TRAFFIC SIGNALS AND VEHICLE LIGHTS

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1. INTRODUCTION

Modern society calls for a large amount of transportation of persons, goods and information. Transportation of persons and goods is performed by air, ship, rail and road. When one considers road transportation more in particular, it is clear that - at least at the moment and in the near future - road transportation is performed primarily by means of motor vehicles, which in their turn can be described as follows: they carry their own source of energy, they are conducted by a driver aboard, a driver who within the limits given him by the vehicle, the other traffic, the regulations and the environment may choose his own position, his own course and his own speed. This choice is made on the basis of the information the driver may collect - at that particular time and place; there is very little central "traffic control" of the type that is customary in air transportation. A certain but small amount of this information is obtained from the instruments within the vehicle, some by other means like noise and vibration, but far out the greatest portion of the information is derived from the visual inspection of the environment.

The type, the quality and the quantity of the visual information which is needed depends, obviously, directly on the things the driver wants to do on the basis of this information. Thus, the driving task has a central position in the considerations regarding the visual information.

Driving a car depends upon the decisions made by the driver. More precisely, driving a car - and this holds also for taking part in traffic in other modes - can be adequately described by a hierarchical sequence of decision making processes. In each of these processes, it is possible to indicate the normal phases: the acquisition of the information needed, the decision itself and the execution of the activities that follow from the decision. We will come to more details in this process later on, notably the phases of coding, decoding and feed-back.
First, however, it is necessary to add a few things on the hierarchical sequence. Apart from decisions related to the aim of the transportation process, the purpose and destination of the trip, and the selection of

the mode of transportation, the actual driving of a car involves three distinct levels. These are related to:

- the selection and the following of the route
- the performance of manoeuvres while driving
- the actual vehicle handling.

The distinction between these three levels is based firstly on the different "time constants" of the processes involved: the route selection has a time constant (that is the area of magnitude of the time over which the direct consequences of the decision making process stretches out) of some minutes or tens of minutes; the manoeuvres stretch out over minutes or fractions of them, whilst the acts regarding vehicle handling takes place in seconds or fractions of them. Secondly, there seems to be a true hierarchy: performing manoeuvres is not possible without handling the car; route selection requires manoeuvres. Thus there is a sequence of priority. At the other hand, route selection and following can be described completely in terms of vehicle handling acts (Schreuder, 1974, 1975, 1977).
Thirdly, there are reasons to believe that the three levels involve fundamentally different physiological and psychological processes. Although this point does require further study, it is clear that the "higher" levels are more of a cognitive nature (they involve a fair amount of reasoning and conscious knowledge) whereas the lower levels are most of the "basic skill" type, requiring training and experience rather than knowledge (Janssen, 1979; Godthelp, 1978).

It should be noted that the concept "decision" is used here in a rather vague, general sense, and not in the specific sense used in the psychology of decision making. What we mean here is an expression of the notion that in the prevailing circumstances certain activities are required from the part of the driver, activities that can be selected from a number of alternatives. The decision process is the process where from these alternatives the most rewarding is selected.
This requires (at least) three distinct aspects:

- the acquisition of the information from which the need to make the selection, and often also the possible alternative actions can be derived;
- the availability and the application of a set of criteria by which

it can be judged which of the alternatives is likely to be the most rewarding;

- a feed-back system which allows to find out whether, after the performance of the action, this particular action really proves to be the most rewarding. In most cases, this feed-back system is identical to the original system used to acquire the information (Schreuder, 1971).

A few remarks should be added. Firstly, in many cases the information which can be derived from the environment, is coded. Thus, before this information can be used, it must be decoded. Obviously, the coding and decoding keys must be known to the one who has to use the information - in this case, the car driver. Secondly, during the acquisition and the processing of the information, it is likely that disturbances from the environment may be felt. In many cases these disturbances have characteristics similar to the information that is to be used - in terms of the communication theory, they are information as well. However, the information is redundant or, even worse, disturbing or conflicting.
conflicting.

Thirdly, decisions can be made only if there is some "frame of reference" consisting at least of a set of criteria which allow to estimate the quality of the outcome of the decision making process. In most cases, these criteria are based on a large variety of different sources, amongst them the residue of earlier experiences. This implies that one should never expect that the decision will be made exclusively on logical grounds. In fact, there are reasons to believe that the majority of the decisions to be made while driving a car, are made primarily on non-rational grounds. This may help to explain the fact that the application of the "classical" decision making theory did not help very much to understand what is going on in actual, real road traffic (see L.G. Vlek & Wagenaar, 1979).

And finally, it should be pointed out that there is a fundamental difference between <u>information</u> and <u>message</u>, in spite of the fact that in the literature these two concepts often are considered as synonyms. The message is the content, it is the actual cognitive content that should be transferred from one to the other (from one <u>person</u> to the other <u>person</u>, to be more precise). What the cognitive content actually

does mean depends on many things, not only on the sender of the message and the receiver. The information at the other hand is the amount of data that are transferred. In many fields of application the information can be expressed quantitatively in the number of bits (binary digits) that is conveyed.
When a message is coded (e.g. in a Morse code) the information can be quantified in the number of dashes and dots. However, also the communication theory is aware of the problem of the meaning of the message It is customary to make a distinction between metric information (the number of dashes and dots) and the semantic information (the actual contents). See e.g. van Soest (1956), Shannon & Weaver (1949), Cherry (1966) or Broadbent (1958).

Finally, a remark regarding the set-up of this paper. After this introduction and a general discussion on information processing, the information requirements on three distinct levels of decision making will be discussed and from this the functional requirements for the information carriers are derived. This leads to a rather general discussion of the technologies involved. The paper ends with two chapters on specific information carriers, viz. vehicle signalling systems and road markings. This is done in order to emphasise the fact that those two information carriers are related simultaneously to at least two of the levels of decision making. And it may be noted in passing that the electronic "signalisation systems" are not discussed here because they operate - in the few cases they do exist - without being noticed by the drivers, excluding of course the displays. These are discussed as far as relevant.

2. THE PROCESSING OF INFORMATION

We have suggested above that the three levels of decision making involve different psychological processes. Looking at it from a more practical point of view, it is obvious that the three levels require different types of information and different types of information presentation.
In all cases, there are certain objects in play, from which information of some kind is needed. This information may be of one out of two kinds and will include either signals or cues according to the following description.

The object itself or some characteristics of it (in this case described as signals) is set up on purpose in order to convey a message of a kind to the observer. The message usually is directly connected to the driving task and particularly to some kind of required response, such as: stop, or keep right. This message is conveyed to the observer in a coded fashion (such as a red, circular light, or a white arrow on a blue background). The message is made explicite, and the coding is conventional. The message is coded in the object and decoded by the observer; thus, the observer must know the coding-key. Further, the coded message may suffer from disturbance (or "noise"). It should be realised that according this description "road signs" should be classified as "signals".

