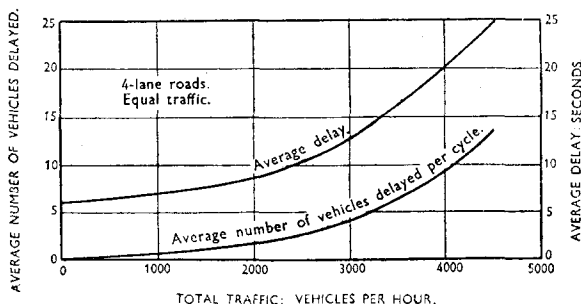


Fig. 5.



The device of using $\frac{1}{2}$ for the mean delay to the last vehicle is only justified by the fact that for normal values of the other quantities it is approximately true and its use gives practical expressions for d and n . For values of D below 200 the simpler method should be used.

Discussion.

The Chairman emphasized the difficulty of arranging meetings of the Section under war conditions, and stated that an effort had been made to meet at least once a year. He hoped that it would be possible to meet more frequently; and the Council would welcome the submission of Papers for discussion.

The Author observed that the Paper dealt with the theory of road traffic flow, and therefore did not contain many practical suggestions. Owing to the war it could not be supported, as it should have been, by adequate new data. He also wished to apologize for any clumsiness in the manner in which the mathematical arguments in the Paper had been set out.

With regard to the taking of statistics, he considered that a quite short traffic census could be adequate. From that point of view, the denser the traffic the shorter the count could be; for example, in a street such as Oxford Street, a count of about 10 minutes on each stream would be sufficient, provided that it were started at one release of the traffic by a signal or police control and finished at the next release. Generally speaking, he thought that thirty vehicles in any significant stream would probably be sufficient for a figure indicative of the behaviour of the traffic to be obtained.

With regard to the history of the subject, Colonel O'Gorman had written a Paper, he believed, just before the last war, in which

suggestions were made upon which the early work in 1924 was based. At about the same time the Board of Trade London Traffic Section had endeavoured to produce a scale of values for various types of vehicles, with the idea of formulating a Board of Trade unit of traffic congestion. The idea was that an ordinary car should be regarded as having the value 1 unit, an omnibus 15 units, a tram 20 units, and so on ; but unfortunately the method was found to be impracticable, and had to be abandoned.

The Paper dealt with the problem of density per traffic-lane, and the few figures given were taken merely for the purpose of illustration, rather than as working figures. He could cite other cases that might be of interest. For example, the "Angel", at Islington, showed a total of 1,200 vehicles per hour per traffic-lane. The Holland vehicular two-lane tunnel under the Hudson river, New York, when running at full capacity, showed a density of 1,250 vehicles per hour per traffic-lane ; its entrances, of course, allowed the full capacity of the tunnel to be utilized. The Haymarket at the north end, at a time when the road was obstructed by repair work, showed a density of 1,800 vehicles per hour. It would be noticed that all of those figures were of the same order of magnitude. A high degree of accuracy could not be expected, perhaps, but the figures seemed to agree with the proposition advanced in the Paper, that a working figure would be between about 1,200 and 1,800 vehicles per hour, according to the type of traffic.

An interesting paradox in traffic was visible in the effect of the bottle-neck in a road carrying traffic in one direction, for example, leaving a football-ground, it was found that the traffic in the one-lane section moved at about 20 miles per hour, whilst the traffic in the two-lane section, before it reached the obstruction, moved at only about 4 miles per hour. That seemed rather strange, but, examination of curve B in *Fig. 1*, p. 252, *ante*, would show that half the maximum capacity was reached at a speed of about 4 miles per hour. Therefore, if more traffic tried to get through the bottle-neck than could be carried by it two lanes were formed, with a volume of about 900 vehicles per hour in each lane, which corresponded with a speed of 4 miles per hour. He suggested that it was possibly that effect, combined with others, which resulted in the slow traffic in the streets with very dense traffic ; that was to say, refuges tended to canalize the traffic into dual carriageways, and an omnibus-stop narrowed the two lanes into one ; the traffic passed the omnibus at the stop at a good speed and dribbled up behind at about walking-pace.

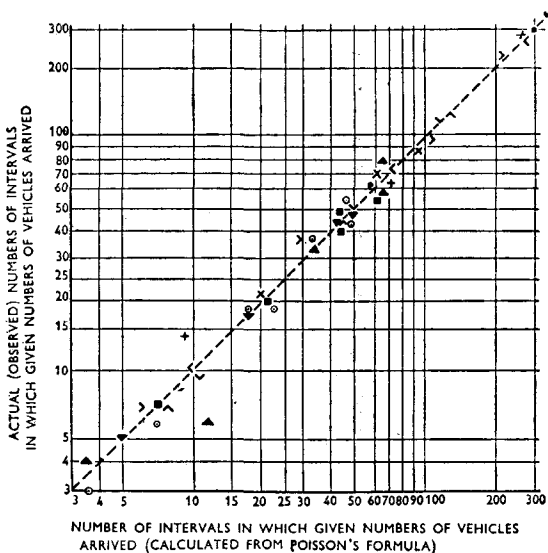
With regard to the effect of slippery roads, the figures used had been taken from the Paper by Messrs. Batson, Bird, and Stradling¹ because they happened to be available ; probably they were not strictly applicable to skidding in the forward direction ; but he considered that they provided sufficient indication of the effect of a slippery road, which, it would be seen,

¹ *Loc. cit.*

reduced the economic speed to about one-half, and also lessened the capacity of the road.

