Visual Problems in Streets and Motorways

By J. M. WALDRAM

Experiments were made to determine (1) the ways in which a vehicle driver uses his eyes when driving and the information he needs, and (2) the means by which this information is conveyed to him in various lighting systems, including daylight, on English urban highways and motorways. The mechanism of seeing in empty roads, medium traffic and heavy traffic have been elucidated, and the effectiveness of daylight, twilight and street lighting appraised. Differences of driving requirements on the motorway and in urban roads were found. It was concluded that vehicle lights were not capable of providing information necessary for safe driving on the motorway if an emergency occurs, but that fixed lighting was capable of doing so. The necessary characteristics of this fixed lighting are discussed.

Introduction

This paper describes and gives conclusions from experiments on the visual actions and the needs of drivers, and the extent to which their needs are satisfied, on urban traffic routes and on motorways in Great Britain, by day and night. The thoroughfares, both urban and motorway, the vehicles, driving habits and the lighting systems in Great Britain differ from those in the United States and Canada. The urban strèets are sinuous and comparatively narrow, with intersections at irregular intervals; the word "block" is unknown, for the rectangular city plan scarcely ever occurs. Vehicles are smaller and traffic keeps to the left. Rules for pedestrians and vehicles differ from those in America; for example, a speed limit, usually of 30 miles per hour, is imposed in urban areas, but there is usually no speed limit on motorways. The construction of motorways has only just begun and there is not yet a coherent network of them, nor widespread experience of motorway driving. Apart from motorways the main rural highways are often single-carriageway, carrying much traffic. Lighting systems also differ from those in America in level, variety and design, and in the lamps which are most commonly used.

Any conclusions reached from these experiments will apply therefore only to Great Britain, and the experiments would have to be repeated in other countries, where other conclusions might be reached. However, the approach to a problem and the methods adopted may have interest and may perhaps stimulate other work.

The Problem to be Solved

Streets are lighted in the interests of safety, particularly safety from traffic accidents. Much work has been done in several countries to establish, if possible, the relationship of street lighting and accidents. A recent report of the Experts Committee on Street Lighting of the International Commission on Illumination[1] has reviewed the results and appraised their reliability. It has been established, with statistical significance, that good modern street lighting, as compared with poor street lighting, can result in a reduction of personal injury accidents at night of the order of 30 per cent, a result of great importance, especially for those responsible for decisions to light streets. Urban streets are being lighted in most countries to a good standard, which is being improved; the civic value of good lighting is generally accepted. Motorways are another matter; they are mostly unlighted. In England there is an official decision, at the moment, that they will not be lighted, except at a few special situations such as the terminal roundabouts. In France and Belgium there is a policy in principle to light them, and some important stretches have been lighted. Lighting a great length of motorway is a formidable undertaking, however, and the case for it needs to be established thoroughly. The accident records on motorways give some indication of the value of fixed lighting, but they are not yet extensive enough nor certain enough to make the case.

The result reported by the Experts Committee, though very important to the administrators, is inadequate for the lighting engineers. They need to know much more detail: what makes lighting good; whether our best is good enough, or whether there are faults to be overcome; where the weak points are, and what their real importance is—not as a matter of opinion or guesswork, but established

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by experiment. The Experts Committee has concluded that to establish this kind of information from a study of accident rates is hopeless. To determine with significance, a change of accident rate of the order of 10 per cent would require the study of at least 1000 accidents, involving the observation, for example, for a year of some 500 kilometers of street of each of the two characteristics studied, the whole of the two lengths of street differing *only* in the characteristics under review. This is impossible and, consequently, another approach must be sought.

New Approach to the Problem

The first step must be to restate the problem. Lighting, whether by day or by night, by itself neither causes nor cures accidents. The cause of traffic accidents is traffic; more specifically, errors of maneuver of traffic, arising from faulty judgment. Errors of judgment may arise from many causes, one of which (but only one) is incomplete or misleading information presented to a driver. The real task of street lighting is the presentation of information; and its usefulness is to be appraised in terms of its capacity to give, to the driver and other road users, the information which they need, clearly, unambiguously and with the proper emphasis. When it has done that, it has done all that lighting is capable of doing, and the responsibility then lies with the recipients to make proper use of the information.

The problem can thus be restated as the following two questions:

(1) What information does a driver need for the proper handling of his vehicle?

(2) To what extent, and by what mechanism, is this information conveyed to him by various systems of lighting and in various circumstances (*e.g.* by day and by night and in wet and in dry conditions, etc.)?

If we can answer these two questions, even qualitatively, we shall be able to appraise the success of lighting systems and to identify the importance of various characteristics, such as glare, patchiness, color, contrast, etc. Only when this has been thus studied shall we be able safely to make quantitative determinations, and indeed quantitative results may not be needed in many cases.

Experimental Methods[2,3,4]

Studies of Driver's Requirements

The first problem is to establish in detail what the driver needs to see. This cannot be done merely by asking a driver, for he is rarely conscious of his needs and actions. The problem was approached by three techniques. First, experienced experimenters drove in various conditions of road, traffic and weather, by day and night, and carefully observed their visual reactions, recording them on a tape recorder. The efforts to do so disclosed more than ever appeared in the records themselves; the experiment trained the observation. Second, films were made in synchronism with the recordings, taken by day and by night from a position as close to the driver's head as possible (Fig. 1). In this way the complete traffic situation could be captured for study. Some of the films made showed, in addition, the driver's actions on the car controls.