Another type of information is conveyed by objects within the field of view that are self-explanatory. Mostly they are not placed on purpose, and are often "just there". Usually, such objects are called "cues". The information they convey is implicite and non-conventional, and they relate to the stimulus aspects rather than to the response.
As an example, the curvature and lay-out of a bend will indicate to the (experienced) driver which will most likely be the appropriate speed to round that bend. However, contrary to the case of signals the speed itself is not indicated; it is left to driver to decide upon this.
As the objects are self explanatory, these is no coding. The information can therefore be used by all (experienced) drivers. On the other hand

the information is implicite and because the objects often just "are there", specifications of the objects cannot be set up.

The distinction between signals and cues is not an absolute one. In some cases it turns out to be useful to define an intermediate form. These may be indicated as "markings". Markings may be considered as signals with a very simple message (such as "presence" and nothing more) or as cues (cue-objects) that are placed on purpose without, however, the explicite purpose of conveing a coded message. Thus, a row of dots or cats-eyes on the road may have no particular coded, legal meaning, but it marks clearly the centre of the carriageway. On the other hand, when a continuous line is present at the middle of the road, this line may not be crossed.

At day under normal weather conditions, the cue-objects, being mostly self-explanatory, offer little problems as regards their visibility, as long as they are properly placed, large enough, and show a distinct contrast (both as regards colour and luminance) with their direct background. Signals that convey coded information need often a special treatment. In many cases these objects are in fact (signalling) lights and the message is coded by means of colour, size, shape, configuration, intensity and flashing frequency of these lights.
At night, or under situations of reduced visibility (fog, snow, heavy rain) most non-luminous objects are not visible any more. Special measures are needed in order to maintain the information transfer. At night this is generally realised by shining light directly to these objects, trusting that they still will be self-explanatory. It is one of the major aims of public (overhead) lighting to provide just this (CIE, 1977a; Schreuder, 1975).

A third group of information carriers can be indicated: the carriers of information expressed in words. Here, not only the coding key must be known to the driver, also the language that is used. For obvious reasons this type of information transfer has great disadvantages for countries like those in Continental Europe, where a large part of the drivers are foreign. Thus, according to the Vienna convention, signs with words should be avoided as far as possible.

3. ROUTE SELECTION

Before a trip is made, a number of decisions must be made (Asmussen 1972, 1974; Schreuder 1972, 1974). They are related to the reasons to make the trip (e.g. economic or social reasons)in combination with the trip destination. Further the decision regarding the mode of transportation must be made (e.g. car or rail). However, as the decisions have to be made before the trip is started, the information must be provided before the begin of the trip as well.
Therefore, the aspect of the decision making process, and the related aspects of information acquisition and processing, will not be discussed here. It is customary to exclude them from the discussion on the driving task as well, although they are essential in many considerations of the transportation decision making process (Griep, 1971, 1972).
The "highest" level discussed here is the selection and following of the route. It might be argued that the selection of the route also has to be done before the beginning of the trip. As, however, the type and amount of information for the selection of the route, for the selection of alternative stretches within the route, and for the control of the following of the route are very similar, it seems justified to look at them simultaneously.
The information required for the selection of the route is primarily cognitive of nature. The decision of the route, i.e. the relation between alternative routes, however, is not a fully rational one.
It has been argued that apart from economic consideration regarding distance, travel time and their monetary consequences, also the total amount of stress (experienced or expected) also plays an important role. See Janssen (1980).
The information required to select and follow the route is expressed in geographical terms. A large amount of study has been performed to find out the best way to present the information to the driver, so that he can perform his task in an optimal fashion. This includes the preference of names of towns and/or road numbers, the distribution of the amount of information on road signs and road maps and, in some occasions, radio broadcast. However, in all systems the road sign

is an essential part. And again very much research has been executed on the best way to make signs (regarding the colour, the colour difference, the dimension of signs and letters, but also regarding the type of messages, the length and number of words, the letter shape etc.).
The relevant literature is surveyed by Dutruit (1976), Godthelp (1977), Richardson (1976), Rumar & Ost (1974), Van Norren (1974, 1977) and Youngblood & Woltman (1971).
All this could be regarded as forming part of the problem how to frase (to code) the message so that the driver can grasp it.

A separate problem is, what is the best way to make the information available to the driver. This deals with the transfer of the information proper.
Nearly all the research regarding this problem has been focussed on the traffic signs. When one considers the requirements for traffic signs and the way these requirements are implemented in their design, the first question one must answer is related to the distance from which the message must be "read". This distance depends on two things: first the driving speed, and second the things the driver has to do when he has received the message. When the message has to do with continuous aspects of the route (e.g. priority road, dual carriage-way road, etc.) the manoeuvre to be performed by the driver is the most simple one, i.e. "just going on". (The different manoeuvres will be discussed later on). Thus, the reading distance does not need to be large. If, however, the message requires a drastic manoeuvre from the part of the driver (e.g. town A to the right, town B to the left), the reading distance must be much larger, particularly if the speeds are high and the road is constructed in such a way that discontinuities in the driving are not very likely. This is particularly the case on motorways; therefore, on motorways all signs must be large and often pre-warning signs are required to ascertain adequate reading distance.
The required reading distance depends, as has been indicated, on the driving speed and on the type of manoeuvre to be expected - and thus to a large degree on the type of road. It does not, however, depend

to any large degree on the lighting or visibility conditions. In particularly, the reading distance at night must be just as large as the required distance during daylight. When the signs carry their own lighting (either floodlighting or transilluminated) this is not a difficult problem. Some regulations and suggestions are published by the CIE (Anon, 1978, 1978a). However, equipping each sign with its own lighting installation is a very costly affair, particularly on overland roads in areas with a low density of the population. Therefore, one tries to equip the signs in such a way with retro-(re)flecting material that with vehicle headlights alone, adequate visibility is ensured.

A large volume of research has been executed in this area, and it has been found that, when certain precautions are made, it is possible to ensure adequate visibility (adequate reading distance) even when only low-beam headlamps are used. Some of the more relevant studies are quoted by Robertson (1973). As an overall conclusion it can be stated that reflectorised signs with high-intensity material perform as well as signs with separate lighting. See also Krochmann & Terstiege (1980) and Rosenthal (1979).

All this is related to aspects of the route that are constant in time. However, in some cases it is necessary to indicate to the driver, that changes in the route become necessary. For this application a number of constructions (e.g. variable messages/signs) are proposed.