In the past the cycle formula had probably been the most frequently used formula for various purposes. One of its first uses was in fixing the relation between the traffic volume and the cycle to be adopted for traffic-

Fig. 6.

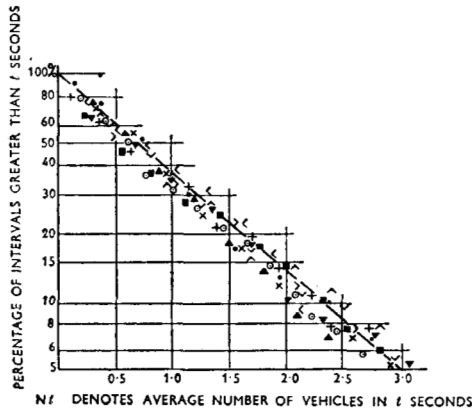


Symbol.	Site.	Traffic vehicles per hour.
⊙	Whitehall	744
■	Cromwell Road	512
▲	Sloane Street	362
▼	Royal Hospital Road	306
×	Holles Street	234
∨	High Street, Canterbury	189
∧	Bothwell Street, Glasgow	152
∧	Sidcup Road	128
<	Footscray Road (Northbound)	95
+	New Dover Road, Canterbury	93
•	Footscray Road (Southbound)	70

signal installations in which the cycle-time was varied according to the actual volume of traffic, instead of being varied in the normal manner, by the incidence of arrival of the traffic; that was to say, if a mechanism had to be designed for varying the cycle according to the number of vehicles which had passed during the previous 5 minutes, some relation must be established between the cycle-time and the volume of traffic; and the

cycle formula had been actually used for that purpose. Many traffic signals had to be adjusted by people who had not much experience, and he suggested that the first trial should be made by using the cycle formula ; it might be wrong, but it was more likely to be right than was guesswork, by which, in his experience, the setting was usually much too high. He had been particularly interested lately in the use of calculations for road

Fig. 7.



Symbol.	Site.	Intervals.	Traffic vehicles per hour.
⊙	Whitehall	1 second	744
■	Cromwell Road	2 seconds	512
▲	Sloane Street	3 "	362
▼	Royal Hospital Road	4 "	306
×	Holles Street	5 "	234
>	High Street, Canterbury	10 "	189
∨	Bothwell Street, Glasgow	10 "	152
^	Sidecup Road	10 "	128
<	Footsray Road (Northbound)	10 "	95
+	New Dover Road, Canterbury	10 "	93
.	Footsray Road (Southbound)	20 "	70

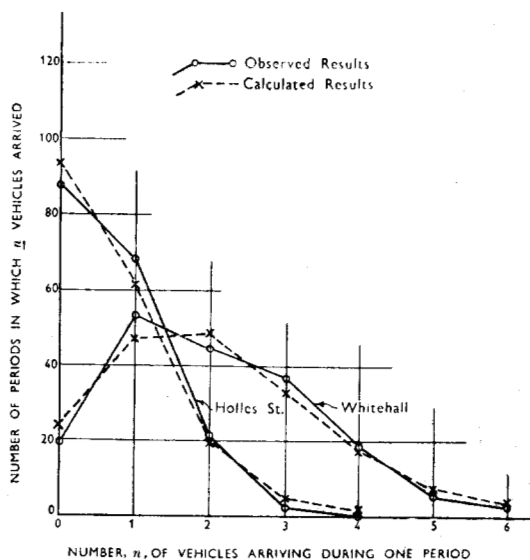
improvements, wherein a knowledge of the effect of some particular improvement was required ; for example, the widening of a road, as compared with a roundabout. At least such calculations furnished an indication. Experience could not be relied upon entirely, because no two cases were alike.

He wished to mention another form of calculation which was not referred to in the Paper, namely, the preparation of a revised traffic working diagram. The best assumption to adopt was that vehicles would proceed to their final destination by the shortest route which the regulations permitted them to take. Sometimes, however, traffic was diverted so far

from its route that drivers were disinclined to return to it. He thought that the best way to establish the diagram was to plot the traffic arriving at all the places where it entered undisturbed and then estimate the volume of traffic going through at a particular point in the circumference of the roundabout. In the case of Trafalgar Square, eleven schemes had been prepared before that finally put into operation was decided upon. He believed that in Paris such schemes used to be tried out with a large party of mounted police or soldiers, but he thought it was better for the temper of the people to experiment on paper rather than on the site.