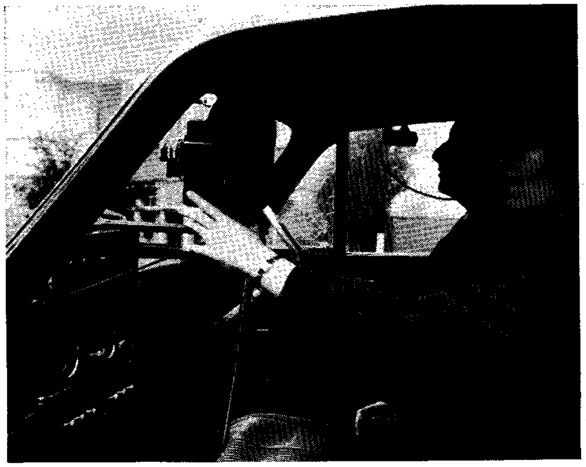

Figure 1. Test vehicle with camera and microphone.

A third very interesting study was made by the kind collaboration of the Road Research Laboratory and the Medical Research Council's Applied Psychology Research Unit at Cambridge,* where Dr. Mackworth[3] had evolved a very ingenious means for recording, on film, the eye movements of an observer viewing a scene. It was not then possible to do so while the subject was actually driving a car; but it could be done by a driver viewing a film taken by the Road Research Laboratory from a moving car and looking at it as though driving. This is not perhaps quite convincing, but films taken of the eye movements of two drivers viewing identical traffic films showed general patterns of eye movement which were very similar, though with characteristic but unimportant individual differences. From this evidence and experience it is considered that the films can be taken as applying to driving conditions with no serious error.

The films showing the traffic record a part of the information which is available to the driver; the films showing eye movements give some idea of his procedure in selecting what he wants, and the films showing the car controls show something of what

*The conclusions drawn from this study are those of the author alone and are not necessarily those of either of the collaborating Laboratories.

he does as the result. However, none of the films can show what we really want to know, the mental process which he uses. The only way of ascertaining that is for the driver to tell us. It follows that the commentaries are more important than the films. In the films of eye movement, unless the driver's eyes are closed or he is looking out of the frame of the camera, his eyes must be looking somewhere, but he is not necessarily giving acute attention to what he seems to be looking at. He may be looking idly and thinking about something else, as happens in a traffic jam when he cannot move at all. Also, he accepts much information parafoveally or peripherally. A film showing that a driver in traffic is not changing his controls but is proceeding at a steady speed, does not mean that his mental processes are at rest. It may well take just as much judgment and decision to keep a steady speed as to decide to make an emergency stop.

Studies of Revealing of Information

Studies of the ways in which objects were revealed were made by several techniques during the day, at night and at twilight. The recorded driving commentary was again used, but directed to recording notes on objects seen clearly or otherwise, and the reason why. In daylight, observations were made in which the observer (not the driver, for safety) wore dark goggles, which reduced the luminance of the scene to levels approximating street lighting, to find whether the daylight mechanism would be effective at night levels. Color photographs were taken in sunlight, up and down light, and luminance surveys made while the vehicle was stationary, by daylight, at twilight and at night.

Conclusions

Urban Traffic Routes—Driver's Requirements

The driver's requirements can be classified under three conditions: driving without other traffic; driving with normal traffic, and driving in very heavy traffic.

Driving Without Other Traffic

The information required by the driver is simply the run of the road, and the fact that there is no other traffic on it or about to enter it. He drives with his eyes fixated usually a little on the offside and 200 to 300 feet ahead, steering the car by the center line if it is visible, either as a white line or a central joint, and by the "streamer effect"[5] of the curbs, which he does not fixate. The position of the curbs is important, and they need to be seen clearly though they are not fixated, but this is casual seeing, and the driver has opportunity to look about if he desires.

Driving in Medium Traffic

In traffic, in addition to the run of the road, the driver is preoccupied by the gap through which he must maneuver his car. It is as though he were stationary, but with control on the lateral movement of the vehicle, while two rows of vehicles are drawn towards him, that on the offside coming at about twice his own real speed, and that on the near side —the stationary vehicles—at his own real speed. What is important is the gap between them, and the likelihood of its closing. He appraises this by recognizing familiar patterns of traffic, learned by experience. His mind appears to work rather like a computer. Information is fed to it continually, the information is sensed and appraised, compared with a memory store, and as a result instructions are issued on the action to be taken. The whole process is rapid and continuous, and is taken well in advance, nowhere near what might be called the "limit of the situation," beyond which he is not able to take safe action. Movements which operate to open the gap he discards. For example, if a vehicle ahead signals a turn to the offside, as soon as he has positioned his car to pass inside it and is satisfied that he has room to do so, he discards that vehicle and looks for the next critical element in the traffic. The reliance on familiar traffic patterns gives point to the great danger of unexpected movements, for they suddenly change a situation which other drivers had supposed to be settled. If he is following another vehicle the driver concentrates upon it, the two vehicles behaving as a unit, though he tries to look around, through or over it to anticipate its movements.

Two very important elements were found to be the stationary vehicle, and the bicycle—a vehicle almost unknown in America, but important in Britain and ubiquitous in the Netherlands. The stationary vehicle is the more important; it can take no action itself, but it imposes action on everyone else. It closes the available gap and will make other vehicles pull out to close it further. Often a stationary vehicle can be seen only in part, and in a momentary glimpse, by very slight clues, often through the vehicle ahead. A driver behind a large opaque vehicle is disconcerted because he cannot receive these clues and so anticipate its movements, and will get in front of it as soon as he can.

Bicycles, being slower than cars, act much like stationary vehicles in affecting the action of others, with the additional disadvantage that they can move sideways with agility and without warning. The observers found themselves fixating bicycles carefully, watching them "right under the wing" lest they should wobble. This means that bicycles claim an unfair amount of the attention which may well be needed for something ahead.