4. MANOEUVRING

It has been suggested that manoeuvres can be subdivided in two groups. The dirst group consist of fairly complicated manoeuvres (sometimes called the complex manoeuvres, Schreuder, 1974), a group which comprises actions like overtaking and passing vehicles when opposing traffic is present, or passing intersections when other traffic approaches on the side roads.
These manoeuvres can be thought to be assembled from more simple actions, which are therefore called "elementary manoeuvres" (Schreuder, 1974). A small number seems to be sufficient to describe all possible complex manoeuvres:

- coming to a stop
- adjusting (reducing) speed
- pulling out (leaving the traffic lane)
- evasion (within the traffic lane)

and for the sake of completeness the fifth:

- just going on.

(This fifth should be included because it is quite possible to make the conscious decision just to go on; thus it should be called a manoeuvre although very little will show).
The two groups are isolated because the underlaying processes are probably quite different. More specific, one may expect that the complex manoeuvres are selected on a more or less rational basis, that their selection involved the utilisation of rather elaborate amounts of information, that the effects of such decisions make themselves felt over some considerable time (maybe minutes or at least tens of seconds) and that the acquisition of the skills to select and execute the more appropriate of the alternative manoeuvres follows rather formal schooling. This in contrary to what one can expect as regards the elementary manoeuvres: the selection must be made often in a short time so that there is not much opportunity for rationalisation. The effect, however, is also short in time, and the required will probably rests more on training than on education (Krendel & Mc Ruer, 1968). There is, however, good ground to bring both groups together under the main heading: manoeuvre, because the kind of information required is rather similar. More in particular, the reason to perform manoeuvres

of either of these groups is primarily the result of the fact that, in a more or less unexpected way, the near future is different from what was anticipated. The unexpectedness may be the result of two distinct causes: either the road (or the near surrounding) is different than anticipated - this implies a sudden discontinuity - or the other traffic changes its influence (See Janssen, 1974).

The discontinuities in the run of the road are nearly constant in time. Thus, the signals to be given to the driver related to these discontinuities can be also constant in time. These signals are either road and traffic signs or road markings. The signs follow the same rule as those which are discussed in the foregoing section. The road markings are a very important group of signals; because they are important as carriers of information for the elementary manoeuvres (see next section) as well, they will be discusses in a separate section. It is sufficient here to indicate that road markings belong to the group of signals that offer structured, and mostly non-coded information.

The signalisation as regards the other traffic can be split up in two distinguished groups. The first are those signals that are applied to regulate the traffic: the signals for road traffic control or, more brief, the traffic lights. Traffic lights are a major constituent of the modern traffic scene, particularly in built-up areas. A vast amount of research had been executed in the last two decennia, resulting in a fairly generally accepted view what are the requirements for effective traffic lights.

They can be summarised as follows:

- the colour should be limited so that in particular drivers with defective colour vision have as much information as possible. This leads to an orange-like red, a pure yellow, and a blue-ish green. The precise colour boundaries are given in CIE reports (Anon, 1975). See also Table 1 and Figure 1; Anon, 1973; Cole & Brown, 1966; Verriest et al, 1980).
- at day, the luminous intensity in the beam centre should be not less than 200 cd maintained value. The maximum value should be not so large as to cause glare. At night, glare is avoided and visibility is ensured if the intensity is between 50 and 100 cd. Values under 25 cd or over 200 cd should be avoided at night (Adrian, 1963; Anon, 1973, Fisher & Cole, 1974).

- for normal urban conditions, where on complicated intersections usually more than one light faces the traffic at the same time, the beam width usually is adequate if the luminous intensity is over 100 cd for angles smaller than 11^{o} laterally and 8^{o} downwards from the beam axis. This implies precise adjustment at the intersection and also a good lay-out of the intersection itself (Fisher & Cole, 1974; Anon, 1980).
- directional arrows and symbols on traffic lights should be light-emitting on a dark background. In this way, medium-range recognisability is ensured by avoiding excessive irradiation, in spite of the fact that a black figure on a light background might result in a somewhat larger detection distance (Horeman & Zwart, 1965; Rutley & Christie, 1966).
- visibility of the signals is increased, and the possible confusion with other (non-operational) lights is decreased when the sun-phantom is reduced as far as possible. At present, it is not yet possible to give quantitative data or regards the phantom reduction, because a good measuring procedure is still lacking (Schreiber, 1967; Anon, 1980).
- the use of background shields around the signals is recommended, particularly if the signals are seen against the direction of the sun, or against the clear sky (Anon, 1973, 1980).

And secondly: traffic lights are usually placed in fixed positions. This implies that information regarding the movements from the other traffic (the other vehicles) themselves should be provided by other means. Apart from the "self-evident" type of information which is presented by the vehicles as a whole, and which can be enhanced at night by public (overhead) lighting, the obvious way is to attach the signal directly to the vehicle.

First a few remarks regarding the lighting of these "self-evident" type of information carriers. In most traffic situations it is enough to illuminate "objects" that are nearly straight ahead of the vehicle. Such "illumination" is needed primarily for the self-explanatory objects that convey structured or unstructured information. As regards vehicular road traffic at night under normal weather conditions, the illumination can be realised adequately in two distinct ways: fixed (overhead, public) street lighting, and lighting by means of vehicle headlamps. Under optimal conditions, the visibility can be similar with these two systems. Both, however, have severe draw-backs. Public lighting is expensive and is therefore often considered as not justified economically for rural roads with little traffic. Vehicle lighting causes severe glare for opposing traffic (both vehicles and pedestrians). The glare can be reduced by the adoption of low-beam (passing beam) headlights, which, however, can be used safely only for low speeds, and which suffer from dirt, water and misaim. The glare can be avoided by the application of polarised headlights, by one-way roads, or by dual-carriageway roads with very wide central reserves - all three expensive.

For adequate visibility, the luminance in the field of view - or at least in the important parts of it, such as the road surface ahead, and the objects on or near it, should be in the order of 1 cd/m^2. For public lighting this falls well within the region of what is technically speaking easy to make, but as indicated the costs are high. Also this level can be realised with high-power high-beam vehicle lights of some 10^5 to 10^6 cd. With low beam this luminance level can only be realised at a short distance in front of the car.

There should be mentioned, however, another factor. With overhead lighting, most objects stand out as a dark silhouette against a relatively light background. With vehicle lights, the reverse is true. Thus, the combination is often less favourable, because the two may counteract. Research and practical experience did show that when as a result of overhead lighting the luminance (e.g. the average road surface luminance) is over some 0.2 cd/m^2 the visibility of objects is not improved when low-beam headlights are switched on even although at 0.2 cd/m^2 the visibility as such generally is definitely inadequate. The obvious exceptions are: reflectorised materials, and objects at very short distances (SWOV, 1969; Schreuder, 1971a, 1976).