Although the Paper was not at all topical, it had some topical applications. It was possible to make some estimate of the delay which would

Fig. 8.



be experienced at a bomb-crater where room was available for one lane of traffic to pass. He had not yet prepared Tables for the purpose, but they could be prepared, and would be worth while. It would then be possible, knowing approximately the volume of traffic along the road, and also the distance entailed by a diversion, to determine whether it would be better to adopt the shuttle system or to divert one stream right round. The question often arose whether it was justifiable to delay the completion of the whole job in order to keep the road open for one lane of traffic, and it might be worth while to have a Table to which reference could be made. The actual results would probably lie well on one side or the other; if they came on the border-line it would not matter which system was adopted.

The Author exhibited three lantern-slides (*Figs. 6, 7, and 8*) illustrating the random distribution to which he had referred very briefly in the Paper. He drew attention to the reasonably close agreement between the observed results and those predicted, and pointed to the fact that although the observations were taken in different parts of the country, and on different types of road, the agreement was not affected.

He observed that when he began to write the Paper he thought that he knew a little about traffic calculations; but when he had finished it he realized that his knowledge was far less than he had imagined. Somebody who had studied traffic theory closely had remarked, in desperation, when dealing with one particular problem, that the population of the United States of America was 120 millions, and there were 120 million traffic experts: and the Author thought that, with an adjustment of the figures, a similar statement might be made about Great Britain.

Colonel Mervyn O'Gorman observed that so long ago as 1926 he had had the idea that a law of flow for motor traffic might, even if only approximate, help to improve traffic control, to augment the economic use of roads, and to reduce road accidents. He considered that analogies from hydraulic flow were misleading. It was obvious that a head of pressure, that was, an accumulation of many urgently-driven vehicles behind the unit considered, produced no effect that could be likened to a pressure to move it forward more quickly. At any time on the Portsmouth road it could be observed that when vehicles were travelling as a discontinuous stream the speed of any individual in that stream was, in a vague manner, decided by the length of the vacant gap in front, that was, the "interspace" between it and the next vehicle ahead. That rather trifling observation was novel on the 27th April, 1927, when Colonel O'Gorman published it in the *Times* and sent the elementary algebra relating to it to the Ministry of Transport, demonstrating also that that type of attack must have some value by posing and answering the following questions:

- (1) When will vehicles in a single traffic lane provide the maximum of flow?

Answer. When they are one vehicle-length apart.

- (2) What speed, in miles per hour, will give this maximum of flow?

Answer. About 14 miles per hour.

- (3) How many vehicles will pass per minute?

Answer. About 30 per minute, or 1,800 per hour.

- (4) Which would be more disorganizing to traffic output, a lower speed than the best or an excess of speed?

Answer. Driving too slowly by 7 miles per hour is worse than driving too fast by a similar amount.

The following was a word diagram. One taxi-cab, with orders to circulate at 30 miles per hour, would be put on a road forming a closed circle 440 yards in circumference. The number of cabs would then be

increased to five, ten, twenty, and so on up to 110. When those vehicles were nose to tail they would hardly be able to proceed at 4 miles per hour. In fact, as the vacant space in front of each car became smaller its speed would become less. At some intermediate number of cars—at a guess, fifty-five—the speed would be about 20 miles per hour if the drivers were careful to space themselves equally.

That guess was uninteresting until it was realized that a half-loading of fifty-five cars travelling at 20 miles per hour represented 250 per cent. more traffic-flow than did 110 cars at 4 miles per hour, or that $2\frac{1}{2}$ times more cars would be cleared past a given point if they were spaced, than if they were allowed to crowd in as tightly as they could, and as, in fact, they did.

To-day, 16 years later, he still did not think that the method suggested was faulty within the reasonable assumptions made; but the point he wished to make was that such calculations were capable of opening up many useful lines of thought. The Paper provided an instance of that, and the Author had utilized his equations for the timing of traffic-control lights. Colonel O'Gorman did not doubt that the Author recognized how very suggestive for other traffic problems such methods were.

The following elementary calculations indicated that the safe speed of urban transport was dominated by brake power, and not by the weight of the vehicle or by its horsepower, and that the road surface and road slope influenced the most economic rate of travel of a traffic-column. Each traffic-speed required a particular length of interspace between the units. Those considerations showed that "cutting-in" (hitherto a vague term of abuse) was sometimes noxious and sometimes permissible, depending upon whether the "cutter-in" intruded his vehicle into the interspace required by the speed of the vehicle overtaken. Justification for the driving-school dictum, "Always prefer to overtake on an uphill," could be found in the fact that interspaces for uphill travel were shorter than for the level or downhill. Similar simple reasoning showed why a long clearance should be allowed for when overtaking on a slippery road. Indication was also given why a side junction to a major road might slow the traffic so surprisingly, namely, that it shortened all the interspaces. The law of interspaces taught that a "blind bend" was not always "blind", but was blind only to those drivers who found that the obstruction intruded into the interspace that they required for the particular speed of travel they were adopting. A town with overburdened streets could relieve its traffic-density, (a) by inducing drivers to avoid driving nose to tail; (b) by keeping the streets clean and not slippery; (c) by using roundabouts exclusively as non-stop vortexes at the speed of maximum output. Moreover, since the assumptions made were very rough, it was evident that a research body on traffic-flow and accidents, competent to measure accurately those data, and also such other data as small increments of traffic-fluidity in relation to control, could firmly

establish the principles upon which congestion and its attendant accidents could be reduced considerably. The saving would then be measured in millions of pounds.