A most important observation was that drivers do not and cannot possibly fixate everything of importance. They accept an enormous amount of important information by peripheral vision, at quite low detail. Cases were recorded of the driver not looking, for example, at an oncoming omnibus, but at a child on the footpath. He knew that it was a bus and what it was doing, but he needed more information about the child, and so fixated her. Pedestrians were usually seen, however, entirely by peripheral vision and the driver was barely aware of them; so long as they walked normally he discarded them. But, should a pedestrian turn to move toward the road, the driver immediately fixated him. This means that information about the presence and motion of the pedestrian was coming in, at very low detail, being appraised as unimportant and discarded again, scarcely entering the driver's consciousness. As soon, however, as a motion was detected which might be significant, the driver was alerted and fixated.

Evidently it is very important that the driver should not be deceived about what he sees peripherally. It happened very occasionally that the driver apparently misread an important traffic element seen peripherally and thought that it was something else, and so did not fixate it. That traffic element, therefore, did not exist in his consciousness or reckoning at all, and was not perceived until much later, to his astonishment and alarm. This is, from time to time, the experience of many drivers, and it is probably in this way, by mistakes in peripheral vision, that accidents are engendered. It is as though his "computer" attempts to work out the commands with one punched card missing or incorrect. The wrong command is issued, and when the missing element is perceived later, the driver is in the wrong position or at the wrong speed. If the situation is beyond recovery, an accident occurs. Had the element been fixated it is inconceivable that the driver would have been deceived, for it is extremely difficult to deceive the eye when it fixates properly.

If the driver is satisfied about what he sees peripherally he does not fixate it unless he deems it critical. If he is unsure of it, he will fixate it until he knows what it is. Bad lighting, in which the observer cannot be immediately sure of what he sees, makes such heavy visual demands, because the driver has to do much more critical scanning.

The bearing of this on lighting practice is that it is very important that fringe objects shall be seen clearly by peripheral vision at low detail. This means that, if possible, the whole object should be distinguished clearly from its background by a consistent difference of brightness. It is often maintained that objects are seen well enough by "glint" and by internal contrasts, or when one part is seen against a dark patch by reversed silhouette and another part against a light patch by normal silhouette. Objects are seen in this way, if they are fixated, but such objects may not be correctly interpreted when they are seen peripherally, "out of the corner of the eye," when detail cannot be resolved at all. For this reason the author does not accept tests of "visibility" made by acuity test-objects such as Landolt rings, which test the capacity to see detail when fixated.

Driving in Dense Traffic

It is often contended that much traffic today is so dense that the driver sees nothing but the back of the vehicle in front, that silhouette seeing is no longer operative and, consequently, much more light is wanted. Observations in dense moving traffic show that the first contention is wrongly observed. Everyone remembers the back of the vehicle in front, not because the traffic is moving, but because it is stopped. One cannot drive except at a crawl in such dense traffic, and there is no visual problem at all; the driver looks about idly. When traffic is moving, it is necessarily far less dense, and one sees it against the road surface and other road features in the usual way; the attention is concentrated upon looking past the vehicle ahead at the inadequate gap, to anticipate the future movements. There is, however, an important difference between driving in heavy traffic and in light traffic, but it is something else.

In medium traffic the driver is nearly always able to discard all the traffic elements except one critical one, and to concentrate on that; he takes the critical elements one at a time, and maneuvers to secure that only one occurs at a time. What disconcerts him is to find that he has to watch two or more critical elements at once, and when that happens, he usually brakes. The difficulty in very heavy traffic is that he has several critical vehicles at once, often on both sides of him, and the demand on his attention and decision becomes extreme. It is, of course, worse when speeds are high.

It does not follow that such conditions necessarily call for extra light, as compared with medium traffic. If the installation has been designed so that one can see any one vehicle clearly and accurately, and any element likely to impinge on the route, one can see 20 vehicles just as well. Such situations demand perfection. One cannot risk missing an element of traffic peripherally, and there is no time for second glances or unnecessary fixations. It is not that these situations demand more light, but that in less dense traffic we may perhaps be content with less than perfection and accept greater visual risks, because there may be more time to rectify mistakes in seeing. There is, however, not always such time, and very awkward situations making great visual demands can occur anywhere.

Urban Traffic Routes—Revealing of Information

A general conclusion was that it was very difficult to deceive the driver about anything that he fixated, even in bad conditions. Though observers were very critical when commenting on the revealing of objects, when recording visual action they referred to objects unerringly by name even when they were very difficult to see, and they seldom commented on the difficulty of seeing. It was surprising to find how little information sufficed; but that is not evidence that it was enough to be safe. We often drive momentarily blind, yet if everyone keeps the rules we do not hit anything. A sense of false security builds up to the point where some drivers must be taking serious risks.

Vision in Daylight

The difference between daylight and night vision is of course, first, that by day the sky is bright not dark, and second, the great increase in luminance which enables observers by day to perceive, with great facility, detail and color which would be quite overlooked at night, even when fixated. There is so much detail visible by day that it is difficult to discern the visual processes. Third, sunlight, in some circumstances, provides very severe discomfort and disability glare.

In daylight the road and footpaths are uniformly bright, and there are no repetitive effects, as objects move along the road, such as occur at night. By day the contrasts between object and background tend to be unvarying.

Color difference is usually important, by day, and can sometimes be more important than brightness difference. For example, a man seen against a fence of the same color may be misread by day as a detail of the fence, but if he differs in color he is less likely to be taken as part of the fence. Objects such as cars, presenting a multi-colored pattern, could merge into a multi-colored background, usually in the distance, and be misread.

Color was the major factor in seeing in sunlight when looking down light, but colors could hardly be discerned when looking up light, for reasons which follow from the geometry and reflection properties. Up light the conditions resemble those in street lighting at night, and similar effects of silhouette occur. Thus, by day, objects are seen by both brightness contrast and by color contrast, and details of both brightness and color pattern are important. The upper parts of objects are often seen against the bright sky, especially at or beyond a hump. The most conspicuous features of cars are the shadow below the body, the wheels and differential casing. Their upper parts usually reflect the sky as a bright glint and the body color is often quite difficult to see from the rear. (In Britain the colors of vehicles are more sober than in America.)