As regards the influence of other traffic participants, the following remarks can be made. These remarks are made here with the emphasis

on motorised traffic, notably on cars; they can be adapted to the circumstances relevant for other vehicles and traffic participants. The signalisation of pedal bicycles and pedestrians, will be explained in a further section.
Signals other than light signals have been abandoned gradually.
Hand signals, quite common in the days of the horse-drawn wagon, proved to be not effective enough for the high-speed motor traffic - not only at night, but also during the day. The result is that nearly all signals used in modern traffic are light signals.
Their function is two-fold. Firstly, the presence of the relevant object has to be signalled. This sets some requirements as regards the light intensity and position of the "marker" lights, but sets none as regards colour, configuration, etc. Secondly, several characteristic aspects of the relevant object have to be signalled. Which aspects are most important depends amongst others on the traffic situation. Some lights serve a double purpose, i.e. marking and signalling. It should be kept in mind that if a high intensity is selected for the marking function, the signalling function may suffer from this.

By "signalling" we have defined as: putting across a coded message by means of a light signal. The possibility of decoding must be considered as part of the signalling system. As said above, "marking" may be considered as a special case of "signalling" (i.e. signalling the presence and nothing more).
Signalling, taking in this sense, is a complex problem for the following reasons:
a) simultaneously a number of variables may have to be signalled to others;
b) is is not always clear for whom the signals are meant: for which category of road users and for which traffic situation. The only certainty is that they are <u>not</u> meant for the driver of the vehicle to which the signals are attached;
c) in the case of signalling all directions must be considered, and not only the front of the vehicle;
d) particularly in respect of signalling towards the front of the vehicle, matters may be considerably complicated by the presence of (glaring) headlamps;

e) most signals are not continuously in operation;
f) not only the position of all relevant objects (i.e. vehicles) at a certain time is important, but it is also extremely important that some sort of prediction should be made about the future position and changes therein.
g) if the relevant object is a moving vehicle, it must be possible to differentiate very clearly its front and rear, i.e. whether it is approaching or moving away.
It is possible to incorporate these considerations into a system that could be indicated as an optimal, integrated system for vehicle lighting and signalling. In a further section, a suggestion for such a system will be given.

When setting up requirements for the signalisation of pedal bicycles, we must consider the fact that the electric-power supply is very limited indeed - in fact so limited that it is not possible to have a reasonable lighting of the path ahead and a reasonable signalling at the side and the rear simultaneously. This automatically leads to two district "schools of thought". In spite of the fact that the lighting of the path ahead is essential for safe and comfortably riding a bicycle (ISO, 1978), it seems justified on the basis of the accident data to consider adequate signalling, particularly at the rear is still more essential (Schreuder, 1980; SWOV, 1973, 1976): based on the evidence for The Netherlands we may estimate that the number of fatal accidents in which cyclists are killed resulting from lack of rear lighting is 10 or maybe 100 times as large as the number of fatalities which can be attributed to lack of front lighting. It should be mentioned here that in The Netherlands retro(re)flectors of a reasonable quality at the rear end of pedal bicycles have been obligatory for many years; they seem therefore to be not effective enough. Recently, the requirements for reflectorisation of bicycles have been made more strong.
It is likely that, in view of the large differences between countries as regards the equipment of bicycles, the road and cycle-path infra-structure, and the age built-up of the cyclists population, the results found in The Netherlands cannot be applied immediately to other countries (OECD, 1971, 1975, 1976, 1976a, 1980; SWOV, 1976). See also Sator (1979).

Pedestrians present a still different problem. Generally speaking, they are not very open to suggestions related to safety measures. May be this has to do with the age distribution of pedestrians: in comparison to the population of motor-vehicle drivers or of moped or bicycle riders, the very old and the very young are more represented. For all practical purposes this implies that signalling lights will not be carried by pedestrians, and that even the use of retro(re)flectors will counter severe opposition. Still, it has been found that well-aimed and well executed propaganda can have favourable results (OECD, 1980). However, one might expect more effect from traffic measures (e.g. walking against the direction of traffic) or, even more, of infrastructural measures (e.g. side-walks, pedestrian crossings etc.).

5. VEHICLE HANDLING

Vehicle handling covers what is often called the actual control task. Here, most research is conducted along the lines of cybernetics, focussing on optimalisation the man-machine system. This level is restricted to those aspects of the driving task that are performed on an automatic level - that is, after adequate training. A survey of the literature is given by Blaauw (1979), who has indicated that firstly the research has been initiated in the areas of air and space travel, and that secondly the approach is too restricted to be applied on road traffic. See also Blaauw (1980, 1980a), Godthelp (1980), Riemersma (1979, 1979a), Veling et al (1978). Here, two aspects particularly should be mentioned: the control task is considered to be monodimensional, i.e. only one variable at the time, and also it seems that the purely mechanical approach is not sufficient to explain driver behaviour. Thus, many researchers who begin, like McRuer and Weir (see McRuer et al, 1977), with simple closed-loop systems add personal (personality) aspects to their models forming sometimes queer sorts of appendices (e.g. Peranio, 1971: see Schreuder, 1973 and OECD, 1972). The model described here does not have these restrictions, being essentially a hierarchical sequence of decision-making processes. The task elements on this (lowest) level seem to be quite simple. In fact, there are only two, because the road vehicle is essentially a vehicle with two independent directions of movement.
This means that the two control tasks are independent of each other - at least as a first approximation; they relate to the control of the crosswise and the lengthwise position. The first can be described as keeping the lateral position (within the driving lane) as closely constant as possible. In fact, it seems that the angular velocity of the aiming angle, and the lateral velocity are the best criteria for this (Riemersma, 1979a). It may be added here that McLean & Hoffmann (1972) prefer the direct control of lateral error. The second has to do with the foreward movement, and will most probably be described by the task of keeping the foreward velocity constant. In case there is a car ahead, it seems more likely that the task is transformed into keeping the distance to the leading vehicle constant. It should be

noted that this implies that the velocity of the leading car is constant. If this is not the case, the manoeuvre becomes more complicated and should be considered as belonging to a higher level.

On this vehicle handling level we consider the classical "car following" task (Botma, 1976; Edie, 1961; Haight, 1963; Prigogine, 1971).

The visual requirements for these relatively simple tasks are rather simple as well. In order to maintain a lateral position close enough to the desired position, only small steering corrections are required. For this, it is sufficient that the lane markers are visible, and only for some scores of meters. At day, and also at night under dry conditions, this can easily be arrived at by ordinary road-marking materials. Problems, however, can be quite serious when the road is wet. Because road markings have to fulfill other requirements as well, we will discuss them separately.

