TRAFFIC AND ROAD SAFETY RESEARCH AT THE ROAD RESEARCH LABORATORY, ENGLAND

GEOFFREY GRIME, *Road Research Laboratory, Harmondsworth, Middlesex, England*

SYNOPSIS

THIS PAPER outlines the organization and describes the scope of work undertaken in the Traffic and Safety Division of the Road Research Laboratory, one of the establishments of the Department of Scientific and Industrial Research.

The research staff of the division, chiefly physicists and mathematicians, are grouped into six sections under the following headings: The Road User, Traffic Flow and Road Layout, Skidding, Vehicle Performance, Vehicle and Street Lighting, Statistics.

Advisory committees on economics, statistics, road layout, vehicles, and road users receive, criticise, and recommend action on reports of work done.

A brief account is given of the work in progress in the sections and some of the results obtained.

● A RESEARCH establishment devoted specifically to research on road traffic and road safety is a comparatively new thing in Great Britain. Valuable work has, of course, been done for many years by the Ministry of Transport and various public authorities, but it was not until 1946 that facilities for research on some considerable scale were made available, when the terms of reference of the Road Research Board were extended to cover road traffic and road safety.

The Road Research Organization, with headquarters at the Road Research Laboratory, Harmondsworth, England, is one of the research establishments of the Department of Scientific and Industrial Research, a government department responsible to the Lord President of the Council. It has been in existence since 1933, and consists of three divisions, the Materials and Construction Division, the Traffic and Road Safety Division, and the Administrative and Services Division; in each of the research divisions is a deputy director, responsible to Dr. W. H. Glanville, the director of Road Research. The deputy director (Traffic and Safety) is Dr. R. J. Smeed, and Dr. A. R. Lee is the deputy director (Materials and Construction). The total staff is about 450, of of whom 180 are scientific and technical personnel, 120 are in materials and construction, and 60 are in the Traffic and Safety Division.

The Traffic and Safety Division has been in existence for five years and is still growing in size. It is staffed mainly by mathematicians and physicists, in the proportions of about one to four, with a sprinkling of engineers. It is organized in six sections, as shown in Figure 1, each under a principal scientific officer, who controls the activities of junior officers in charge of teams of workers.

A very strong link between the laboratory and the engineers and others who have to solve practical problems is provided by the Road Research Board and its committees, which advise on the conduct of the work of the organization. For the Traffic and Safety Division, the committees are those on statistics, economics, road layout, vehicles, and road users, the last a joint committee with the Medical Research Council. The members are selected for their individual knowledge and experience from county and borough engineers and surveyors, chief constables of police, officers of the Ministry of Transport, experts in the motor industry, scientists, economists and others; they are appointed for three years. Certain government departments are also represented. Coöperation with other bodies interested in traffic and safety is an important feature of the activities of the division, not only in committee, but in the conduct of investigations, where they often play an important part by providing facilities, by making observations themselves, and by giving advice. Practically all the work of the Division is reported to the Committees, and summaries of all but a few confidential reports are issued monthly to interested bodies. Open publication of the material in these reports generally follows.

PEDESTRIAN SAFETY

The work of the Road User Section concerns the human element in road accidents, an im-

portant factor which remains when all engineering measures such as road and vehicle improvements have been made. Of all road users the pedestrian is perhaps the most important, because he is involved in so many accidents; in Great Britain, in 1949, about one third of all road injuries and one half of all road deaths were sustained by pedestrians. The problem of reducing pedestrian accidents and, in particular, of getting the pedestrian across the city street safely without imposing intolerable delays to traffic, is pressing and has received more attention than any other from the Road User Section.

crossings and the traffic flow, and of the distances people will walk in order to use a crossing. An interesting investigation was also made to find out whether safety propaganda or the improved marking for the surface of the crossing was the more effective in promoting the observance of crossings. We are now turning our attention to subways and pedestrian-operated light signals. Although we know how the driver reacts to changes in the appearance of pedestrian crossings, he has not yet been studied as closely as the pedestrian. One investigation is in progress to determine where the driver looks as he steers his vehicle along

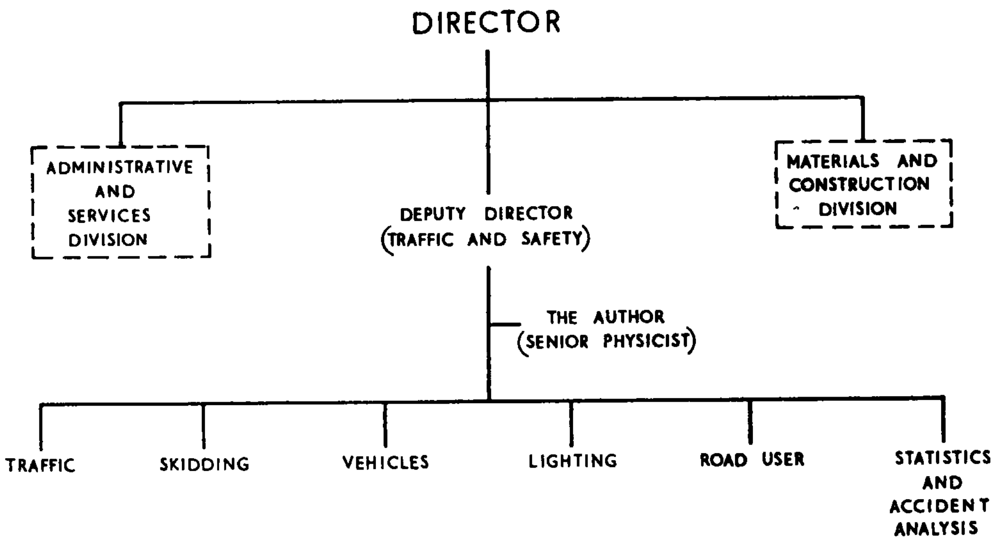

Figure 1. Organization of the Traffic and Safety Division of the Road Research Laboratory.

In Britain we have pedestrian crossings, which were introduced in 1934, to provide relatively safe places for crossing the road; they are placed not only at intersections, like crosswalks in the United States, but also *between* intersections on busy streets, and up till quite recently the majority were marked by a beacon on the footway and by road studs let into the surface of the carriageway. A considerable amount of work has been done on these crossings, first, to devise and test an improved marking for the crossing and then to study the effect of that marking on the behavior of pedestrians and drivers. This has been followed by studies of the delays to pedestrians and drivers at crossings, of the relation between the usage of pedestrian

the road; but a satisfactory technique for continuously recording where he is looking presents formidable experimental difficulties which have not yet been completely overcome.

Zebra Crossings. The striped markings shown in Figure 1 have now been adopted by the Ministry of Transport for all pedestrian crossings. Experiments with various patterns on the model scale in the laboratory indicated that alternate black and white stripes, parallel to the curb, were more conspicuous than any other pattern studied. In 1949, a nation-wide Pedestrian Crossing Week was held with a view to improving both pedestrian and driver behavior at pedestrian crossings by a propaganda campaign and a thousand crossings up and down the country were striped. In collabora-

tion with the Ministry of Transport we took advantage of this opportunity to carry out the investigation to find out whether propaganda or zebra markings were the more effective in improving the observance of crossings: counting methods were employed before, during and after the campaign at crossings carefully selected to ensure the validity of the comparison. Pedestrian behavior was assessed by the proportion of pedestrians who used the crossing in a length of road extending for 20 yd. on each side of the crossing. Driver behavior was assessed by the proportion who stopped for or gave way to pedestrians on a crossing. The results are given in Figures 3 and 4; the scale for Figure 3 is derived from the measures of pedestrian behavior, adjusted to a common zero representing behavior in the three weeks immediately before Pedestrian Crossing Week. The counts showed that road marking had a greater effect on behavior than propaganda and was more lasting. The permanence of the effect has been confirmed

Figure 2. A zebra pedestrian crossing.

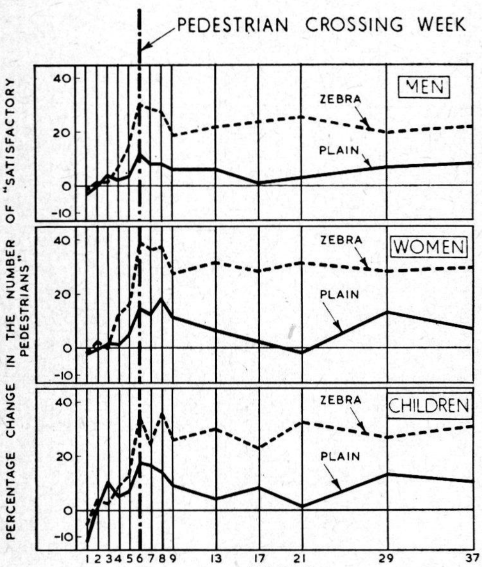

Figure 3. The effect of propaganda and propaganda plus zebra marking on the observance of pedestrian crossings by pedestrians (1949).

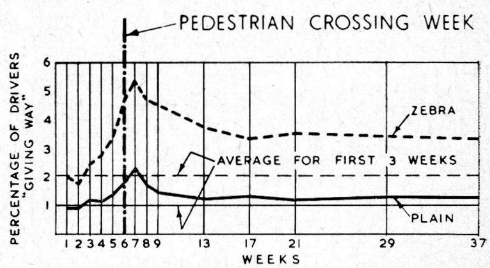

Figure 4. The effect of propaganda and propaganda plus zebra marking on the observance of pedestrian crossings by drivers (1949).

from counts made over a period of two years. It is interesting to note that these and other observations have shown that women make more use of crossings than men and that children were better than women.