In overcast daylight relative luminance differences tend to be comparatively feeble. When they were reduced to night levels by dark goggles, observers found that the contrasts were quite inadequate for safe driving. This confirms results obtained in model experiments in 1928. The mechanism used in street lighting employing the properties of the road surface resulted in greater relative luminance differences which could be well seen despite the lower levels. This was investigated quantitatively, by first making a survey of the luminances with a telephotometer by day, twilight and at night, and then applying Hopkinson's curves[6] to transform these figures into values of apparent brightness which are more closely related to what we see, allowing for effects of adaptation. Differences in apparent brightness are related to contrasts as seen.

During the day the relative differences of luminance vary with the direction of view relative to the brightest part of the sky. They were not high, but the capacity of the eye to adapt, and so compensate for changes in level, resulted in these differences being seen as quite high differences in apparent brightness, even when the level of daylight had fallen. The apparent contrasts by day were either positive or negative, *i.e.* either direct or reversed silhouette. Because their range was large, very few objects presented a difference which was too small for sure discrimination, and even these were usually well revealed by details.

At late twilight, just at lighting-up time, however, the adaptation mechanism is reaching its limit and the differences in apparent brightness become small, most of them falling within the limit where contrasts are too small for certain discrimination. This confirms the usual experience.

Vision in Street Lighting

With street lighting the conditions for producing adequate contrasts with a small amount of light are better than by day. The differences found in apparent brightness were greater than those at late twilight, lying mostly outside the uncertain region, and all on the side of normal silhouette. They were, however, much less than by day. Levels of lighting up to, for example, an order higher, would produce greater apparent contrasts and more certain seeing, possibly with advantage. Since drivers were seeing satisfactorily in such poor conditions, it is scarcely possible to make a strong case for much higher levels of luminance than at present. We do not know with certainty how much we need; the contrasts in full daylight may be overgenerous.

Indeed in nearly all the installations, with both sodium and tubular fluorescent lamps, it was concluded that drivers were given all the information which they needed in dry weather and with moderate traffic. However, any circumstance tending to impair the installation, such as obstruction by a tree, could result in lost information. The least satisfactory information was of objects seen against fences, which were sometimes quite inadequately displayed. Another feature of streets to which insufficient attention has been given is the slight vertical hump curve. This often has the effect of removing all the effective street surface background and leaving objects on the crest or beyond it with only a background of haze or of a medley of distant and often lighted buildings, against which the objects could easily be lost. The conditions are much worse than in daylight, for there is no bright sky. Furthermore, the hump brings distant luminaires much lower into the field of view, increasing glare and causing confusion, to which at least one serious accident is known to be due.

By night the general difference of brightness is the most important parameter. There is often a significant change in brightness between the upper and lower parts of objects and these parts are often seen against different backgrounds; that of the lower part is often the carriageway, and that of the upper part the dark sky, in fact, illuminated haze. At a hump the lower part of an object just past the crest may lie in dead ground and so be physically invisible.

To a driver color is scarcely seen as such at night, though it is more important to pedestrians. Even in good fluorescent installations, and indeed in the Avenue des Champs-Elysées in Paris, where a very powerful installation of excellent color rendering exists, colors were not seen while driving. That is not to say that there are no significant effects associated with color. Unaccountably low contrasts have been observed, which may be associated with the use of sodium light, but the reasons are very difficult to identify.

True disability glare is difficult to distinguish from effects of discomfort. However, there are good reasons[7] for expecting it to have most effect in the regions in which seeing is difficult in any case, such as at the edges of the road for objects seen against the footpath. Something of the kind has been observed in installations with severe glare. An effect which can be quite serious is the flash on a wet or dusty windshield, which operates analogously to disability glare. In cutoff lighting this can be disturbingly repetitive.

It is probably too early to draw conclusions about patchiness. Without formal experiments, experience on very patchy experimental installations at short spacing and high levels seems to indicate that it may not be serious, but the principal danger may lie in the peripheral effects mentioned above, which would require longer experience with more traffic to establish it. Patchiness is probably rightly considered as a blemish, especially when its pattern conflicts with that of the road geometry. No satisfactory or proven methods yet exist for appraising it, although the uniform brightness experienced by day is clearly advantageous compared with the more patchy effects at night.

Wet and foggy conditions have not yet been explored, and it is hoped to continue with them.

Motorways: Driver's Requirements and Revealing of Information

Day Conditions

The first impression of motorway driving by day is that it is much easier than driving in traffic routes. On the motorway, in spite of the much greater speeds, the driver has little to do, as was shown by films taken of his operation of the controls. He must, however, be very alert and cannot look about. On the motorway there is far less irrelevant visual information. Nearly all that he sees on the carriageway is important, and he has to make much less selection. There are no advertisements, shops or extraneous lighting, no footpaths to watch even unconsciously, no pedestrian crossings or signals, no stationary vehicles or bicycles, and no opposing, turning or cross traffic. There is almost no "gap" driving and usually much better driving discipline. Conditions are better than on a clear traffic route. When other vehicles are present they are seldom close, and the driver drives by them in a cloud of vehicles rather like aircraft in formation, the opening and closing rates being very slow. The road and fixed features are scarcely noticed, though they are coming past very quickly; the boundaries are farther away than on traffic routes and the sensation of speed is much less. Indeed, motorway driving is boring; the need for keen attention is not obvious and there is a temptation to relax or even to go to sleep on a long run.

If driving on motorways were not much easier than on traffic routes by day, they would have failed in their purpose. They have indeed gone some way to demonstrate Newton's principle of the equivalence of a body at rest and a body moving with uniform motion in a straight line, which one observes almost perfectly in an airplane. Driving problems are simplified by referring all motions to the driven car considered as stationary. On the motorway the car almost seems to be stationary, but, in fact, it is moving very fast and there are fixed objects, a situation which has less advantageous consequences.