Maintaining constant speed does not seem a very complicated matter. We might expect that apart from visual information, also auditory and kinestetic cues will be used. However, there has been little research on this matter. The task to keep the distance to the leading vehicle constant is more critical, both as regards the visual aspects as the consequences on road safety. The research in this area is mostly restricted to highly schematised laboratory set-ups, so that it is not quite clear in how far the results can be applied to real traffic situations (see e.g. Fisher & Hall, 1978; Janssen, 1974a). The major conclusion, which seems to be generally applicable, is that it is best to have the signalling system symmetrical at the rear of the car. This has been elaborated upon by Roszbach (1971, 1972, 1974).

Based on these results and taking into account the studies by Mortimer (1969, 1971, 1979), Schreuder (1971, 1971a, 1976), Rumar (1970, 1972) and others, a suggestion for a signalling system for motor vehicles is given. This suggestion is described in a separate section.

6. AN INTEGRATED LIGHTING SYSTEM FOR MOTOR VEHICLES

In Section 4 a number of considerations have been given that relate to the signalling aspects of motor vehicles (notably cars) at the level of manoeuvring; in Section 5 further aspects are added related to the level of vehicle handling. This can be incorporated in an integrated signalling system for motor vehicles. Integrated means that all lighting aspects are being taken into account; it should be pointed out that the aspects of "illumination" have been dealt with already to some extent in Section 4. In this section, a suggestion for such an integrated system will be given. In this example, there is quite much in common with to-day's practice, but there are also important differences. Introduction of a system like this will cost money, and therefore should be considered very carefully. The benefits cannot be quantified in detail at the moment. However, it is likely that such a system will improve road safety and driving comfort in a degree which can be indicated qualitatively.

The suggestions given here are based on the following considerations:
a) signalling lights for position, speed, and their change and future changes, are indispensable.
b) such signalling lights must operate at day and at night, and in different conditions of visibility.
c) it is required that several classes of vehicles can be distinguished like bicycles, cars, long or very wide trucks, slow-moving vehicles.
d) the signalling is needed for all directions.
e) at night without public lighting (or with lighting of poor quality) vehicles need lights to illuminate the road.
f) the driving task should be kept as simple as possible.

As said earlier, when signalling lights are used for these purposes, they will have to convey coded information. As regards the possibilities of coding a message, the literature leads to the following conclusions:
a) colour is not suitable as a primary coding dimension (Hargroves, 1971; Projector et al, 1969; Roszbach, 1972, 1974; Schreuder, 1976, 1976a).
b) because red is nearly exclusively restricted to the rear of vehicles, only yellow and white are left for the vehicle front lighting (Schreuder, 1976).

c) the dimensions are not critical for the signalling function. This leaves ample for the design of the signalling lights (Anon, 1980; Janssen, 1972).

d) the luminous intensity should be adjusted to the environmental conditions. The following values can serve as a first approximation:

- night, clear atmosphere	20 - 1000 cd
- night, fog	200 - 2000 cd
- day, clear atmosphere	200 - 2000 cd
- day, fog	over 5000 cd

(Balder, 1956; Behrens & Kokoschka, 1973; De Brabander, 1972; De Boer & Vermeulen, 1951; Fisher & Hall, 1970, 1978; GTB, 1960; Janoff et al, 1970; Jehu, 1965; Moore & Cooper, 1972; OECD, 1976; Pocci, 1960; Schreuder, 1976; SWOV, 1969; Thiry, 1971).

e) the configuration of the lights on the vehicle offers possibilities for indication of the class to which the vehicle belongs (Roszbach, 1974; Attwood, 1976).

f) a standard position makes the estimation of distance and speed (differences) more accurate. Furthermore, the position on the vehicle may influence the visibility (Mortimer, 1969, 1971).

All this is incorporated in the suggested system as given in Table 2. When this suggestion is considered for application on cars, all signalling lights should be placed symmetrically on the vehicle.

Some further simplification can be considered. It may be assumed that three levels will be sufficient for nearly all cases:

- high for daytime and reduced visibility
- medium for day, clear atmosphere and night, reduced visibility
- low for night, clear atmosphere.

Further, it can be assumed that for direction indicators and brake lights, two levels will be sufficient: no separate low level seems necessary because the risk of glare is not great for lights which are not constantly in operation. Thus, only medium and high are necessary.

Next, it is assumed that the high-level front-marker lights can be used as well to illuminate the road when no adequate road lighting is present.

Finally, it is usually considered possible to have lower intensities at the rear and the side of vehicles than at the front. This assumption looks sensible with regards the difference in relative speed.

These considerations are included in the example given in Table 2.

7. ROAD MARKINGS

In the preceeding sections we have mentioned road-marking systems already several times. We will begin our discussions on road markings with some quotations from the comprehensive OECD report (OECD, 1975a). A clear and precise system of horizontal signing in the form of road markings together with lateral delineators (posts) serve a special purpose by facilitating driver guidance, thus improving traffic flow and contributing to driving comfort and safety.

Although investigations have shown that the driver's eye is much more attentive to markings on the roadway than to lateral signs (Bhise et al, 1975; Rockwell et al, 1970), such as delineators, these nevertheless have the advantage of remaining visible under conditions such as very dense traffic, heavy rain and snow. Lane markings on the roadway help drivers to keep within lanes and ensure, together with directional traffic arrows, a better distribution of traffic flow on the roadway, thus making traffic more fluid. Edge markings and delineators make the limits of the roadway show up more clearly and provide optical guidance. These types of longitudinal markings also provide valuable guidance for driving at night or in fog. The purpose of markings such as solid longitudinal lines, arrows, stop lines and marked surfaces is to indicate the driving manoeuvres to be carried out or ensure that traffic restrictions are obeyed. They thus greatly contribute to facilitating traffic control, especially at intersections (OECD, 1975a; Serres, 1975).

On the basis of studies carried out it can be concluded that the improvement of traffic service offered to road users by applying road markings has a beneficial effect on traffic fluidity and driving comfort and may also enhance traffic safety (O'Flaherty, 1972; Musick, 1960; Womack, 1966; Charnock & Chessell, 1978; Anon, 1972; Wilson, 1960).

A general awareness that uniformity of the use of marking devices was desirable, especially because their geometric form and colour constitute as messages to drivers, gradually led to a set of regulations specifying shape and colour of marking devices. International standardisation also

proceeded and has led to the "Convention of Road Signs and Signals, opened for signature in Vienna on 8th November, 1968" (Vienna Convention). In Europe, more detailed regulations are given in the "Protocol on Road Markings, Additional to the European Agreement Supplementing the Convention on Road Signs and Signals opened for signature in Geneva on 1st March, 1973" (European Road Marking System) of the E.C.E. (Economic Commission for Europe).
The regulations of different countries should be consistent with these international standards. However the regulations of the United States "Manual on Uniform Traffic Control Devices for Streets and Highways" differ to some extent from those of the "European Road Marking System", although both are consistent with the Vienna Convention (after OECD, 1975a).