Advance Warning Signs for Pedestrian Crossings. The experimental method in the Road User Section will be illustrated by a brief account of an investigation undertaken to find out whether the safety of pedestrian crossing places could be improved by a special advance warning sign placed some distance before the crossing. The idea was that the pedestrian would then have right of way if he stepped onto a crossing before a vehicle reached the advance warning sign but not otherwise.

The data for a decision on the value of this scheme were collected by making observations on the pedestrian crossing shown in Figure 2. Marks were made on the road at convenient distances in front of the crossing and a team of observers was stationed at a window from which the crossing could be watched without the observers being seen. Each observer was given several push buttons by which marks could be made on the chart of an Esterline-Angus 20-pen recorder moving at a known speed. Thus one observer charted the movements of vehicles past known points in the road, another those of pedestrians approaching the curb and crossing the road at the pedestrian crossing. Since all the pen signals were on a common, known time base, the speeds and delays of pedestrians and their interrelations could be worked out. One of the results of this study is shown in Figure 5, from which it may be deduced that a pedestrian about to cross the road does not look for a distance gap in the traffic but makes a judgement of speed and distance and aims for a constant time gap. Taking into consideration the stopping distances of vehicles observed on the road and the speed distribution of the vehicles on the road, Figure 6 could then be drawn showing the delays to pedestrians and vehicles with advance warning signs placed at different distances. It was found that if the warning sign were placed far enough from the crossing to insure pedestrian safety in conditions of light traffic it would result in serious delays to pedestrians when traffic was heavy and speeds lower.

Relative Safety of Different Types of Crossings. An analysis of pedestrian accident records at crossings of different types on some busy London streets, and elsewhere on the same

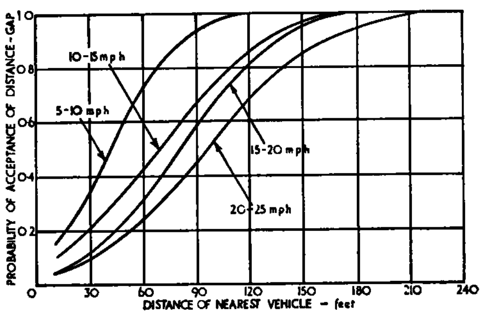

Figure 5. The probability that a pedestrian will pass in front of a vehicle travelling at a particular speed and a given distance away. (Slough P.O. crossing).

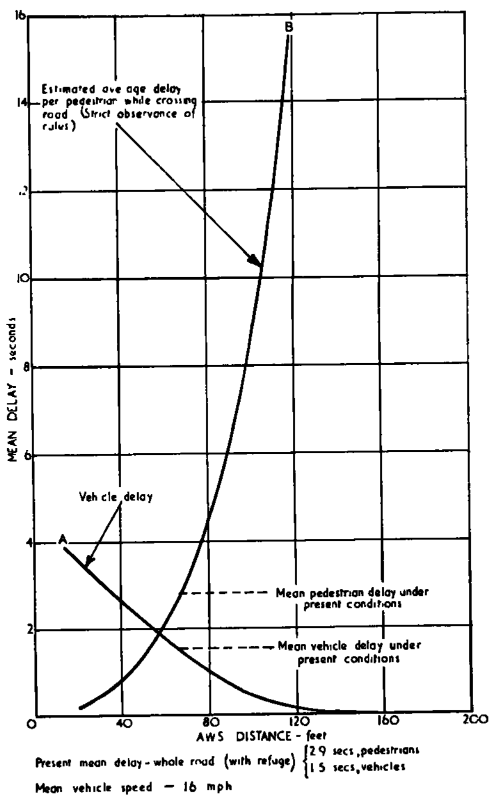

Figure 6. Probable effect of an advance warning sign at a Slough pedestrian crossing (with a refuge) on pedestrian and vehicle delays.

streets, has been combined with counts of pedestrians crossing those streets to determine the relative risk to the pedestrian crossing the

road on or off crossings. The risk ratios given in Table 1 were calculated by dividing the accident rate (number of accidents per 10,000 pedestrians crossing) at each site by the accident rate for crossing the road not on a crossing.

The ratios show that for the locations studied and the prevailing conditions, it was slightly safer to use a crossing where no lights controlled the vehicular traffic than not to use a crossing at all, a refuge increased safety considerably, and it was safer to cross at traffic lights than anywhere else. Some caution has to be exercised in interpreting these figures, since the people who use crossings may have different characteristics from those who do not. We have not been able to investigate this and indeed there are considerable difficulties in doing so.

TABLE 1
RISK TO PEDESTRIANS IN CROSSING THE ROAD

Off Crossings	Uncontrolled Crossing Without Refuge	Uncontrolled Crossing With Refuge	Light-Controlled Crossing without Refuge	Light-Controlled Crossing With Refuge
1.0	0.89	0.71	0.53	0.36

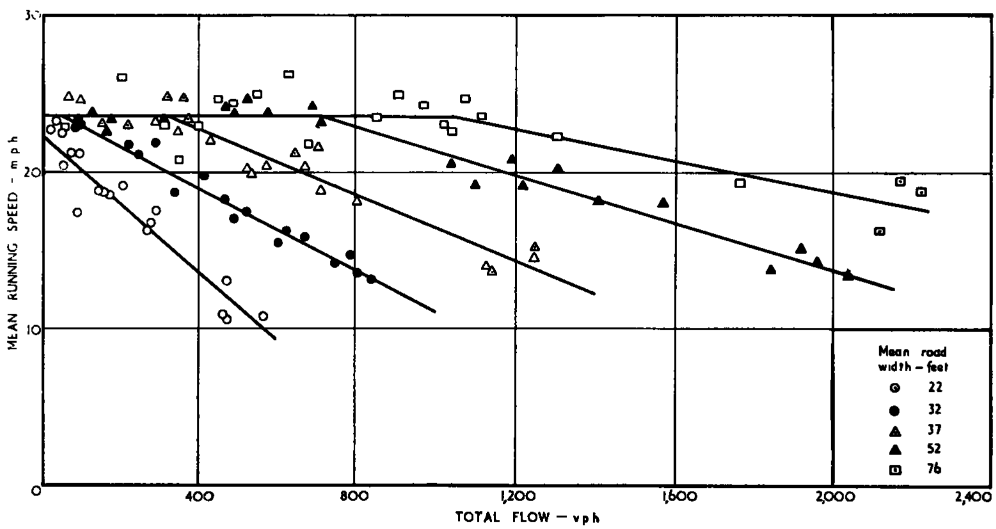

Figure 7. Mean running speeds against total flow.

TRAFFIC FLOW AND ROAD LAYOUT

From the point of view of accidents and of traffic, the urban areas of Great Britain are of greater importance than the rural ones. In 1949, for example, 75 percent of all injuries in road accidents in Great Britain occurred in urban areas, and surveys by the laboratory have shown that traffic in Central London spends nearly one third of its time stopped. The resources of the Traffic Flow Section have therefore been devoted mainly towards obtaining an understanding of pressing urban problems, and little research relating to safety has been made on rural roads. Most of the work on town conditions has been done in London, where many studies have been made of the factors which operate to reduce the speed of traffic. Little attention has hitherto been directed towards the more ambitious aspects of the replanning of cities, such as the provision of new main arterial roads, although the results of the London traffic studies have some bearing on this question.

Capacity of Urban Roads. Much of the work in connection with the capacity of urban roads has been done by using the moving-observer technique. Cars carrying observers travel in both directions along the route being studied, as far as possible at the mean speed of the traffic; the observers note the times at which selected points on the route are passed and count the parked vehicles and the vehicles approaching from the opposite direction. The method is not new for determining traffic speeds and delays, but the laboratory has ex-

tended the scope to the determination of traffic flow from the counts of opposing vehicles.

The relations between traffic speed, flow and street width for a number of streets in central London are summarized in Figure 7. It should be noted that the running speed represented in this figure is the average speed between stops at intersections; most of the effect of intersections is therefore eliminated but time lost in accelerating and decelerating is still left and results in running speeds which are lower than those maintained when traffic is moving normally between intersections. It should also be noted that the results are quoted for the conditions which were actually encountered when the measurements were made; no attempt has been made to correct the results to allow for variations in the number of parked vehicles or of pedestrians.

TABLE 2
COMPARISON OF OBSERVATIONS OF CAPACITY

Number of 12-ft. Lanes (Two-way Roads)	Road Width	Capacity per 12-ft. Lane: Central London (R.R.L.) — All traffic (15 mph.)	Capacity per 12-ft. Lane: American (Normann) — Passenger cars with 20 percent commercial vehicles (35–40 mph.)
	ft.	*v.p.h.*	*v.p.h.*
2	24	220	620
3	36	340	560
4	48	400	1250
6	72	550	1250

There is a substantially linear relation over most of the range of flow investigated except that there is a levelling out at running speeds of 25 mph. (corresponding approximately to the 30-mph. limit imposed on speeds of urban traffic). If the capacity of a street is considered as the traffic flow at a specified speed, the data allow an estimate of the capacity of London streets under practical working conditions to be made. In central London, average running speeds are of the order of 15 mph., and the capacity per 12-ft. lane in London conditions at this speed is given in Table 2.

We are not aware of any American figures which may fairly be compared with these, and we welcome any information of this kind. Figures due to Normann (*1*) are included in the table, but his values are generally more than twice the values obtained for central London, although his speeds are in the range of 35 to 40 mph., which on the basis of our findings would be expected to give lower values for capacity. The difference can be accounted for by the different conditions and composition of the traffic. The American results refer to uninterrupted roads, whereas the streets in London are very frequently interrupted, and the presence of buses would be expected to reduce capacities still further. A recent census of London traffic showed that 15 percent consisted of buses, trams, and trolley-buses, and a further 35 percent consisted of commercial vehicles.

