only	III 100	IV 80	V 80	
"road"	-	VI 60	VII 60	VIII 50
"street"	-	-	IX 50	X 40

Table 3

composite manoeuvres	elementary manoeuvres needed	I	II	III	IV	V	VI	VII	VIII	IX	X
A	a	+	+	+	+	+	+	+	+	+	+
B	a	–	–	+	+	+	+	+	+	+	+
C	a;b	–	–	?	+	+	+	+	+	+	+
D	a;b;d	+	+	+	+	+	+	+	+	+	+
E	a;d	–	–	–	–	–	+	+	+	+	+
F	a;c;d	–	–	+	+	+	+	+	+	+	+
G	c;d	+	+	+	+	+	+	+	+	+	+
H	c;d	+	+	+	+	+	+	+	+	+	+
I	c;d	–	–	–	–	+	+	–	+	+	+
J	d	possible at all types of road									
K1	a;b	–	–	–	–	–	–	–	–	–	+
K2	a;b	–	–	–	–	–	–	–	–	+	+
K3	c;d sometimes e	–	–	–	–	–	+	+	+	+	+
K4	c;d	+	+	+	+	+	+	+	+	+	+
L	d;e	possible at all types of road									
M	e	–	–	–	–	–	–	–	–	+	+

Table 4 Manoeuvres on different level

b	a	V_o: 10	20	30	40 m/sec
	2	28	105	235	410
0,3	3,5	17,5	63	140	240
	5	13	45	100	170
	2	35	120	255	440
1	3,5	25	77	160	270
	5	20	60	120	200
	2	55	160	310	520
	3,5	45	115	220	350
	5	40	100	180	280

(a, b, V_o see text)

Table 5 Values of s (in m)

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