A car becomes less maneuverable as its speed increases, and any movements relative to other vehicles have to be made very slowly, for hasty maneuvers at a high speed may provoke a skid, especially on a wet surface, or send the vehicle out of control. A vehicle travelling fast is to one at 30 mph rather as one at 30 mph is to a bicycle. To the fast driver, a slow car makes everyone else maneuver to pass it, but it can move sideways with an agility denied to the fast car. At speed, therefore vehicles must move relatively with the deliberation of invalid chairs. This is very marked in braking. The important case is the normal stop, not the emergency stop which is so often quoted. Certainly the distance in which a car can be arrested in emergency increases with speed, which is obviously important. What is more important, however, is the avoidance of the emergency conditions which demand such a stop, which is right on the limit of the situation and one of the most dangerous of all maneuvers. A driver intending to stop from 30 mph can do so, with ample precautions and warning to other traffic, in a few hundred feet. A similar normal stop from 70 mph requires about a quarter of a mile and deliberate planning.

On the motorway, therefore, the driver needs information about other vehicles, and must give information about his own, at much greater distances than on the urban traffic route. Instead of fixating 200 to 300 feet ahead, the driver is concerned with conditions 1000 feet and more ahead and astern. The most important information, particularly on the motorway, is the closing rate, which is more difficult to discern as the distance increases. It is detected by movements of the observed vehicle in the framework of the perspective of the road. As the distance increases these movements are proportionately less. Without the framework, the closing rate cannot be estimated. Steering is also more delicate in proportion to the speed, and the driver relies more on the streamer effect for steering at high speeds than he does at low speeds. For reasons again associated with perspective, it is much easier and more sensitive to steer by a centerline straddled by the vehicle than it is to drive by the lane lines, as Calvert has shown.[5]

The most important difference between motorway and urban driving is that on the motorway it is assumed by everyone that nothing will be stationary. If by any mischance there is, it is completely unexpected and extremely dangerous. A capsized car or a packing case fallen from a truck will, in effect, shoot through the cloud of oncoming vehicles rather like a car coming through a car park at 70 mph with the additional hazard of the kinetic energy of the other cars. A stationary obstacle is not only unexpected, but even by day it is difficult to appreciate in time that is is stationary, and that the closing rate is not a few miles per hour, but equal to one's own speed. The danger is not only that of colliding with the stationary object itself, but also in the unexpected movements which it will impose upon other vehicles.

The dangers of fog and especially of patchy fog, increase as speed increases. By day one is aware of the presence of uniform fog, but it is extremely dangerous to run unexpectedly at speed into a denser patch in which vehicles ahead will have slowed down but are invisible. Fog is more difficult to appraise on the motorway because there are so few fixed objects by which to judge its density.

The consequences of an accident at speed are usually far more serious than at 30 mph. The kinetic energy of a vehicle increases as the square of the speed. In an accident the car is very likely to go completely out of control and to behave unexpectedly. Other vehicles are less able to avoid it because of their reduced capacity for maneuver and because at speed one has travelled farther before one can appreciate what has happened. Accidents are likely to become multiple as the density of traffic increases.

It appears, therefore, that motorway driving is much easier than traffic route driving provided that all goes well, but emergencies are much more serious. On the motorway we now have the speeds of trains, with much less mass, better acceleration and better braking than trains, with the possibility of and necessity for steering, but with no rails, signals, or control and much less headway. The situation is not simple to assess, even by day.

Night Conditions

The statement of what the driver on the motorway needs to see by day, and how these needs differ from those in traffic routes, indicates the requirements which a successful lighting installation will have to meet, though not the only requirement. There is much interest in examining the conditions at night as they are, without fixed lighting, since this may indicate whether a technical case exists for fixed lighting.

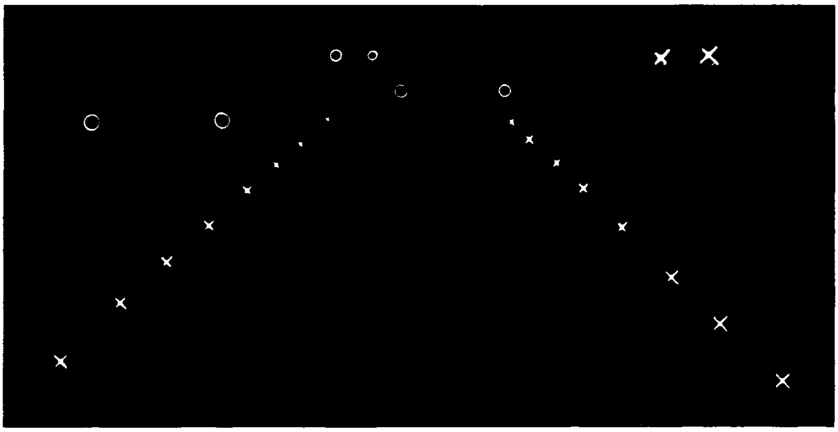

Figure 2. Pattern of lights visible on motorway at night. x = white lights or reflector studs; o = red lights.

At present night driving is by headlights, and one can see very little with them. For a substantial part of the time in England they have to be used dipped, although if the center headlight screen* is extended it may be possible to use driving beams more. The useful range even of the driving beam in revealing the course of the motorway by the reflector studs** of the lane markings is quite short, perhaps 300-400 feet,† and with the dipped beam it is a good deal less. The first consequence is that one drives only by the studs and the lights of other vehicles. The conditions are not unlike those in the blackout, when every light was significant. Even the fixated eye cannot identify objects ahead, though occasional glints may give clues. The run of the road ahead is unknown, unless it is indicated by vehicle lights. This is much more serious than merely a restriction of information on where the driver will have to go, which is not very important on a road in which there will be no hazards of alignment. Other vehicles are seen only by their obligatory lights, and unless those lights can be referred to a recognizable framework of the road, they cannot be located.