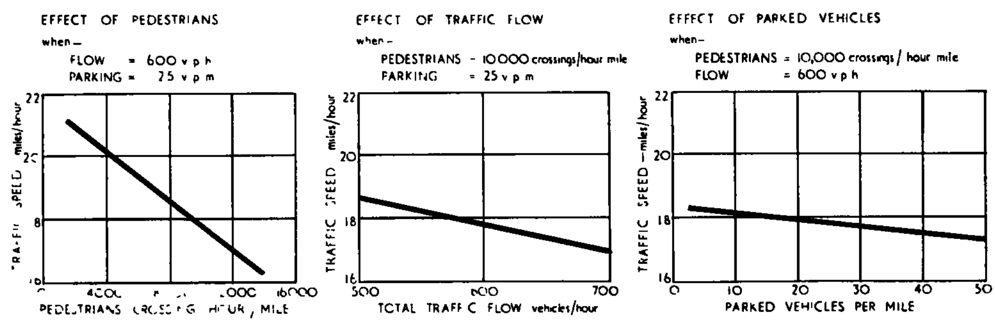

Figure 8. Effects of pedestrians, traffic flow, and parked vehicles on traffic speed. Effects of varying one of the factors while the other two remain at their average daily values.

Following the work on traffic speeds in central London, where no attempt was made to show how pedestrian flow across the street and the number of parked vehicles affected the result, a separate investigation has been started to determine the influence of these factors. The technique for the first of these studies was that of timing identifiable vehicles. Observers who carried synchronized stop watches were stationed at each end of the

length of street studied and noted the registration numbers of vehicles passing and the times at which they passed reference points. Other observers made counts of standing vehicles and of the number of pedestrians crossing the street. The results of the first of these investigations is shown in Figure 8. It is of interest to note that the results over the observed range of values are represented by the linear expression:

$$V = 27 - 0.00039p - 0.0081q - 0.023\tau$$

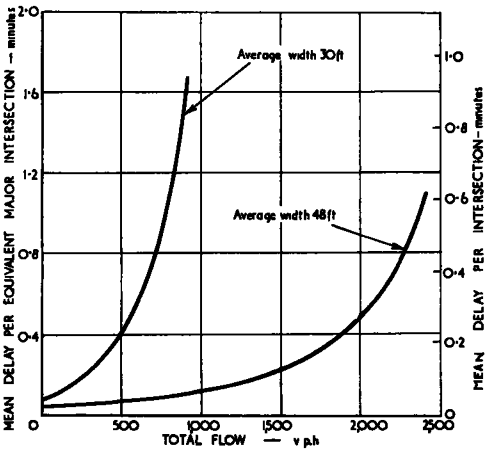

Figure 9. Delay per intersection on two groups of streets in central London.

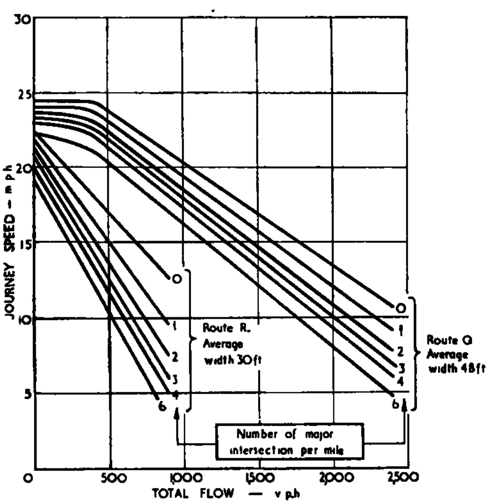

Figure 10. Effect of intersections on journey speed.

where V = the average speed in miles per hour in either direction (average speed for the whole journey not the running speed) p = number of pedestrians crossing per mile per hour, q = the total vehicular flow (in both directions) in vehicles per hour, τ = the number of standing vehicles per mile of street.

In the circumstances prevailing in this particular street, where p varied from 1,600 to 14,000, q from 500 to 660, and τ from 3 to 50, the conclusion to be drawn is that pedestrian flow across the road is a dominant factor in determining speed and that the alterations brought about by reducing the number of parked vehicles are much less effective. The reason for this may be that even a very small number of parked vehicles per mile is sufficient to sterilize the lane near the curb, and unless this last small number is removed, no big effect on the vehicle flow can be expected, that is, only the total prohibition of stopping traffic would be expected to have a large effect. This would, of course, have to include buses. These studies are being continued.

At the high traffic flows which occur at peak periods in London and other large cities severe congestion occurs and long delays are of common occurrence. In these conditions it is generally the intersections which limit the flow, and therefore the study of the delay at intersections forms an important part of the work on urban traffic conditions. Estimates of delay have been made from the results of an extensive survey of the speed-flow relations on London streets carried out by means of the moving observer technique as described earlier. The streets used for the analysis were divided into two groups of average width, 30 ft. and 48 ft. The mean delay per controlled intersection is plotted against total flow in Figure 9.

The average delay for major intersections (junctions of main traffic routes) on roads in central London was 34 seconds and for minor ones, 7 seconds. Thus, a minor intersection causes one fifth of the delay caused by a major one. Knowing the proportion of major and minor intersections on the routes studied, a scale of delay per "equivalent major intersection" may be put on the graph, where the number of equivalent major intersections equals the actual major intersections plus one fifth of the number of minor ones; this scale is shown on Figure 9. The effect of inter-

sections on the speed-flow relation is shown in Figure 10.

Other studies on delays at intersections are yielding information on light-controlled intersections, the effect of standing vehicles, turning traffic and traffic composition.

Rural Roads. Work on rural roads has been concerned with the safety of operation of traffic. Only a small proportion of the main roads in the rural areas of Great Britain are of modern design, and fewer still are divided highways. The work done has, therefore, been mainly on undivided highways, where investigations have been made on the influence of lane markings on the transverse position of vehicles, the relation of accidents to the curvature of the road, and the design of rural junctions.

Road Markings. In Great Britain, there has, for many years, been a difference of opinion as to whether roads about 30 ft. wide should be marked with three or two lanes. Some tests have been made to find what effect these markings have on traffic. The positions of the wheels of vehicles were recorded by means of segmented detector strips laid across the road and 20-pen recorders, a technique similar to that used in the United States. The observations were on three 30-ft. roads, either unmarked or divided by white lines into two or three lanes.

The results showed that in daytime there was little difference between the positions of traffic whether the markings were two-, three-, or no-lane. Other factors, such as the difference between the two sides of the road and between the two sites, had a greater influence on the traffic. However, as far as the results indicated any difference, they were in favor of the three-way marking. When this marking was in use, the average separations of the opposing traffic streams was slightly greater than when the highway was divided into two lanes only. The conclusion for night conditions, with the lines marked out by "cats-eye" reflectors was similar.

It is tempting to conclude from these experiments that line markings might be omitted on straight roads without any noticeable change in traffic behavior. It must be remembered, however, that the observations did not take account of the use a driver may make of these markings, particularly in overtaking, to judge the position of his own car and that of others cars on the road; in any case, markings are required for conditions of fog and poor visibility at night. Further work is required.

Curves and Sight Distances. A survey of curves on some of the main roads in Buckinghamshire has been made with the aid of automatic apparatus, which, mounted in a car, indicates on dials the horizontal and vertical inclination of the car with respect to a fixed base provided by a gyroscope. From photographic records of the dials, taken with a ciné camera at intervals of 1 sec. the curvature of a road may be quickly determined.

Data obtained in this way has resulted in the Table 3, which relates accident rates and road curvature.

TABLE 3
ACCIDENT RATES AND ROAD CURVATURE

Degrees of Curvature (degrees per 100 ft.)	Accidents per Million Vehicle-Miles
0–1.9	2.6
2–3.9	3.0
4–5 9	3.5
6–9.9	3.8
10–14.9	13.6
15 and over	14.9

Junctions on Rural Roads. Because of the intricate network of roads in Britain there is a very large number of rural junctions. The number of accidents occurring at any one of these is very small, but the aggregate is considerable. Their design is therefore being studied and at present particular attention is being paid to the proposals of G. T. Bennett (*2*). He has recommended that at rural three-way junctions traffic should be able to turn right from the major road (a left turn in the U. S. A.) without having to slow down, the design he proposed for this purpose is shown in Figure 11(*a*). This recommendation was based on a study of accidents at rural junctions in Oxfordshire. An analysis by the laboratory of accidents at a further series of rural junctions of types (*b*), (*c*), and (*d*), suggested that a junction combining a square entry into the major road with a gradual exit from it, Figure 11(*e*), might be safer than other simple types considered. Experiments are now in progress in which two junctions of this type will be built and kept under observation.

Before-and-after comparisons are particularly difficult in cases like this, because accidents are so infrequent, and so an attempt is

being made to analyze the maneuvers of vehicles and to infer from these maneuvers whether an improvement has been made or not. Records of the maneuvers are made either by means of ground records, from transverse position indicators placed across the road or by aerial photography from a balloon. The results of this study are not yet available.

The work described in the foregoing paragraphs provides answers of general interest and applicability, but a considerable amount of before-and-after work has also been done to assess the value of changes designed to improve traffic flow or safety in a particular place. This includes work on "No Waiting" regulations, one-way streets, the effect of a bus strike, and, of the introduction of wider buses on the flow of traffic.

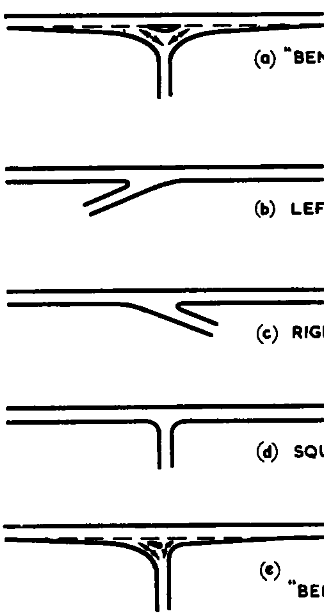

Figure 11. Types of three-way junction.