If v denote the speed of the car in feet per second, f the acceleration (negative) produced on a car by braking, x the space, in feet, in which the cars came to a stop, from the time when the driver intended to apply the brakes, and L the length, in feet, of the vehicle (average) plus a varnish clearance from its neighbour ahead, then, since $v^2 = 2fx$, $x = \frac{v^2}{2f}$, and when, in a moving line of vehicles, the distance from the nose of one car to the nose of the next was $x + L$, that distance $= \frac{v^2}{2f} + L$. The number of vehicles to pass a given point per second was $\frac{v}{x+L}$, which equalled $\frac{1}{\frac{v}{2f} + \frac{L}{v}}$.

That expression was a maximum when $\frac{v}{2f} = \frac{L}{v}$, which reduced to $v^2 = 2fL$.

Comparing that expression with the previous one, $v^2 = 2fx$, it was found that for maximum flow $L = x$, that was, the vehicles should be separated from one another longitudinally by a distance or interspace equal to their individual length. That was not quite correct, because, of course, deceleration on braking did not start from the moment when the driver intended to put his brake on; he had to have his mental reactions, and the time when he intended to put his brake on differed from the time when he actually put it on. Nevertheless, the formula $L = x$, would give approximately the maximum number of vehicles along a single traffic lane.

Assuming $L = 20$ feet; and f (a high rate of braking) to be 10 feet per second per second. Then $v^2 = 2fx$ became $v^2 = 2 \times 10 \times 20 = 400$, and $v = 20$ feet per second. Therefore $V = 14$ miles per hour. At that rate of braking, therefore, 14 miles per hour was the ideal speed for the maximum flow at which the maximum flow of vehicles per hour could be realized over some bridge, tunnel, or other similar section of roadway without side entrances.

The number of vehicles passing per second was $\frac{v}{x+L} = \frac{20}{20+20}$ per second $= \frac{1}{2}$ vehicle per second, that was, 30 per minute, or 1,800 per hour, per traffic-lane.

If the speed were halved to 7 miles per hour, or 10 feet per second, that was, if the interspace were reduced, the number of vehicles would be

$$\frac{10}{\frac{100}{20} + 20} = \frac{10}{25} = 0.4 \text{ vehicle per second.}$$

Therefore the output or carrying-power of the bridge would be reduced by

20 per cent. As was well known, a greater reduction in flow occurred when the vehicles were driven in the manner affected by drivers to-day, so as to have only a negligible clearance ; that would reduce the speed to 3 or 5 miles per hour.

If the speed were increased to 20 miles per hour, the number of vehicles passing would again be less than the number at 14 miles per hour, namely, about 9 per cent. less (accurately 0.46 vehicle per second). Thus there was less disadvantage to flow if the interspaces were increased by some small measure than if the interspaces were decreased by an equal measure. That conclusion had some practical value, because if traffic-controllers were ever to require drivers to observe an interspace, it would be known that to exaggerate the interspace (a likely fault with an inexperienced driver) was not so pernicious to flow as was the taxi-drivers' fault of cutting interspaces much too fine.

Colonel O'Gorman observed that the practicality of the examples was the more remarkable because the approximations were admittedly very rough. The ability of the driver to stop was considered, but his even more valuable ability to avoid collisions by steering to clear the obstacle was disregarded. The variable coefficient of friction of various road surfaces was assumed to be the same for all vehicles and all speeds, etc. Tributary roads were assumed to be non-existent.

Captain F. A. Rayfield wished to emphasize the fact that the Paper dealt with a subject about which far too little had been heard in the past. There had been too much loose talk, particularly about the hydraulic analogy, which was not strictly true, and the sooner quantitative analysis was undertaken the better. About 10 years ago he had made some investigations into traffic capacities and economic speeds, and, although his records were not available, he felt sure that the results corresponded very closely with those given in *Fig. 1*. He had been surprised at the time, because he had not seen the statements put forward before, and he had doubted his own results ; but careful checking had led him to the same conclusion.

He was also particularly interested in the analysis of the methods of ascertaining the capacity of intersections. He was quite sure that the traffic problem could be solved only by attention being paid, in the first place, to intersections. In great cities in the past considerable money and time had been spent in widening streets, but little or no attention had been devoted to dealing with the additional load placed upon the intersections by that method of procedure. Even in London one could think of many cases where the widening of a street had increased the traffic-delays. In short, if a given sum of money were available for solving the traffic problem (there was never enough for that purpose, and he supposed there would not be enough in the future), greater value could be obtained by spending it on intersections than in any other way.