Road markings have a number of functions, which lie in different levels of decision making. The major functions are related to

- selection of the route (warning signs, locations etc., indicated by letters and words).
- selection of specific manoeuvres (stop signs, directional arrows, stop lines, zebra crossings etc.).
- control of specific manoeuvres like rounding bends, negotiating intersections etc. (side markings, delineators etc.).
- selection and control of elementary manoeuvres at the vehicle handling level. This pertains primarily to the control of lateral position within the traffic lane (lane markers).

As regards the visibility aspects, we will concentrate on the markers actually on the road, as they are usually the most critical. As they carry their own lighting only in exceptional cases (Schwab, 1972 ; Harrigan, 1977; Hopkins & Marshall, 1974) the visibility is in nearly all cases gouverned by the contrast between the marking and the adjacent portions of the road surface. As the markings are placed directly on the road surface, the illumination (and hence the illuminance) of the marking and the adjacent portions of the road surface are to be considered for all means and purposes as identical. Thus, the contrast (the luminous contrast) is determined exclusively by the differences in the reflective properties of the marker and the road surface.

The reflection of a body (i.e. the amount of light which is reflected by the body in the direction under consideration - usually the direction of the eye of the observer) can be described by the incident light (directions, quantity, spectral composition etc.) and the characteristics of the material of the body. This implies a large number of variables, and one should not be surprised to find that the assessment of the contrast between road markings and the adjacent portions of the road surface proves to be a rather complicated affair.

As regards the illumination, a distinction should be made between two ways of light incidence. The first is the more or less diffuse (i.e. from several directions at the same point) illumination such as prevails during the day and with public overhead lighting. Because at a specific point of the road surface, and thus also at the road marking attached at that point, the light comes from different (often very many) directions, the resulting luminance can be described rather precisely by the diffuse reflection of the materials of the road surface and of the marking. It turns out that as regards the visibility of road marking it is not necessary to make a difference between daylight and public lighting, nor to specify in detail the type of public lighting - this contrary to the experience in road lighting in general (See e.g. De Boer, e.d., 1967). The second system of illumination to be considered when dealing with road markings is the lighting by means of vehicle headlighting. Here, the direction of incidence of the light co-incides nearly (but not fully!) with the direction of observation. Furthermore, neither the direction of incidence on the object to be illuminated, nor the direction of observation, nor the angular difference between these two directions may be considered as constant. In fact, all these may change quite considerably for different distances between the observer and the object. At present, there is much discussion going on on this matter; even the basic terminology and the basic concepts of the geometry for observation and for measurement are not in agreement.

As far as the objects are concerned, the reflection can be described in terms of retro - reflection (again here the terminology is confusing and inconsistent; from linguistic point of view the term to be preferred is retroflection; see Schreuder, 1980a). Before this point is discussed further, one more remark: it is customary to deal with the visibility of road markings by considering only the way car drivers look at them. This, however, is obviously a restriction; when one considers the visibility of the road markings used for pedestrian crossings (zebra stripes) one must take into account the fact that the pedestrian looks at it from a completely different direction as does an approaching driver.

The second factor which determines the lumimance of the materials involved, and thus any contrasts between them, is, after the illumination, the reflection. Here, one must discern several aspects. First the properties of the material itself, then the properties of additives (e.g. ballotini), thirdly the shape of the material as it is used in road markings (e.g. corner-cube reflectors) and finally the state the marking is in.
The last point is of major importance, particularly as regards the possibility of a water layer on top of the surface. This layer most probably is much more important than the aspects of dirt and wear.

The different types of reflection are described in detail in the literature (e.g. Serres, 1975; OECD, 1975a, etc.). In diffuse reflection the light is scattered in different directions, so that the resulting luminance depends only on the illuminance and the reflection factor. In specular (mirror) reflection Snell's law is followed, and the luminance of the object is zero seen from most directions. Only in the specular direction the luminance is not zero; then it equals the luminance of the light source, multiplied by the (specular) reflection factor. Although these two ways of reflecting light are theory only, it turns out that most practical surfaces can be considered for most applications as belonging either to the one or to the other group.
It is customary to add "retro-reflection" as a third class. This is very useful for practical purposes; from theoretical point of view, however, it is not fully justified. Retro-reflectors of the corner-cube type consists essentially of mirrors that are placed in such a way (the way as a corner of a cube!) that all incident light is reflected three times, and it is re-emitted in the same direction from where it did come - independent on the position of the reflecting element in relation to the

incident beam.
Retro-reflectors of the ballotini type are in fact ordinary reflectors - usually of the diffuse reflecting type, and in the high-intensity class often of the specular type - where the glass beads or ballotini serve as auto-collimators.
The end effect is that most of the light is re-emitted again in a direction close to the direction where it did come from. One more point regarding the glass beads. Now, a sphere of glass acts as a lens, focussing a parallel beam of light. When the lens is spherical and made of ordinary glass with a refractive index of some 1.5 to 1.7, the focal point will be behind the lens. A reasonable "degree of retro-reflectiveness" can be arrived at only when a reflecting surface (e.g. of the specular kind) is placed in the focal point, i.e. at some distance behind the lens. This is the usual construction of retro-reflecting materials of the high-intensity type. In most road marking materials, however, the glass spheres (or glass beads) are placed directly on or in a white, diffusely reflecting binder; in this case the "degree of retro-reflectively" is usually much lower than can be arrived at with the (sheet type) materials (see James & Hayward, 1960; Dray, 1977; Morren, 1979).
The reason is that the collimating effect is not optimal when the re-flector is not in the focal point, but ahead of it. Obviously, this draw-back can be avoided by selecting glass with a refractive index of 2.0, so that the focal point is exactly on the rear surface of the sphere (see Walther, 1959) or by making the lens longer than would correspond with a sphere (the "elongated sphere"). This last construction allows the use of ordinary, cheap and wear resistant glass, and still arrive at a "high degree of reflectivity". Such elongated spheres, however, require precise manufacturing and accurate adjustment, so that they cannot be used as pre-mixed or sprayed-on beads. In fact, they are usually made quite large, and are incorporated in the reflectors of the well-known "cat's eyes" type.

Under day conditions it is not difficult to make road markings in such a way that they are clearly visible. The major problem in marking roads, however, is to ensure adequate visibility also when the road is wet - particularly when the road is lit only by means of vehicle headlamps.