SKIDDING

Although skidding may occur on dry surfaces, it is primarily a wet-weather problem, and the skidding section of the laboratory concerns itself only with the wet surface. Skidding accidents receive a great deal of attention in Great Britain, for several reasons. The roads are wet for a considerable proportion of the year; in London, one of the driest districts, observation shows that the road surface is wet for about one fifth of the year. Another reason is that many of our large towns still have considerable mileages of very slippery surface, chiefly wood blocks and stone setts. They are being replaced as quickly as circumstances permit, but while they remain, our motorists are forced to be very alive to the dangers of skidding. The police statistics for 1949 showed that, in the opinion of the police officers recording the data, skidding was a factor in five percent of all accidents.

Work on skidding was started about 20 years ago by Bradley and Allen (*3*) of the National Physical Laboratory, and the machines and tenchique they devised are still in use with only slight modification. The aims of present day research are to: (1) provide road engineers with measurements of skidding resistance; (2) study the interaction of the tire and the wet road surface; (3) design non-skid road surfaces; (4) devise simple methods of measuring skidding resistance, capable of use by road engineers; and (5) find how the slipperiness of a road affects its accident record.

Measurements of Skidding Resistance. Measurements of skidding resistance have been made on a routine basis for highway authorities for many years, and between 1,000 and 2,000 measurements of this kind are made every year.

As already mentioned, the apparatus was developed by Bradley and Allen about 20 years ago. In the form developed by them, it has the advantage of giving a continuous record of skidding resistance at a fixed or variable speed. Figure 12 is a photograph of one of the special motorcycle combinations with which the tests are made. The sidecar wheel, fitted with a smooth tire, is set at an angle of about 20 deg. to its direction of travel, and the skidding resistance of the surface under test is assessed in terms of the ratio of the sideways force acting on it to the load it carries. This ratio, called the sideway-force coefficient (S.F.C.) is recorded continuously on a paper chart as the machine is driven along the road. It was shown by Bradley and Allen that the angle of 20 deg. insured that the maximum sideways force was developed; and that the sideway-force coefficient obtained in this way is approximately equal to the braking-force coefficient in straight braking with a smooth tire. The accuracy of the method is good, and,

on a very uniform surface, it can give readings for the average value of the coefficient over a 5-yard length of road which have a standard error of about 0.01. On most road surfaces, however, variations in texture from place to place increase the standard error of individual observations and the figure may be as high as 0.05.

The sidecar machines have the advantages of maneuverability and good visibility, but the driver is rather vulnerable, and although runs at speeds up to 60 mph. have been made, the machines are not suitable for speeds of over about 40 mph. Before the war, a high speed skidding machine was in use, consisting of a sideway force wheel towed by a supercharged Mercedes-Benz car, and a similar recording arrangement is now being designed to be housed within the wheelbase of a motor vehicle.

Records of skidding resistance are generally set out in a table or a figure, such as Figure 13, giving the variation of the sideway force coefficient with speed. It is usual also to quote a skidding distance from 30 mph.; this is a calculated figure for the braking distance of a car with smooth tires, assuming that the wheels are locked instantaneously at 30 mph. and that the sideway force coefficient applies to this condition.

Fundamental Research on Interaction of Tire and Road Surface. Many phenomena of fundamental importance were investigated in the years before the recent war in the course of work with the sidecar machines. Results were obtained showing the dependence of the skidding resistance on speed; the influence on the sideway force coefficient of factors, such as wetness of the road, slip of the tire, tire-inflation pressures, and tire hardness were examined; it was recognized that surfaces of certain types always gave poor results; the seasonal changes of coefficient observed with some surfaces were studied; and work was done on the deterioration of surfaces with

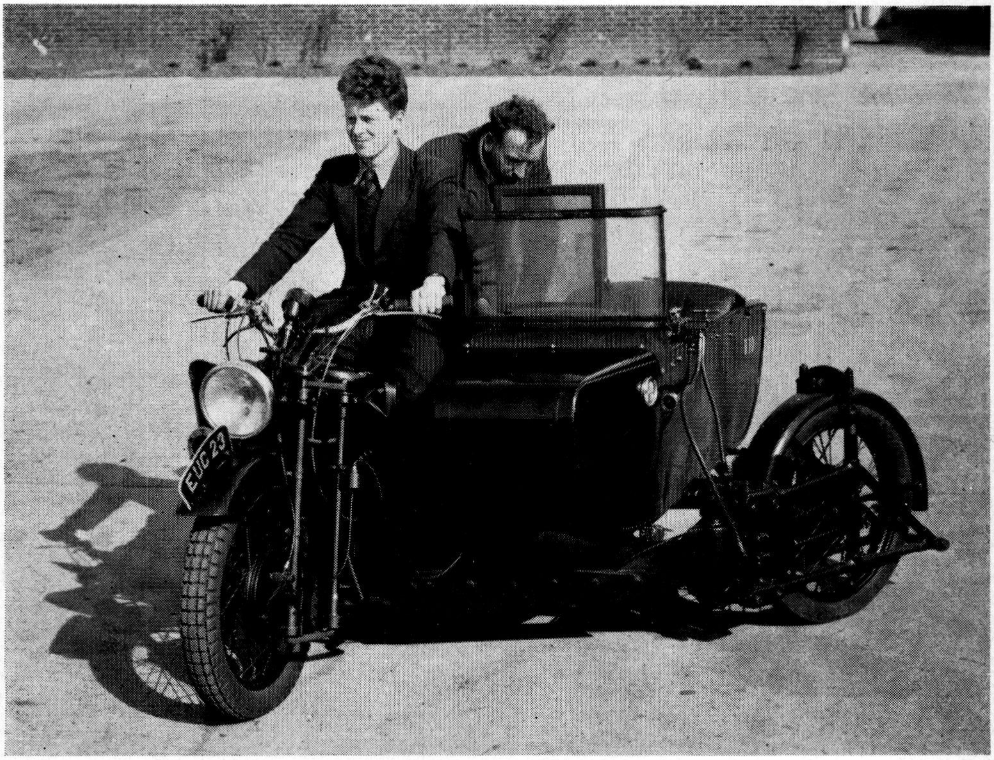

Figure 12. Motorcycle combination for measuring the skidding resistance of road surfaces.

age. The work generally tended to support the hydrodynamic theory of skidding put forward by Saal (*4*) and to show the importance of providing drainage channels in the surface of the road, so that the water film is expelled rapidly from beneath the tire. Some experimental work at the laboratory (*5*) showed that the sharpness of the projecting aggregate

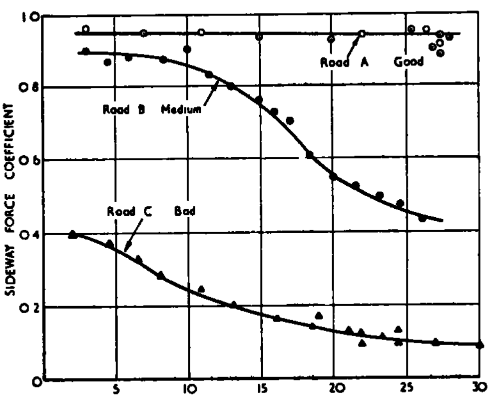

Figure 13. Frictional properties of typical wet road surfaces at different speeds.

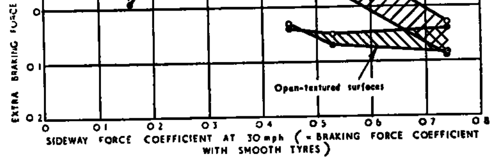

Figure 14. Increase of available braking force on slippery surfaces due to tire tread.

might also play an important part in improving the skidding resistance of a surface.

Since the war, basic research on the skidding problem has been concerned with particular aspects of drainage and shape of aggregate. In connection with drainage, an investigation is being made of the relative effectiveness of different tread patterns in increasing the retardation of a vehicle skidding with locked wheels on surfaces of different textures. It had been noticed that the improvement of skidding resistance due to the tread pattern was more pronounced on smooth than on rough surfaces, an observation also made by Shelburne and Sheppe (*7*) and Moyer (*8*); the investigation now being made is designed to determine the amount of this improvement for various conditions of tire and road. The first series of tests was conducted in the following way: Tires of natural rubber having a number of different tread patterns, including smooth treads, were fitted in turn to a test car, which had good brakes and which carried a recording accelerometer, and apparatus for timing the duration of brake application. The test procedure was to drive on to the wet road surface, apply the brakes so as to lock the wheels for one second, and record the deceleration of the vehicle. Enough runs were made with each tire tread to obtain reliable averages, and the tests were repeated on surfaces covering a range of sideway-force coefficient and texture depth. Subsidiary tests were made to determine the influence of tire hardness and inflation pressure, and sideway-force coefficients were measured at intervals during the course of the investigation.

The main results are shown in Figure 14. They lead to the conclusion that on close-textured slippery surfaces, such as that shown in Figure 15, tire treads are very effective, but on open textured surfaces they are slightly inferior to smooth tires. On the close-textured surfaces, the tire treads are most effective for sideway-force coefficients in the neighborhood of 0.3, where the available braking force may be almost doubled by the presence of a good tread pattern (as compared with a smooth tire). There was a considerable difference between the best and worst tread patterns, as shown by the width of the band in Figure 14. It was difficult to relate performance to any particular feature of the tread; all that could be said was that the patterns which were most broken up were best. It appears, then, that the drainage channels may be provided either on the road surface or on the tire; putting them on both is slightly worse than on one only.