The quantitative approach to the capacity of intersections was therefore

doubly important, and it enabled alternatives to be placed before those responsible for the expenditure of public money. It was possible to say, for example, that three different methods of solving a problem would give certain degrees of improvement in the existing conditions, and that those various methods would cost £X, £Y, and £Z respectively; and it was for authority with financial responsibility to say which method should be adopted.

A fairly recent example in London was that of the treatment of an important bridge-head. Two methods were available by which the traffic delays anticipated at the northern approach could be reduced. One was a relatively simple and inexpensive method which would have resulted in an improvement in traffic-capacity and a reduction in traffic-delays which, when integrated, would have effected an improvement of 30 per cent. The other was a very comprehensive improvement, costing twelve times as much, which would have resulted in an improvement of about 70 per cent. It was a matter for consideration whether the additional improvement would justify the higher expenditure; and it was only by such methods as were outlined in the Paper that scientific approach could be made.

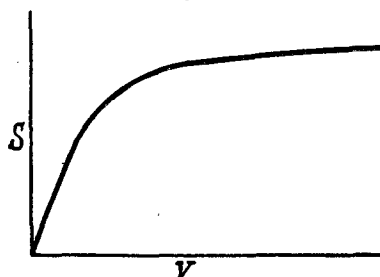
Although some of the suppositions and the bases for the calculation of capacities might not be strictly accurate, so long as they were the same in each case a comparable basis could be obtained; and the lantern-slides which had been shown indicated that they were often very close to the actual mark in practice. That led to a study of intersections, and naturally one would like to start any comprehensive scheme of improvement by dealing with those intersections at which traffic-delays, and therefore the cost to the community, were the greatest. If that were done in London, for instance, one found that it was not at such important and heavily-trafficked intersections as Hyde Park Corner that the community suffered most. He thought he was right in saying that Ludgate Circus and certain places in south London, such as the "Bricklayers' Arms", in Old Kent Road, would yield a much higher return for money spent on their improvement than would some of the better-known intersections.

Although it might not be strictly relevant to the subject of the Paper, he wished to express the hope that architects and others who prepared town-planning schemes might have their attention called to the necessity for a specialized study of traffic. Town-planning consisted in the main of two principal sub-divisions: zoning, which was largely a matter for architects, and transport, which, he submitted, was a matter for engineers with road experience. He hoped, therefore, that the Ministry of Transport road engineers, and those who dealt with roads in ordinary life, would be allowed to play their part in any scheme of reconstruction.

Mr. W. F. Adams observed that at any given speed of traffic the maximum volume that a single lane could carry could be expressed by the equation: $S = \frac{5280V}{h}$, where V denoted speed, in miles per hour, and h

the distance, in feet, between heads of vehicles. Then, either h depended upon the traffic-speed, or it did not. If it did not, one could give up the idea of a "traffic science"; but if h did depend upon the traffic-speed, the equation could be written $S = \frac{5280V}{f(V)}$. Colonel O'Gorman had regarded $f(V)$ as a quadratic, the Author had regarded it as a linear function for cyclists and a quadratic for other traffic, and other people had made other suggestions. The Massachusetts Highway Accident Investigation Board had suggested something depending upon the 2.2th power. If, for a certain speed, the total traffic had a maximum, it meant that $\frac{f(V)}{V}$, that was, $V^{-1} \cdot f(V)$, was a minimum. Differentiating, the speed for maximum traffic could be calculated from $V^{-1} \cdot f'(V) - V^{-2} \cdot f(V) = 0$, which gave

Fig. 9.



$V \cdot f'(V) = f(V)$. That was straightforward mathematics; the whole of it followed once it was conceded that the distance between vehicles must depend upon the traffic-speed.

The next step was to consider what the function might be. If $f(V)$ were linear, $f(V) = AV + B$ and $f'(V) = A$; hence $AV = AV + B$. That expression could not possibly be satisfied unless $V \rightarrow \infty$; therefore if $f(V)$ were linear there was a limit to traffic, but no saturation, and a curve of the type illustrated in Fig. 9 was obtained. The Author had given a formula of that type for cyclists, and it would be interesting to know whether any evidence was available to support it.

The next simplest form to the linear was the square law, $h = f(V) = AV + BV^2 + C$, and a quick rise to saturation occurred, followed by a less rapid fall (Fig. 10). The same form applied if any power higher than the second was involved.

If $f(V) = A_0 + A_1V + A_2V^2 \dots A_nV^n$, then the speed which produced the maximum volume of traffic could be found from

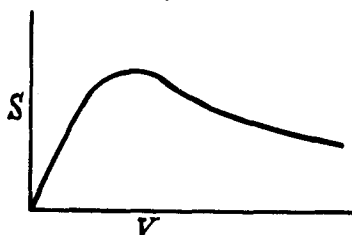
$$\sum_{r=2}^{r=n} (r-1)A_r V^{r-1} = A_0.$$

It was curious and interesting that everyone who had had to deal with traffic in mass, or to study the properties of traffic in mass, had come to the conclusion that the second type of curve was the more appropriate; yet at least half of those who had studied the actual spacings between vehicles had arrived at a curve of the first type.