The lane reflector studs, of course, come rapidly toward the observer. The other lights move about slowly, but their movements cannot be interpreted without the frame of reference of the remainder of the perspective. Closing rates cannot be estimated unless the vehicle is so close ahead that its lights appear to move rapidly, relative to the others, by which time it may be too late to take safe avoiding action. A stopped vehicle on the carriageway would be most unlikely to be correctly interpreted, and an unlighted obstacle would certainly not be seen in time for safe action. The driver does not know what the other vehicles are, where they are or what they are doing. At night he sees the lane lines and vehicle clearly only for a short distance. Beyond is a cloud of red lights which it is often quite impossible to interpret. Figs. 2-4 illustrate the confusion which may occur and some of the reasons.

*On the M1 motorway experiments have been made with a 5-foot central headlight screen of expanded metal.
**The lane lines are marked with retroreflecting buttons at a spacing of 50 feet popularly known as "cat eyes." They are set in rubber blocks in such a way that depression of the block by a vehicle wheel wipes the lenses clean.
†Based on driving experience. The figure quoted for maximum range, presumably under optimum conditions is 700 feet.

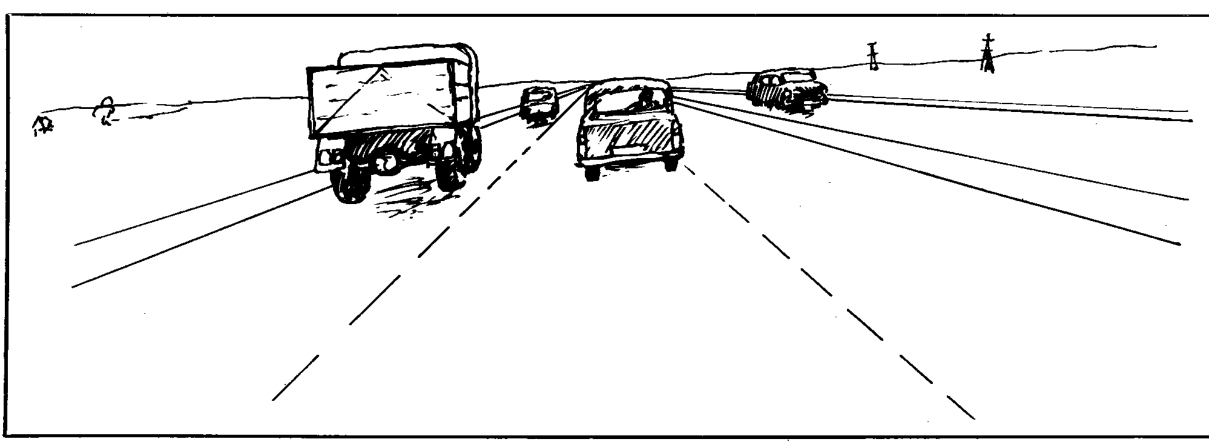

Figure 3. Traffic inferred from pattern shown in Fig. 2.

Fig. 2 shows the view at night with the reflectors in the lane lines and the rear and headlights visible. It is not necessarily clear what is the pattern of vehicles ahead, or which lights are the two rear lights of one vehicle. Figs. 3 and 4 are two views of quite different configurations of road and traffic, each of which gives the pattern of lights shown in Fig. 2. In Fig. 3 the traffic is what one would naturally assume from the observed lights; the road is straight, there is a truck close on the slow lane with a car some distance ahead of it, and a car on the center lane fairly close. In Fig. 4, although the pattern of lights is the same, the road curves to the right and instead of one car on the slow lane well ahead of the truck there is a second truck immediately in front of it, and another second car close ahead of the car on the middle lane. In the first situation one could overtake safely on the fast lane; in the second it would be unwise to do so in case the car ahead pulled out. Much more complex and obscure patterns have been observed. Glare from headlights on the other carriageway is another difficulty. The central headlight screen will greatly reduce this glare, but with some vertical curves, headlights will inevitably be seen over the top of the screens, usually, however, well off axis and at a fairly long range.

Closing rates of overtaking vehicles which are seen in the driving mirrors are much more difficult to assess. The field of view is restricted and there is no frame of reference at all; even the lane studs are invisible. Moreover, rear windows and wing mirrors are quickly soiled. In dirty weather the windshield also may be unexpectedly obscured by the cloud of muddy spray which extends much further than usual behind the vehicle ahead, a particularly disconcerting occurrence when one is passed unexpectedly by a fast car.

Patchy fog is a real menace at night when the only lighting is by headlights. There is no effective way of revealing it until the driver has entered it at speed, when the consequences are far more perilous than by day. Serious multiple accidents in fog have already occurred.

Notwithstanding all these difficulties, driving at night on the motorway in good weather, though far more exacting and fatiguing than by day, is safe so long as everyone keeps the rules. With present traffic the accident rate is quite small. Evidently, headlights alone give quite insufficient information. The chances are fairly high of misreading the traffic situation, and of getting into difficulty if anyone does the unexpected. As traffic increases, the probability of these situations developing into accidents, and of accidents becoming multiple accidents will obviously increase. Our thinking must clearly be based not on today's conditions and traffic, but on tomorrow's.

Vehicle Lights on the Motorway

It is clear that vehicle headlights as used at present are not adequate for providing the driver with the information he needs for high speed driving, and that they never could be. The present useful range of headlights, when showing up reflector studs, is of the order of 400 feet. It would probably be necessary to increase this to at least 1000 feet for speeds up to 70 mph to give a frame of reference for locating traffic ahead. Even without allowing for veiling haze, this would require intensities in the range between 1 and 10 megacandelas, which, even if they could be realized on the vehicle, would be intolerable if the headlights were encountered as a glare source. However, even such headlights would not, by themselves, clearly reveal the traffic situation ahead, nor give adequate warning of fog.