The investigation which has just been described was made with tires all of which were nearly new. It is being continued at intervals during the life of the various sets of tires, and until it is known for how long the im-

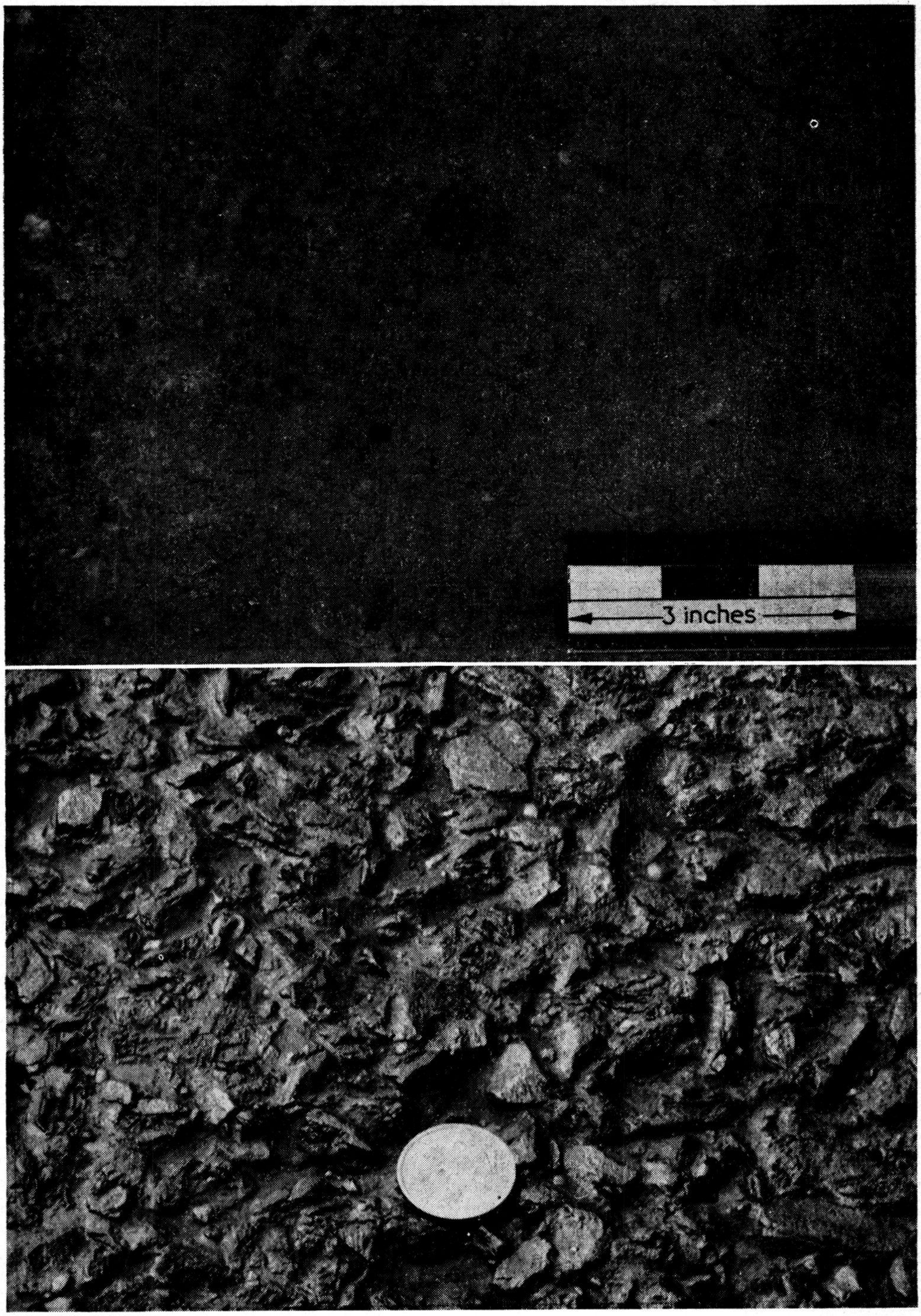

Figure 15. Test surfaces in the tire-tread experiment. Above: Close-textured surface, with sideway force coefficient of 0.37. Below: Open-texture surface, with sideway force coefficient of 0.54.

provement due to tread pattern is maintained, it is not possible fully to discuss the obvious implications of the results.

Interest has recently been taken in methods of studying the sharpness of aggregate and the way in which the sharp edges may wear away or change under the passage of traffic. A method is being tried for measuring the pressures on the tops of the stones by means of a pressure-sensitive photographic film placed between the tire and the road. When developed, the film is blackened in regions of high pressure and the density of the blackening can be related to the pressure. Although the method is not yet working well, it has shown that very high pressures, in some cases in the neighborhood of 8,000 psi., may be set up between the tire and the aggregate.

The Design of Nonskid Road Surfacings. A considerable proportion of the effort of the Materials Division of the laboratory is devoted to the design of surfacings and, in particular, to the design of the bituminous surfacings, with which most of the roads of Great Britain are laid. The most-important property of a road surface is probably its durability, but it is also very necessary that it have a high resistance to skidding. Many surfaces are judged to have ended their useful life on the grounds of slipperiness alone. An important part of the work of the Skidding Section is, therefore, to measure the skidding resistance of test sections of road surface laid for experimental purposes. The factors which may affect the skidding resistance of a surface, particularly one constructed of bituminous materials, are numerous; some of these factors are the type, size, shape, and grading of the aggregate, the type and amount of binder, the weather, and amount of traffic.

With so many sources of variability in the results, reliable conclusions on the design of surfacings likely to give a long life and a high resistance to skidding can only be arrived at as the result of carefully planned, large-scale experiments with limited objectives carried out for a number of years. Several experiments on these lines have been made and are still in progress; for example, more than 700 different examples of surfacings were laid on the Colnbrook bypass in 1939, and this experiment was followed up in 1945–48 by large-scale experiments at four other sites where the behavior of local aggregates was specially examined. In all such experiments the skidding resistance of each section is measured every few months. The results of these experiments were described in a paper by A. R. Lee (*6*). One outstanding conclusion was the predominating influence of the amount and nature of the bituminous binder on the performance of the surfacing.

Simple Methods of Measuring Skidding Resistance. The motorcycle test machines are unsuitable for unskilled use and several attempts have been made to devise simple methods of measuring skidding resistance, suitable for use by road engineers.

It was at one time thought that a simple way of measuring the texture of the road surface might furnish the method sought, and many surface textures were measured by means of the sand-patch method. A known volume of fine sand is spread into a circular patch on the road and enlarged until the holes in the surface are just filled. The "texture depth" is then the volume of sand divided by the area of the sand patch. A rough correlation was found between texture depth and resistance to skidding for concrete surfaces, but no generally applicable method has emerged. For example, some of the best nonskid surfaces are those with sandpaper finishes, which have a small texture depth.

The most promising outcome of the search for simple devices is the locked-wheel-braking method, similar to that used by Shelburne and Sheppe (*7*) and by Moyer (*8*) in their researches on skidding, except that instead of measuring stopping distance, the maximum deceleration in the first second after the brakes are applied is recorded. A commercial decelerometer of a pendulum type fitted with a rachet device to retain the maximum reading is mounted in the vehicle, and set level. A switch is attached to the brake pedal, and when the brake is applied, a timing device is set in motion. The correct time of application of the brake is indicated by a green light; if the brake is released too soon a white light appears; if it is held too long a red light appears. When making a test the vehicle is driven at some standard speed (generally 30 mph.) and the brakes are applied so as to lock all four wheels for one second. It is important that all four wheels should lock and that the time interval is correct. If the brake is held on too long the coefficient may be too high because

for most road surfaces it rises as the speed drops; if the brake is not held on long enough the decelerometer does not reach its final reading. The test procedure is not difficult, however, and the results give figures useful to the road engineer.

The main disadvantage of the method is that the results depend to some extent and in rather a complicated way upon the tire tread and the kind of surface. It is necessary, therefore, to decide upon the use of standard tires, which may be either smooth or treaded. Smooth tires have the advantage of giving an answer equal to the sideway-force coefficient, but the vehicle may be difficult to control on a slippery surface.

Skidding Resistance and Accidents. In all the work on road safety it is usual to try to estimate the effect of the phenomenon under consideration on accidents. For skidding, this is being done in two ways, first by means of before-and-after studies of accidents on roads where a slippery surface has been replaced by a better one, and secondly, by measuring the sideway-force coefficients of roads which have been the scene of skidding accidents, or have been the subject of complaints of slipperiness.

The before-and-after investigations prove that very marked improvements result when very slippery surfaces are replaced. For example, replacing a wood-block surface in Finchley Road, London, with a sideway-force coefficient of 0.2 at 30 mph., by a surface with a coefficient of about 0.5 at 30 mph. reduced personal injuries in skidding accidents from 32 to 2 in comparable winter periods. Other examples of the same kind exist.

Measuring the coefficients of accident sites and of roads about which complaints have been made has resulted in Figure 16; 90 percent of these accident sites had coefficients below the value 0.4 at 30 mph., which is normally regarded in the laboratory as the safety limit. In order to show that the distribution is not simply that of the relative frequency with which these coefficients are met driving about the country, Figure 17 has been prepared, giving the results of tests on a sample of 137 lengths of road in three counties, the lengths being selected at random from all the classified roads in the counties in such a way that the chance of any length of road being tested depended on the amount of traffic using it. In this diagram only 40 percent of the roads

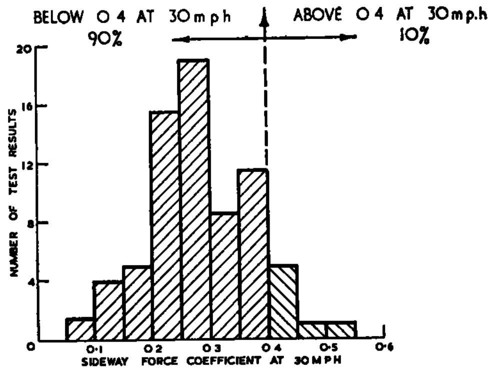

Figure 16. The skidding resistance of roads which when wet were the scene of skidding accidents or the source of complaints of slipperiness. (Results of tests on 71 surfaces).