The divergence between those who studied the mass of traffic and those who studied the spacing between vehicles opened up a field of research requiring no more apparatus than a pencil, a notebook, and a stop-watch, although other means had been used, for example, cine-cameras, aeroplane-cameras, and portable range-finders.

The Author had stated that, "Attempts to measure the distances between moving cars at various speeds have not yielded consistent results"; Mr. Adams agreed that that was true. The important point, he thought,

Fig. 10.



was that the type of curve rising to a maximum and falling again provided a conservative basis for traffic design. It was found from that curve that saturation traffic was about 1,500 to 1,800 vehicles per hour, and not the 3,600 or 4,800 vehicles per hour given by most authorities for the linear type of curve.

He agreed that the hydraulic analogy was misleading; and the electrical analogy for traffic could be equally misleading. Possibly less misleading than others was the kinetic theory of gases, in which a number of independent particles were considered, travelling at different speeds and moving independently of each other; but the idea of each individual vehicle suffering something like half a million collisions per second "were a thing imagination boggles at."

Under the heading "Units and Definitions" the Author had stated: "The number of 'lanes' of traffic a road can carry is the number of vehicles which can move abreast or pass upon it; in a two-way road this may be an uneven number if there are no central obstructions." Mr. Adams considered that the words "in a two-way road" could quite well be omitted.

The Author had also stated that: "The denominator of the right-hand side of equation (2) represents the headway, in feet; this is not the full pulling-up distance, as consideration will show to be reasonable, since

any cause for stopping will be visible in front of the forward car." Mr. Adams thought that an even more important reason why the denominator was not the full pulling-up distance was that the forward car could not stop instantaneously, and that the driver who was following made an unconscious allowance for that fact.

Equation (7) was very interesting, because it showed that at any intersection where control was necessary, that was, any cross-road with heavy traffic, the maximum traffic-capacity T of a simple intersection could never be greater than half the traffic-capacity of the streets entering it. It was evident that $\left(1 - \frac{2a}{c}\right)$ could not possibly be greater than 1, and MS represented the total amount of traffic that could enter the junction by all streets.

He wished to utter a word of caution with regard to the statement on p. 258 that: "The small roundabout has not always twice the capacity of a signal-controlled intersection. For example, in this case, if the roads were double the width, the signals would have double the capacity, but the capacity of the roundabout would remain unaltered." That statement might be taken as implying that it would always be possible to make a signal-controlled junction pass as much traffic as a roundabout if the roads were sufficiently wide. That, of course, was not true. The paragraph applied only to the small roundabout, that was, the roundabout which was not sufficiently large to pass all the traffic which could enter it from all the contributory streets.

With regard to traffic planning, the ill-fated Charing Cross bridge scheme might, perhaps, be cited as the first case of deliberate traffic planning in Great Britain. That bridge would have had its drawbacks, but at least it would have been capable of carrying more traffic than any other London bridge.

Mr. Adams particularly appreciated the robust practical approximations which had always characterized the Author's work.

Mr. R. B. Hounsfield observed that more than eighteen months had elapsed since his work in connexion with traffic had been brought to a stop, and his only means of keeping abreast of events had been to watch the Press. Although many references had been made to town planning and to post-war architecture, he had seen no reference to the necessity for comprehensive regional traffic planning, and he was rather disappointed to find that the Author had confined himself within the limits imposed by pre-war conditions, when only isolated junctions or possibly two or three junctions close together in a short length of street could be dealt with, and any attempt to think further afield was of merely academic interest. He thought that it would be agreed that most of the discussion on the Paper had been concerned with individual junctions, except for Captain Rayfield's remarks about the necessary relationship between traffic planning and town planning. He was glad that Colonel O'Gorman had emphasized

the importance of traffic research in war time, but since no reference had been made to the necessity for regional traffic planning, he would like to take the opportunity—rather rare in war-time—to make a plea with regard to that. He wished for definite steps to be taken to establish regional traffic planning in Great Britain, with the status that it deserved. Traffic planning should follow on automatically from town planning, at all events in large areas: in small areas it might not be necessary. At long last town planning in Great Britain was receiving the attention due to it. Its purpose was to draw up a general outline of the distribution of life in a city. In a large area it should then be ascertained where traffic volumes would exceed the capacity of the ordinary street system. It would then be possible to obtain a general idea of the traffic network required to handle that traffic, and the architect could be informed not only of the regional distribution in a city, but also of the traffic needs that had to be met. Unfortunately too many architects visualized wider and wider streets as the only solution of the traffic problem. Naturally an aversion existed to enormous traffic arteries in the centres of cities, and that was probably the main cause of a large number of suggestions for prohibitory and distortive regulations to deflect traffic and cause it to behave in an unnatural manner. Distortion of traffic was just as detrimental to the life of a city as the distortion of the breathing apparatus would be to the human body. London had a character of its own, and the provision in London of wider and wider streets to carry larger and larger volumes of traffic was altogether foreign to that character. In order that the character of London might be preserved, it was important that the traffic problem should be handled in a positive manner, and not by means of evasive and prohibitory regulations.