Even a thin layer of water obstructs the incident light to penetrate in the reflector itself: the light is reflected mostly at the top surface of the water layer. This results in the fact that differences in colour of wet objects disappear mostly, and, more seriously in the case of road markings where the light strikes the surfaces at a glancing angle, the retro-reflecting characteristics of glass beads do not show. This is the reason for the well-known fact that on wet roads the road markings are practically invisible, particularly at night under conditions of vehicle head lighting. However, the remedy is also obvious: readjust the reflecting elements of the road markings in such a way that the light does not strike them at a glancing angle. In practice this means that the markers should stick out over the surface of the road ("raised-pavement markers").

The three distinct types of road markings (the horizontal markings, the raised pavement markers and the delineators) each have their own set of required characteristics. These are given as follows in OECD (1975a).

In the application of a system for horizontal markings many facets of the overall problem must be considered such as design, layout, application conditions, materials etc.

The importance of individual characteristics will naturally vary depending on location, environmental conditions and traffic volumes, and consequently a system of priorities cannot be assigned in the general case. Nevertheless, some priority must be assigned to each characteristic depending on individual needs which will ultimately produce optimum return. Within this context markings should have the following properties:

- minimum interference with traffic during application
- good visibility
- durability
- good resistance to skidding
- low cost
- easy removal, if necessary.

Each of these criteria would, perhaps, suggest a different choice of marking, however, it is not inconceivable that the majority of the characteristics could be embodied in a single material if sufficient effort was concentrated on the problem. Present materials usually possess but a few of the characteristics and thus they must be either improved by adding other materials or alternatively the deficiencies must be tolerated.

Raised pavement markers include various devices used to amplify, supplement or replace horizontal markings employed for guidance within the travelled way. These markers, which were little used in the past, have important visual and safety aspects which compensate for some of the adverse factors of conventional horizontal markings. These aspects include good visibility of markers under adverse-weather conditions where the retro-reflective surface extends above surface water and, moreover, the markers are constructed of a very durable material. The rumble effect, as tyres cross over raised-pavement markers, can alert the sleepy or indifferent driver, and the bi-directional surface of these markers, which may provide different colours to opposing traffic, contributes to improved safety. However, as has been already pointed out on several occasions, it is generally accepted that raised pavement markers most probably offer a final solution for the night time visibility of road markings when wet, more particularly the raised pavement markers with corner-cube reflectors (see Tooke & Hurst, 1975; Schreuder, 1980a; Bali et al., 1976; Kenton, 1978). It may be mentioned here that "corrugated" hot applied, beaded thermoplastic stripes may perform also quite satisfactory when wet (Jonker, 1972; de Groot, 1974; Tooke & Hurst, 1975; Schreuder, 1980a; Visser, 1977; Griep, 1972a). Furthermore, it may be added that the adverse factors of damage by snow-plows can be considered as solved (Schreuder, 1980a; Anderson, 1971; Mc Naught & Capelli, 1975; OECD, 1980; Anon, 1978b; Hogervorst & Clee, 1977).
And finally, the delineators. The major requirements are again given by OECD (1975).

The role of delineators is to give drivers visual assistance, particularly at night. Delineators provide a continuous system of visual guidance which is either independent or combined with edge markings. Delineators are simple, effective and economic devices and are widely used in several countries. From a practical point of view, their aim is to give a clear indication of the road alignment at a distance ahead. Amongst the various marking techniques, delineators are the best means for giving advance information on any horizontal or vertical changes in the road alignment, especially in the case of particular and complex road locations and of changes in the width of the road. They also perform efficiently in very severe-weather conditions such as heavy rain and snow during which markings on the road surface may be hidden or not visible. In some countries special delineators are used for temporary purposes, such as deviations, road works, indications of two-way traffic on one of the carriageways of a motorway, and in particular situations, such as mountain roads, tunnels, traffic islands, lay-bys, ramps at interchanges.

Delineators must be effective both by day and by night or in bad weather conditions. This is ensured by using a two colour system which is equally visible in snow conditions and, for night time visibility, by providing retro-reflective units.

The posts (supports) should meet the following requirements:
- low cost
- easy transport
- easy maintenance
- high resistance to the most severe atmospheric conditions
- no safety hazard to road users
- no psychological obstacle to road users with regard to keeping the vehicle in a correct position near the road edge.

Furthermore they should be designed so as to ensure:
- a width adequately visible at a long distance
- a high enough position of the retro-reflective unit so that it will not be too soiled by mud.

Delineators are installed vertically so that the retro-reflective units are facing the traffic.
The retro-reflective units should be made from materials which should have at least the following characteristics:

- a minimum intensity of the reflected light
- stable optical characteristics
- colours corresponding to standard colour charts
- durable attachment to the support.

Compared with the advantages of delineators - low material and installation cost, long durability and high effectiveness - there are very few negative aspects.
However, some adverse factors should be mentioned. The effects of alternating hot and cold, ultra-violet rays, as well as exhaust gases etc. can bring about accelerated ageing and a deterioration in the quality of the materials. Temperatures below -20°C are harmful to plastics and cause them to become fragile. Retro-reflective units in coloured plastic material may fade in countries with much sunshine if they are not made out of good quality methyl-metacrylate. Iron, wooden or concrete posts must be regularly repainted. Due to dirt the support and the retro-reflective unit will have to be cleaned periodically. This may be very costly in certain circumstances and this expenditure - additional to the initial installation cost - must be taken into account. Also, maintenance cost for the roadside (mowing of grass) will be increased due to delineators. Lastly, the hazard and damage caused in the case of vehicle accidents involving delineators, particularly concrete and wooden posts, should be mentioned; delineators may also be damaged during snow removal in winter time, by vandalism or in rural areas by animals.

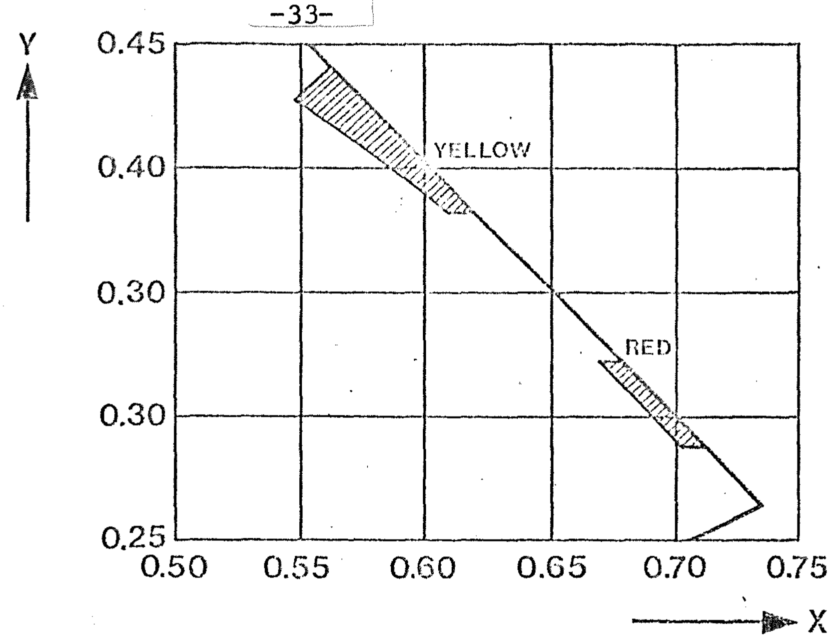
In conclusion, the following remarks can be made regarding road marking and delineation (after OECD, 1975a).