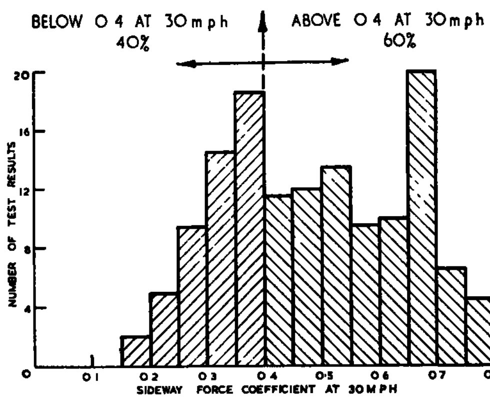

Figure 17. The skidding resistance of present day roads in wet weather. (Results of tests on 137 lengths of road selected at random from the classified roads in three counties).

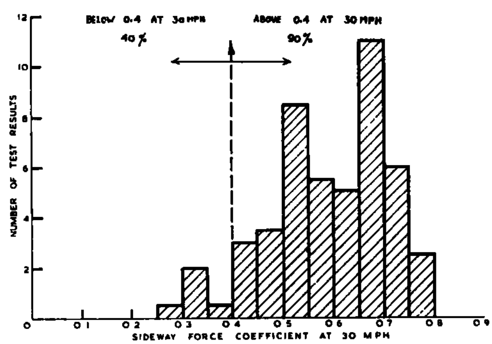

Figure 18 Results of skidding tests on a sample of forty-eight sections of road in one county.

were below the value 0.4, compared with 90 percent for the accident sites.

The figure of 40 percent below the desirable figure of 0.4 however leaves much room for improvement, and Figure 18 has been in-

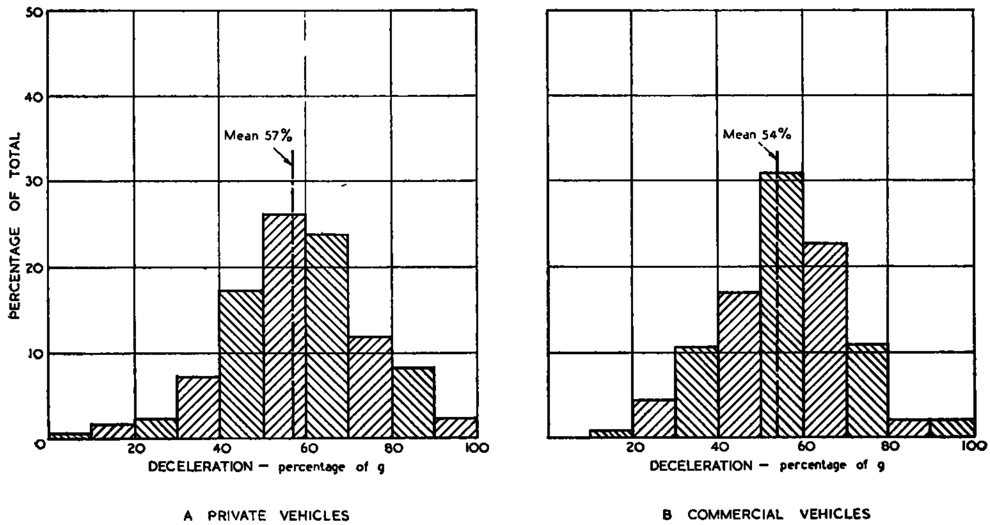

Figure 19. Results of brake tests on vehicles selected at random.

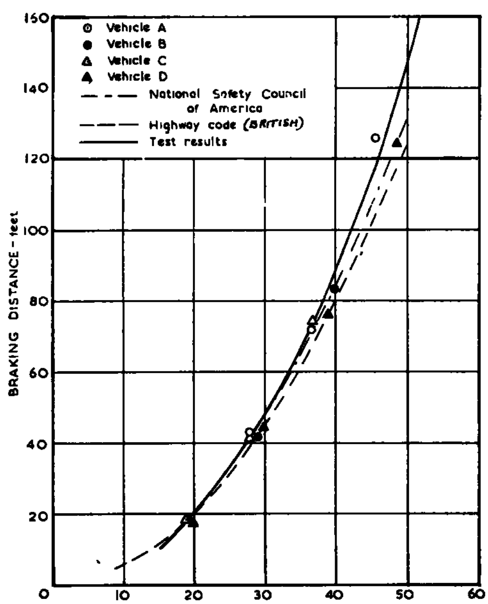

Figure 20. Braking distance—speed relation for 4 cars based on average results for 6 drivers and comparison with other published figures.

cluded to show what can be done. This gives the results in one of the three counties surveyed. Over 90 percent of these results were over 0.4 at 30 mph.

VEHICLE PERFORMANCE

The Vehicle Section has so far investigated only one factor in the mechanical performance of the vehicle: brakes.

Much of the work on braking has been in anticipation of the possible introduction in Britain of periodic brake-testing similar to that carried out in vehicle-testing stations in the United States. The aim has been first to determine the present level of braking performance for vehicles in use on the road, secondly, to estimate the improvement if all vehicles were brought up to the level of the best, and lastly, to find out how to check the braking performance of vehicles of all types.

Braking Test Results. The braking performance of vehicles on the road has been studied by the laboratory by methods similar in many cases to those employed by the Bureau of Public Roads in 1941–2 (*9*). In some of these tests, undertaken in collaboration with a number of police forces all over the country, the performance of random samples of vehicles were investigated by means of decelerometers and the results were submitted to the laboratory for statistical analysis. Some of the results are shown in Figure 19; they refer to emergency stops by the usual driver of the vehicle, from about 20 mph.

The performance to be expected under the best conditions has been investigated by

measuring the braking distances of vehicles known to have good brakes. Braking stops from speeds up to 60 mph. were made on the concrete runway of a disused airport; the concrete was dry, in good condition, and had a good nonskid surface. Braking distances were measured from a mark made on the runway surface by a pellet fired automatically from a gun at the instant when braking started. The best results for cars were in excellent agreement with braking distances given by the American Safety Council and in the British Highway Code; the three sets of values have been plotted in Figure 20. The results for certain commercial vehicles are shown in Figure 21. It will be noted that a heavy truck with a loaded trailer had a poor performance. In this particular vehicle the brakes were power-assisted and the assistance was very slow in building up; further work is in progress to find how far this defect is present in vehicles on the road today.

Driver Reaction Times. In the investigations on braking performance just described, the driver's reaction time was not considered, but some work has been done on this aspect of braking. Times of reaction to light and sound signals have been measured with both a stationary and a moving car. The reaction times recorded were about 0.4 sec., and were in approximate agreement with values obtained in many earlier investigations of the same kind (*10*). This method probably gives reaction times which are shorter than can be achieved on the road when the driver has to be on the look out for road hazards and further investigations have therefore been carried out with a test car driven in town traffic.

A ciné camera was mounted beside the driver and pictures were taken of the road in front of the car, of a clock face, and of instruments showing when the brake was applied. The driver was instructed to react to a pedestrian stepping off the pavement at a pedestrian crossing by applying the brake. Thus from the ciné record which showed the instant when the pedestrian stepped off, the drivers reaction time to this situation could be determined. The result is shown in Figure 22; as expected, some of the times are very much longer than those obtained in a straight forward reaction time test; in other cases, however, it is clear that the driver had anticipated the pedestrian's action.

Control of a Vehicle in Emergency Stops. Even in the best circumstances cars often deviate from a straight course when brakes are applied suddenly. This was demonstrated during the experiments which gave the results shown in Figure 20, and which were carried out in the most favorable conditions; the runway surface was flat and straight, the cars were new with properly adjusted and balanced brakes, and the cars were running straight when braking started. Even in these circumstances the cars often swerved during braking, and not infrequently the brakes had to be released for the driver to regain control. On the road, however, conditions are generally less favorable, emergency braking is often necessary on a bend or while swerving to avoid some obstacle, and brakes are frequently not properly adjusted or balanced. Thus, far more

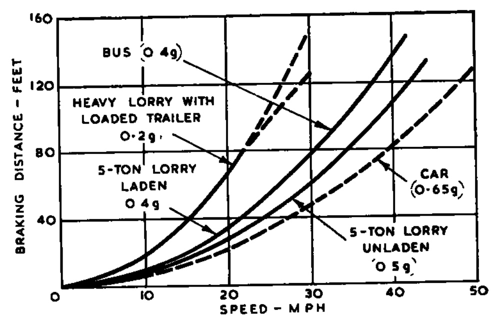

Figure 21. Observed braking distances of vehicles of different classes having brakes in good condition.

loss of control is likely in emergency stops on the road than in the tests and the laboratory is therefore investigating the effect of unbalance in the braking system between (1) front and back wheels and (2) near and offside wheels. An apparatus has been made for recording separately the speed of rotation of each wheel so that the instant at which each wheel locks may be determined. It is hoped, by means of this apparatus, to learn much about the way in which skidding takes place on both dry and wet surfaces, and of the conditions in which unbalance may seriously impair the driver's control of the car.