Mr. Hounsfield wished to put his plea for comprehensive regional traffic planning in a definite form. He realized that traffic staffs had been decimated, and that the Author, as one of the few survivors, was very busy. It was all the more important, therefore, that the limited time available should be spent in studying the broadest issues of traffic behaviour.

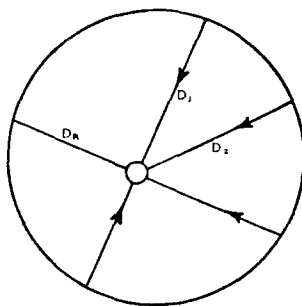
He suggested that investigations should be made into the relationship between the sizes of cities and the volumes of traffic to be encountered, and also between the distances travelled and the volumes of traffic travelling those distances. Further, the relative attractiveness of trunk roads and local streets for journeys of various lengths, in regions where both trunk road and local street networks existed, should be ascertained. Thus a basis for calculating the probable volumes and distribution of traffic in a post-war city would be provided.

He realized that it would be difficult to carry out some of that work in war time, but he felt that much of the difficulty could be overcome by seeking the co-operation of people abroad. For instance, considerable traffic research and regional traffic planning had been carried out by the Traffic Department of the Port Authority of New York under Mr. Cherniak,

and he felt that great benefit would be derived from a study of the results of that research work, which had been carried out over a number of years. He considered that a start made on those lines would establish regional traffic planning in Great Britain with the status necessary to ensure the correct design of our cities. It might enable some very serious mistakes to be avoided, and prevent people from grossly underestimating the magnitude of the problem.

It was important nowadays to study traffic planning and the possibilities of the future, not because bombing had facilitated the re-laying of streets from a material point of view, but because it had created such an upheaval in the public outlook that the possibilities were out of all proportion to the number of buildings destroyed.

Fig. 11.



Town planning, therefore, should be automatically followed by regional traffic planning in a large area. The traffic problem would then be properly handled and solved, and not only would a positive constructive solution be found, but also the character of our cities would be preserved.

Dr. F. Garwood said that the hydraulic analogy had been condemned by previous speakers, but he thought that, if interpreted with caution, it was useful in visualizing some of the problems and calculations with which the Author had dealt. For instance, in the calculation of equation (5), where the Author gave the formula for the general case of a multipart cycle of n phases with a dead period of r seconds, he envisaged that problem somewhat as follows.

He assumed a number of channels leading to a junction and a road feeding each channel at densities D_1 , D_2 , and so on all the way round (*Fig. 11*). Each of the inlets could pass the traffic at a saturation-density S , which would obviously be greater than the sum of the D 's. Starting from the "go" period for one inlet, all the other inlets being closed, traffic flowed in at a density S while it was being held at each of the other points. The "go" period, g_1 , had to be reduced to $g_1 - a$, the reason being, according to the Author, the constant time required to reach saturation. The traffic would run out for that time at a rate S . That would go on all

the way round until the completion of the time $g_1 + g_2 \dots + g_n$, the sum of all the "go" periods, but the cycle was not quite complete, because there was a dead period, r , presumably to allow pedestrians to cross the road. The question was, whether that cycle-time was sufficient to prevent each of the inlets being blocked up, and he imagined that that might be a problem of some practical importance. To take a very simplified example, suppose the first channel to be 600 feet long and the traffic at 60-foot intervals, so that when it was actually flowing through freely, there would be ten vehicles in the channel. If each vehicle were effectively 15 feet long, and the traffic were held up, 150 feet of the approach would be occupied, leaving 450 feet, that was, room for thirty more vehicles. If the length of the approaches were known, it would be possible to obtain a value for each of the extra capacities. It was then possible to see what mathematical conditions the cycle must satisfy to prevent those capacities being exceeded, that was, to avoid congestion at the farther ends of the channels.

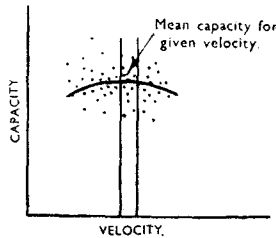
He thought that the Author's formulas (1) and (2), in relation to saturation-density and velocity, might be misleading, as tending to make people think that if the velocity were given the capacity could be calculated, or vice versa; but in practice he did not think that was so. If observations could be taken of velocity and capacity, or of distance spacing, it would be very surprising to find always that one quantity was related to the other. He thought there would always be a tremendous variation, and it was necessary to go a little more carefully into the meaning of the equation in question before applying it in practice and before drawing any conclusions; it was important to define exactly what was meant by "velocity" and "capacity." He agreed that in a street in which traffic was released very freely it usually moved in a more or less solid homogeneous flow, and therefore the velocity must be much the same for every vehicle; but, as the Author had pointed out, the spacing would not be consistent, and Dr. Garwood did not think that was surprising. Suppose observations of velocity were taken at a given point, the capacity measured by counting the vehicles passing in a fixed time, say 1 minute, and the capacity plotted against velocity, then a scatter of points would be apparent. The longer the period over which the spacing was taken the smaller would be the scattering.