There is in Britain still need for improvement in

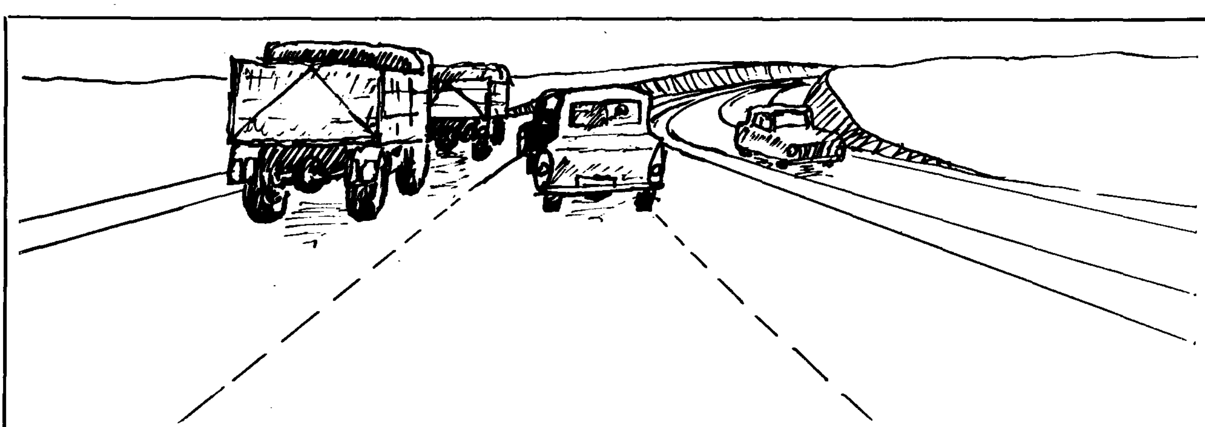

Figure 4. Traffic which might also give the pattern shown in Fig. 2.

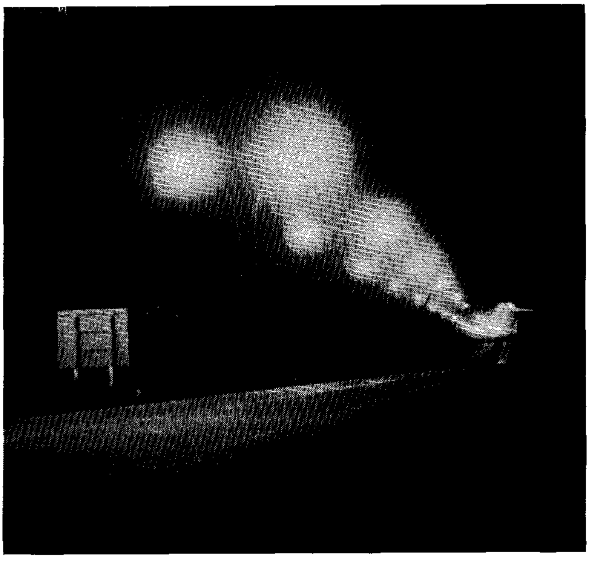

Figure 5. Autoroute du Sud near Paris.

the rear signals of vehicles. The present signals are fairly satisfactory in lighted traffic routes, where drivers have far more other information, but they are not, in the author's view, adequate for high speed driving when they are the only clues to the presence and intentions of the vehicle ahead. A suggestion for a new signal is given in an appendix to this paper.

Fixed Lighting on Motorways

Fixed lighting is capable of revealing to a driver on a motorway all the information which is available to him in daylight. If it does this, it does all that lighting is capable of doing. An example is the excellent lighting on the Autoroute du Sud, recently installed near Paris (Fig. 5) where drivers drive just as in daylight without headlights. Good fixed lighting does not limit the distance at which objects can be seen. They are visible up to the topographical range beyond which they are physically hidden. The luminaires give an unusually good indication of the course of the motorway, and provide adequate indication of fog and of its density. By good fixed lighting the driver is shown the perspective of the road, and can, therefore, locate other vehicles and estimate closing rates. He can judge overtaking traffic in his mirror. Unusual conditions, accidents or stationary obstructions can be appraised.

There are of course disadvantages, of which the worst is the hazard of columns to a car leaving the carriageway out of control, especially columns on the center reservation. Another is the tendency to form confusing forests of columns and constellations of lights, particularly at complex junctions (Fig. 6), the more so since the installation can usually be seen for a very long distance ahead.

Requirements for Motorway Lighting

The following requirements are set down partly as the result of the visual experiments and partly from experience of the few installations of motorway lighting which it has been possible to visit. Only requirements which arise from driving conditions are discussed. There are many other economic and engineering requirements.

1. The first requirement is to show, clearly, the carriageway ahead, sufficiently well to reveal any vehicles on it so that their position and closing rate can be judged. The luminance should be high enough to reveal any obstacle, or to show what has happened if an accident has occurred.

2. The rearward view should similarly permit the distance and closing rate of overtaking traffic to be judged in the mirror.

3. The luminance of the road surface should be as free as possible from obvious patchiness, which is confusing, especially when it forms a background to an object of small subtense. A smooth

Figure 6. Complex of lanterns at junction of motorways.

variation in luminance across the carriageway is probably less troublesome than a mottled or patchy effect, and it should be achieved on a wet surface as well as on a dry surface. A light-colored running surface will greatly assist the lighting.

4. It is unnecessary to provide for good visibility at the margins beyond the running carriageway, although the limits of the carriageway should be very clear.

5. It is necessary, if possible, to provide good visibility of vehicles ahead when they are near the crest of a rise, since with the gentle vertical curves on motorways such objects may be deprived of a background of road surface for some distance.

6. It is very important to avoid discomfort glare, which can be distressing on a long run. There are no light buildings at the sides which would alleviate discomfort glare, and many more luminaires are visible than on a traffic route.