Brake-Testing Apparatus. If periodic brake testing were made compulsory in Britain, it would be necessary to decide how brakes should be tested. The laboratory is therefore studying methods of testing brake perform-

ance. Brake-testing machines of the roller type and the platform type and decelerometers are being investigated, but the work is not yet at the stage at which the results can be discussed.

the time taken to stop from a known speed, and 3) timing the car between two posts during the braking stop. Table 4 compares the three methods.

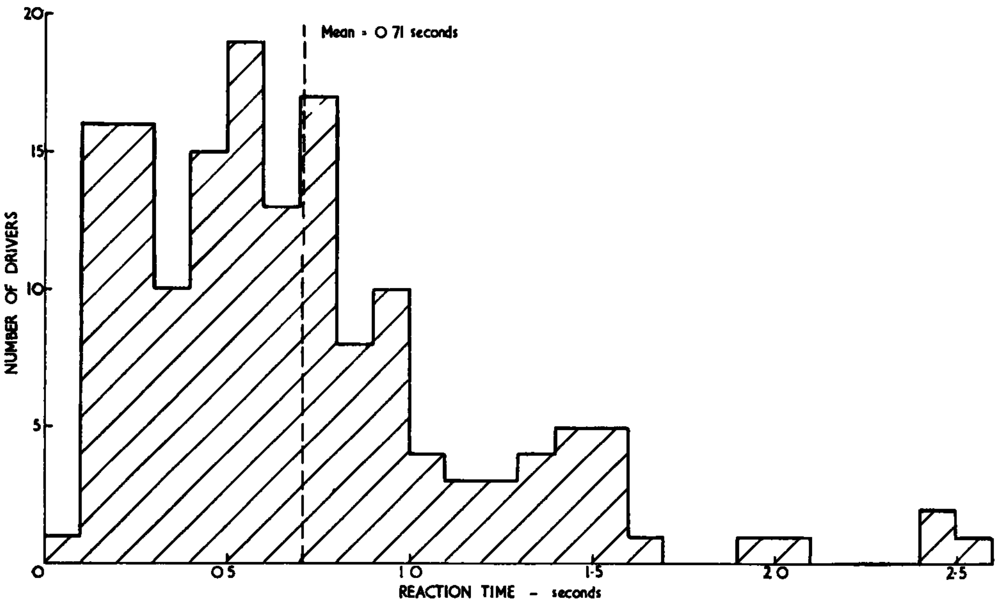

Figure 22. Distribution of reaction times for drivers in town traffic.

TABLE 4
SUMMARY OF MEAN PERCENTAGE ERRORS OF DIFFERENT METHODS OF MEASURING BRAKING DISTANCES, REFERRED TO GUN METHOD AS STANDARD

Method	Mean Percentage Error = E	Standard[a] Deviation of E
Stopping from a fixed object	11.5	10
Time to stop from a given speed	15	14
Time to cover a known distance with the brakes applied	23	18.5

[a] Indicates that 95 percent of individual percentage errors would be expected to fall within ±2X (standard deviation of E) of mean percentage error E.

Both a fifth wheel and a simple gun device firing a pellet to mark the road surface have yielded accurate measurements of braking distances. Three rather crude methods of measuring braking distances still occasionally employed have been shown to be very inaccurate. These were: (1) braking when passing a post and measuring the distance from the post to the stopping point of the car, (2) measuring

LIGHTING

The Lighting Section is concerned with vehicle and street lighting in relation to road safety, and attention has been paid to the problem of glare, the improvement of the passing beam, requirements for vehicle rear lights, and the part played by the road surface as a component of the street lighting system.

Vehicle Headlamps. Whenever the problems of vehicle lighting are discussed, the question of glare comes to the fore, but it is always necessary to remember that the fundamental problem is two-fold, first to provide light in the right place in order to see and secondly to minimize glare. These are the two objects of work on vehicle lighting.

When work was first started in 1947, it was decided to proceed in two directions, first, to make a survey of the state of vehicle lighting on the roads, and, secondly to make tests with the object of improving the passing beam. The design of an improved driving beam was judged to be of less importance and no work has yet been done on this.

The first glare survey was made in the winter of 1947 with the help of several police forces. The observers, who were in cars with properly adjusted headlights, noted how many of the oncoming cars were using: (1) driving beams, (2) dimmed headlights, (3) special pass lamps, (4) side lamps only; and the observers judged whether headlights were glaring. The main results were the following: (1) the amount of dazzle (glare) was considerable: about one in seven of the cars met on unlit main roads were judged to have headlights which caused glare; (2) on unlit main roads carrying fairly heavy traffic, 80 percent of the cars when first seen, were using a passing system (dipped headlamp or special pass lamp); (3) most of the glare was therefore due to badly adjusted passing beams and not to undimmed driving beams; and (4) the low-mounted pass lamp was about twice as likely to be glaring as the dimmed headlamp.

As a result of these investigations, a regulation was issued by the Ministry of Transport prohibiting the use of passlamps mounted at less than 2 ft. from the ground, except in fog or snow.

Assessment of glare by the judgment of observers is useful for giving an overall picture of the situation but does not lend itself to measuring such small changes as may result from improvement in lamp design or maintenance. Instruments for measuring glare are being developed and when they are available it is intended to make periodic surveys of the amount of glare on the roads of the country.

The glare survey showed the need for improving the adjustment of passing beams and a critical examination of the various headlamp setting devices on the market is being made and methods of bringing them into more general use are being considered.

A good deal of work has been directed towards improving the passing beam and beams of many types have been tested. No single method of test appears to be wholly satisfactory. The usual method and the one we have used most, is that, described by Roper and Howard (*11*), of measuring the distances at which test objects can be seen from the moving car in the presence of glare from opposing headlamps; this, however, may give little idea of the confidence (or lack of it) which the driver has when using the beam, and which probably arises from the feeling that he knows exactly where he is on the road. A carefully controlled road test is necessary to judge this quality of the beam. A third kind of test is required for beams with a side or top sharp cutoff. The Roper test gives little idea of the value of these beams on the road, since if critically aimed they can give very large values of seeing distance without glare. On roads with bends and vertical curves, however, they may give rise to severe glare, unless dipped to such a degree that the seeing distance obtainable is much reduced. A test for glare on average roads is therefore required before their value can be properly assessed; we have not yet devised a satisfactory test of this kind.

Passing beams fall into four main classes, according to the distribution of light in the beam: (1) the American sealed-beam type, with an asymmetric distribution of light and no sharp cutoff. This class includes most British headlamps, past and present; (2) the European type with a horizontal symmetrical distribution of light and sharp horizontal cutoff (certain British passlamps are of this type); (3) the beam with vertical cutoff, directing light on the nearside of the road only; and (4) the diffuse beam, with a low candlepower in all directions, and no sharp cutoff.

In the main series of tests we have used a modification of the technique devised by Roper, in which two cars carrying similar passing beams approach at a known speed and the distances at which test objects placed on the track are seen is measured. For the sake of speed in testing, we have usually been content to use one moving and one stationary car and a single test object placed 10 ft. behind the stationary vehicle; this is probably the worst situation for seeing in the face of glare.

The investigations have been designed to furnish basic data which, it is hoped, will lead to a method of computing the seeing distances from the distribution curves of the headlamps, as well as to compare the performance of different headlamps. Most of these investigations are still in progress and it is therefore only possible, in a paper of this kind, to give examples of the information being collected.

Measurements have been made of the dependence of the distance at which a test object can be seen on the candlepower of the

headlamp. The results of one such test are shown in Figure 23. With no opposing glare, as the candlepower of the beam was increased the seeing distance also continued to rise. With opposing glare, however, there was little increase above a candlepower of about 5,000; the increased glare almost exactly countered

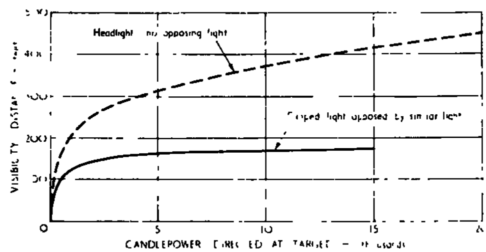

Figure 23. Visibility distance for unopposed and opposed lights as a function of candlepower. Target 6 percent reflection factor, speed of vehicle 20 mph. target behind stationary vehicle.

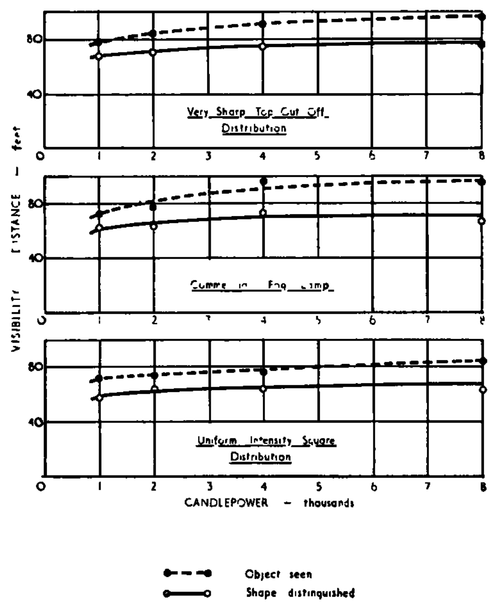

Figure 24. Visibility distance—candlepower curves in fog with low mounted lamps for three types of beam distribution

the increased candlepower on the target. For the calculation of seeing distances in the presence of glare a large amount of information of this kind is required; this is being collected at the present time, and the results will shortly be available.