1) All marking devices are placed for the purpose of guiding, regulating or controlling traffic and as a means of information for the driver.
The following advantages are expected from the use of marking devices:
- considerable improvement of driving conditions (driver comfort), especially in conditions of poor visibility
- improved fluidity of traffic on roads and at junctions, increased traffic volumes and reduced journey times

- positive benefits to traffic safety, especially in conditions of poor visibility.
Negative effects of properly applied marking devices are not expected.

2) Materials used for marking devices should:
- have good visibility during the day, at night and in all weather conditions, above all in conditions of poor visibility
- have as few adverse effects on traffic during application or placement as possible
- not present a hazard to traffic on the roadway (skid resistance) or roadside (heavy delineators)
- have good resistance to wear
- be economical (low costs, satisfactory lifetime).

3) The achievement of the required characteristics is made difficult by the following adverse factors:
- poor visibility, especially of horizontal markings, in wet weather
- tendency of certain materials (thermoplastics) to discolour
- retention of dirt (especially raised-pavement markers and delineators, but also pavement-surface markings if they are not cleaned by traffic)
- poor resistance to wear (painted pavement-surface markings), especially as regards studded tyres
- poor adhesion characteristics of some materials on certain pavements.



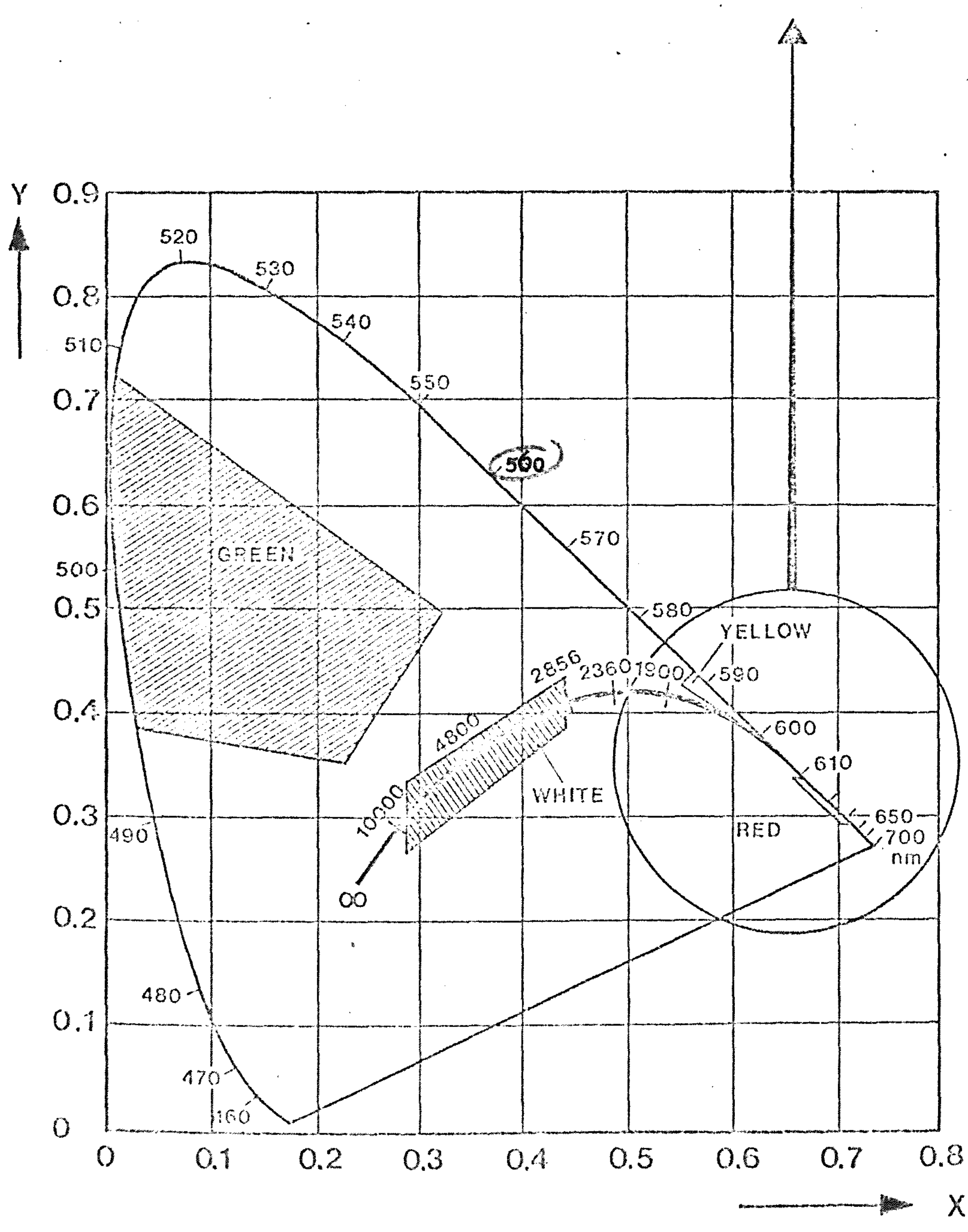


Fig. 1. (after Anon, 1980)

Colour of signal	Boundary	Equations
Red	Purple*	y=0.990-x
	Yellow*	y=0.320
	Red*	y=0.290
Yellow	Red	y=0.382
	White	y=0.790-0.667 x
	Green	y=x-0.120
Green	Yellow*	y=0.726-0.726 x
	White	x=0.650y
	Blue	y=0.390-0.171 x
White	Yellow*	x=0.440
	Purple	y=0.047 + 0.762 x
	Blue	x=0.285
	Green	y=0.150 + 0.640 x

* Denotes a restricted boundary

Table 1. Recommended colour boundaries for light signals for road traffic control (after Anon, 1980)

	day, fog	day, clear night, fog	night clear
front markers	high beam	low beam	town beam[xx)]
direction indicators (both front and rear)	high	medium	medium
rear lights	high[x)]	medium	low
stop lights	high	medium	medium

The actual values should be specified in further details. The values quoted above may serve as a first approximation.

[x)] similar to the present fog rear lamps

[xx)] sometimes indicated as city beam, dim-dip headlamps, etc.

Table 2.

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