7. It is important to avoid repetitive effects from the lanterns as the car traverses the installation, such as occur with a sharp cutoff. It is similarly important to avoid a repetitive flash on a wet or dusty windshield.

8. Columns or supports should not be placed on the center reservation and should be at as great a distance as possible beyond the hard shoulder. They should be so constructed that a vehicle striking them will not suffer avoidable serious damage, and if the column is carried away lighting equipment will not fall into the road.

9. Constellations of lights are to be avoided, especially at complex junctions where the siting of lights should be carefully designed to lead vehicles clearly to the available paths, which should be distinguished appropriately. The use of lamps giving light of different colors might be considered.

10. The lights on the motorway should form neat lines which clearly indicate its course for a long way ahead. They should be such as to give adequate warning of the presence and density of fog.

11. The lighting equipment should be as inconspicuous as possible so that by day the long runs visible do not appear to be cluttered with forests of columns.

These requirements point to luminaires with a distribution having a cutoff (item 6, possibly 5) which is not too hard (7, 10) providing a little light up to the horizontal (10) fairly narrow in azimuth (4), mounted high (7) in a single row for each carriageway (3, 10) at a spacing-height ratio depending on the running surface but probably not exceeding about 3.5 (3). The luminaires should be long (3) and of low luminance (6).

Conclusions on Motorway Lighting

The value of street lighting from the point of view of safety is to be judged, in the end, by the reduction of accidents which results from its installation. At present the accident rate on most motorways is low and this has been given as a reason for not installing fixed lighting. However, on some busy motorways the accident rate has been high, and it was for this reason that lighting was installed on the Autoroute de l'Ouest out of Paris (Fig. 7). As a consequence the night accident rate fell by 27 per cent in a period in which it rose by 20 per cent on unlighted lengths. After this experience it was decided, in principle, to light all future autoroutes. The aim for roads surely should not be less than that for travel by rail, sea and air; to provide as far as possible really safe conditions with plenty in hand, and not to rely on conditions in which, given reasonable luck, one generally arrives whole.

It seems clear from the considerations discussed in this paper that without fixed lighting the visual information given to drivers is not adequate for safety, and that in consequence the accident rate can be expected to rise as traffic density on the

Figure 7. Autoroute de l'Ouest near Paris.

motorways increases. Fixed lighting has been shown to be capable of supplying the visual needs of drivers and of making the roads visually as safe and as expeditious as by day. A technical case for the installation of fixed lighting has been made.

Acknowledgments

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Appendix—Some Suggestions for Improvement of Guidance and Signal Lights

Guidance

There is reason to suppose that much better lane guidance could be given by center lines than by lane lines, especially in fog. There are obvious difficulties such as confusion of the center lines with the lane lines, and provision of three lines instead of two for three lanes.

Stopped Signal

There can be no doubt that the stationary vehicle —the most dangerous even on a traffic route—is perilous on the motorway. Its presence can arise only as the result of accident or breakdown, but if it does, other vehicles will be upon it at speed long before police can get to the scene and put out warnings. Brake lamps are an insufficient warning. They merely mean that brakes have been applied, perhaps an indication of something amiss if several vehicles display it, but not a warning of emergency. It is suggested that a special warning meaning that the car is stopping, or has stopped is needed. This warning should be displayed so long as the stopped vehicle is on the carriageway. A flashing red light is suggested. If a driver switches it on at the first indication that he must stop, the signal can be repeated back by each vehicle behind and warning will be given at once and in good time. The equipment itself could be simple—a projector like a spotlight, attachable to the inside of the rear window by a sucker, a control unit with flasher, switch and repeat lamp which could be attached to the steering wheel, and a lead direct to the battery. This could be fitted to any car without damage to the coachwork, and by the owner, without professional assistance.

DISCUSSION

M. E. Keck:* Mr. Waldram has made two very important points which are so basic that I must ask him for further explanation and substantiation. Mr. Waldram indicates that: "For this reason the author does not accept tests of 'visibility' made by acuity test-objects such as Landolt rings, which test the capacity to see detail when fixated." While I cannot quote the author's reasons, since they occupy several pages of the paper, it appears to me that the author bases this statement on the assumption that objects appear, are identified, and are kept track of from information received entirely from peripheral vision areas. If this is true, then Mr. Waldram is correct in placing no faith in visual acuity measurements as an evaluation of visibility. Since the work of Mr. deBoer and Dr. Blackwell are both based on visual acuity determinations, this is, I feel, a most important point. I submit to Mr. Waldram that it may be possible, that instead of following the procedure in which the brain receives information with which to perceive, identify, and keep track of objects entirely from the peripheral areas of vision, that what happens in actuality is that an object is perceived and identified at a considerable distance ahead at the time of eye fixation and that once identified the brain is able to keep track of the position and movement of an already identified object by means of peripheral vision. If the latter interpretation were correct, then one must accept acuity test-object visibility as being related to over-all visibility in driving. I have no facts to substantiate my proposed interpretation but feel that this point must be established with certainty.

My understanding of the visual process is that once the eye is fixated it transmits information to the brain from both the foveal area and the peripheral area. With the distances involved in street lighting, if the eye fixates at a point 500 feet ahead, and foveal area of approximately two degrees will cover a distance of sixteen feet in width, thus enabling the identification of a considerable number of objects in each fixation.

The second very basic point which I find in Mr. Waldram's paper lies in the following quoted statement: "Levels of lighting, up to say, an order higher would produce greater apparent contrasts and more certain seeing, possibly with advantage; though drivers were seeing satisfactorily in such poor conditions that it is scarcely possible to make a strong case for much higher levels of luminance than at present." I feel that this very strong statement may quite likely be misinterpreted since I am firmly convinced that Mr. Waldram means for it to apply only in those cases

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