An experimental technique is being worked out for a test to use as a substitute for road trials of passing beams. Two cars fitted with similar headlamps are normally used on a test track about half a mile long, having a long straight section and two curves. Dummy men of dark material are placed at the sides and center of the road. The cars start at about the same time from opposite ends of the track, and the drivers are able to assess the merit of their passing beams both with and without glare from a similar opposing beam. The object is always to compare two different passing beams so that having made a run with Beam A, both drivers change over to Beam B, and so on, making several runs with each. They then record their preference. The experiment is repeated with the road wet, and the whole procedure is gone through with about a dozen drivers.

A series of tests is being made in this way, in which particular attention is being paid to comparisons of the sealed-beam type of distribution with the European beam with a horizontal cut-off. At the same time the opportunity is being taken to obtain subjective judgments of glare.

An investigation was recently completed on fog lamps. The distances at which a target could be seen in a moderately thick fog were measured with three lamps of widely different characteristics, one having an extremely sharp cutoff, a second with no cutoff at all, and a third a commercial fog lamp with a fairly wide spread. The mounting height and the candlepower of all three lamps were varied, with the results given in Figure 24. None of the changes had very much effect, although as might be expected best results were obtained with a low-mounted beam with a sharp cutoff. It was concluded that the most important thing was to put the light where it is wanted, and that a very wide beam of low candlepower, showing up the sides of the road, was likely to give the best results. Practical trials with a lamp having these characteristics has confirmed this conclusion. Theoretical work has shown the important role of secondary scattering by the water droplets in a thick fog.

Vehicle Rearlights. Another investigation which yielded interesting results concerned the intensity requirements for vehicle rear lights. It was in three parts, first, a statistical investigation of the accident data, secondly, the experimental determination of the distances at which rear lamps could be seen under various conditions of weather, etc. and,

thirdly, a survey of rear-light intensities on the British roads.

The statistical analysis was based on two-vehicle accidents, and particularly of those in which one vehicle had run into the back of another at night. During the 3-month period (October to December 1949) 5,159 two-vehicle road accidents occurred at night and 9,189 by day. Table 5 shows that 50 percent of these accidents excluding those in which one vehicle ran into the back of another, occurred at night, but for several types of rear end collision the night-day ratio is significantly higher than 0.5. The ratio is particularly high in non-built-up areas (where street lighting is not usually provided) for parked or stationary vehicles and moving bicycles hit in the rear.

TABLE 5

NIGHT-DAY RATIO OF TWO-VEHICLE ACCIDENTS TO NEW AND OLD VEHICLES TAKING PLACE OCTOBER-DECEMBER, 1949

Type of Accident	Vehicles Involved	Night-Day Ratios	
		Old vehicles (1930–39)	New Vehicles (1946–49)
Parked vehicle hit in rear	Cars	*2.3*	0.4
	Goods	*2.2*	*2.2*
Temporarily held up vehicle hit in rear	Cars	*1.0*	0.2
	Goods	*1.7*	0.7
Vehicle hit in rear by another moving in same direction	Cars	0.5	0.6
	Goods	0.7	0.5

The italic figures correspond to night-day ratios significantly different from the expected value of about 0.5.

Table 5 shows that new cars, (which have lights to SAE standards) are struck less frequently by night than by day, but that commercial vehicles and old cars, which have poor rear lights, are struck more frequently. If we assume that improving rear lights (including bicycles) to SAE standards would bring the night-day ratio of all rear-end collisions to 0.5, total road casualties in Great Britain would be reduced by 2 percent or about 4,000 casualties per annum.

In the field survey, a visual telephotometer was used to measure the intensities of rear lights. The median values observed were: public service vehicles, private cars and motor cycles, 0.05 candelas[1]; commercial vehicles, 0.02 candelas; bicycles, 0.007 candelas. About three quarters of the vehicles had rear lights with intensities below 0.25 candelas, the SAE standard.

Measurements of visibility distance were made from a car moving at 30 mph. The observer noted the instant when a rear light became (a) just visible, (b) just unmistakable as a red light, (c) just obvious, and (d) just brilliant. The observations were made in various weather conditions, with and without opposing glare, and for a range of intensity of the rear light. Observers were in agreement that, as drivers, they would be certain of taking action on the road when a rear light became just obvious.

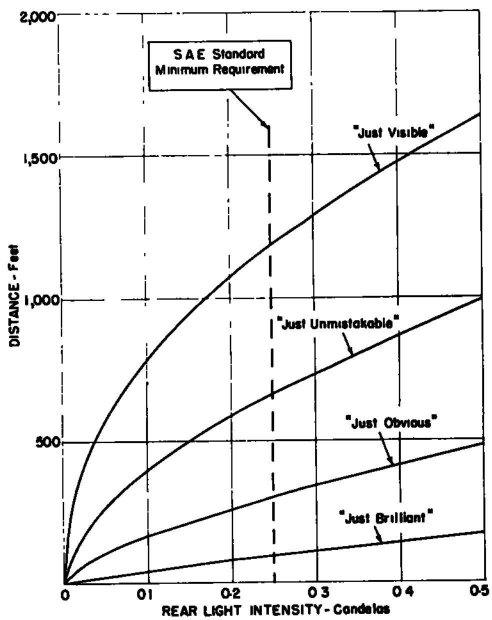

Figure 25. Variation of visibility distance (using four standards of visibility) with rear light intensity for glare intensity of 5,000 candelas.

Figure 25 gives results when the opposing glare intensity is 5,000 candelas, a value not unlikely to be met if headlamps are incorrectly aimed. A red rear light of 0.25 candelas is then just obvious at about 300 ft. This appears to be by no means an excessive warning distance in view of the number of vehicles on the road with poor brakes. The conclusions of the work as a whole confirm that the SAE standard for rear lights is adequate but not excessively strict.

Street Lighting. The importance of street lighting in the accident situation is shown by

[1] The *Candela*, adopted in 1948 to replace the old *international candle*, differs from the American *standard candle* by about ½ percent for tungsten filaments; hence U. S. engineers may read *candle* for *candela* for practical purposes. —*Ed.*

the fact that three quarters of the night accidents in Great Britain take place on roads lit by street lamps. Up to the present, however, it has not been possible to devote as much attention to this subject as its importance merits.

Our attention has been mainly directed towards the investigation of the part played by the road surface as a component of the lighting system. A photographic method of measuring the reflection properties of a surface has been used to check the theory of Bloch, who attempted to explain the reflection characteristics of road surfaces by assuming them to be composed of numbers of small reflecting planes. Bloch's theory has not been confirmed, but the work is likely to furnish a concise method of describing the reflection properties of a road surface in a form suitable for research engineers.

STATISTICS AND ACCIDENT ANALYSIS

It will already be clear that the activities of the Statistics and Accident Analysis Section permeate the whole of the work of the Traffic and Safety Division. The results of several accident analyses have been mentioned, and a great deal of work of this kind is done.

There are also more general analyses, in which background statistics, such as the relative vehicle mileages of various kinds, are collected. These provide comparisons of personal injury accident rates, on a vehicle-mile basis, corresponding to various types of vehicle, times of day, week, and year; weather conditions; etc.

This is not the only work of the section. Guidance is given in the design and analysis of the more complex experiments of other sections. In this work statistical considerations can sometimes be of value in producing a design which is economical in experimental effort and is most likely to lead to valid conclusions.

Finally, it should be mentioned that a number of before-and-after investigations are made from time to time. An example of this was an analysis of the effects of the experimental police patrol scheme operated before the war by the Home Office. Accidents in 1938 in police districts operating the scheme were compared with those in the remainder of England, the basis of comparison being the percentage change from the preceding year. The analysis showed that the scheme resulted in an average reduction of 10 percent in personal injuries.

ACKNOWLEDGEMENTS

The investigations at the Road Research Laboratory referred to in this paper were conducted as part of the program of the Road Research Board. The paper is presented by permission of the director of road research.

REFERENCES

(1) NORMANN, O. K. AND WALKER, W P.: Highway capacity: practical applications of research. Public Road, *25*, Nos. 10 and 11, (Oct., Dec., 1949).

(2) BENNETT, G. T.: Road junctions: suggestions for improved designs. Public Works, Roads and Transport Congress and Exhibition, 1947—Final Report. London.

(3) BRADLEY, J. AND ALLEN, R. F.: Factors affecting the behavior of rubber-tired wheels on road surfaces. Proc. Inst. Automob. Engrs. 1930–31, *25*, 63–92.

(4) SAAL, R. N. J.: A laboratory investigation into the slipperiness of roads. J. Soc. Chem. Ind. 1936, *55* (1), 3–7.

(5) MARKWICK, A. H. D. M. AND STARKS, H. J. H.: Stresses between tire and road. J. Inst. Civ. Eng. 1941, *16* (7), 309–23.

(6) LEE, A. R.: Full-scale experiments in road research with special reference to surface dressings and thin carpets. Inst. Civ. Eng. Road Paper No. 21, London, 1950 (Institution of Civil Engineers).

(7) SHELBURNE, T. E. AND SHEPPE, R. L.: Skid resistance measurements of Virginia pavements. Highway Research Board Research Report 5-B, Washington, 1948.

(8) MOYER, R. A. AND SHUPE, J. W.: Roughness of skid resistance measurements of pavements in California. Highway Research Board Bulletin 37, Washington, 1951.

(9) Brake Performance of Motor Vehicles Selected from the Everyday Traffic Public Roads Administration. Federal Works Agency, February 1944.

(10) DE SILVA, H. R. The Human Factor, *10*, No. 1, 1936.
NEAL, H. E. Department of Highways, Division of Traffic and Safety, Ohio, Sept. 20, 1946. Highway Research Board Abstracts, October 1946.

(11) ROPER, V. J. AND HOWARD, E. A.: Seeing with motor car headlamps. Trans. Illum. Eng. Soc. (U. S. A.) 1938, *33*, 417.