He could not say what connexion that scatter diagram, which was a representation of the real facts, had with the curve of the equation referring to saturation-density and velocity which was a theoretical equation based on some hypothesis. One could reduce the scatter diagram to a curve by considering the arrays of points corresponding to short elements of velocity, as in *Fig. 12*. The mean of each array would follow a curve which could be interpreted as the average capacity attained by vehicles actually travelling at a given velocity. Clearly that was not the maximum capacity, since probably half the points of the diagram would be above the curve.

The relation of that curve to any theoretical equation was a matter for further investigation. He realized the difficulty of taking observations. Conditions were not the same as they were on highways, rural roads, and by-passes. On such roads in America observations had been carried out and curves had been calculated, which were effectively estimated from a scatter diagram.

He considered that *Fig. 4* was an interesting and instructive representation of the phenomena at a traffic junction. He did not quite follow the reason for using the expression $\frac{l}{2}$ for the mean delay to the last vehicle delayed; he thought that it would be adequate to assume that the delay to the n th vehicle was the minimum, and that the next vehicle just got through without delay, so that it followed on the preceding one after a spacing of $1/S$, the saturation-spacing. However, the result he had

Fig. 12.



obtained on that basis was near enough to the Author's formula (6) for practical purposes.

Mr. N. Herwald considered that the speed of vehicles was determined by road rather than the width of the road by the speed. He could not see the use of the intersection-factor. In the case of Whitehall the Author had divided 550 (presumably the number of vehicles per hour per traffic-lane) by the intersection-factor and had asserted that the road was clearly working to the limit of available capacity. Therefore 550 was the saturation-density, and Mr. Herwald did not understand why the Author had divided it by the intersection-factor and produced a figure of 1,500. The figure of 1,500 was not stated as any particular unit, and he assumed, therefore, that that figure, and not 550, was the saturation-density.

With regard to headway, Mr. Herwald could not see that the length of a car bore any relation to it. The headway had been expressed in time-units, but he did not see why the time taken to travel the distance between the cars should bear any relation to the length of the cars. With regard to the statement that, "the headway required is therefore $1 + \frac{L}{v}$ seconds," he assumed that $\frac{L}{v}$ represented the time required

for the car to pass out of its own length on the road ; but perhaps what the Author meant by L was the length of the car, plus the distance between the cars, although Mr. Herwald thought that the length of the car should not be included in the headway.

Mr. Herwald took exception to the Author's statement that, "the phase should end as soon as the density falls off to any extent." The traffic-control policeman brought about that end ; he waited until no more traffic was left in a road and then barred that road, to give the right of way to the traffic on the other road.

In December, 1937, in an article entitled "Some Theoretical Aspects of the Control of Road Traffic ¹", Mr. Herwald had prepared a graph in which the ordinate was the delay, in vehicle-seconds, and the abscissa was the velocity, in feet per second. The curves, which were not complete in effect because they bent down to zero, were very similar to that drawn by Mr. Adams (*Fig. 10*), although not related to the same ordinates. The curves showed, in effect, that the delay, in vehicle-seconds, increased as the vehicle stood still. When vehicles approached a cross-road against the light, it might not have changed by the time they arrived, so that they had to stop. It could not be asserted that, because those vehicles had to stop, the junction was not working efficiently ; it might be working perfectly efficiently simply because vehicles were passing through the intersection. Two opposing traffic streams could not pass through the intersection at once ; therefore one stream had to be stopped and the other allowed to go through. It had been found by experience that short cycle-times (that was the change from one road to the other and back again) were better than long cycle-times, because of the fact that vehicles were stopped by the red light, and the longer they stopped the longer was the delay, in vehicle-seconds. Therefore he thought that the Author's statement that, "the phase should end as soon as the density falls off to any extent", was incorrect because it assumed that there was more or less continuous traffic at the intersection ; therefore only one cycle-time at that density would give efficient working of the junction, and that was not nearly so high as the actual time that the saturation fell off.

Cycle-time was not a fixed period. The duration of the old fixed cycle was unvarying, whether the traffic was there or not ; but progress had been made since then, and in the case of vehicle-actuated systems the vehicles themselves set the cycle-time. If one road had no vehicles in it the signals would not change, whilst if there was one vehicle in one road and a long stream of traffic in the other road the cycle-time would depend upon the fixed settings on that road, which was there as a limiting device only and not to set the cycle-time.

Mr. W. F. Adams, referring to the tests mentioned in the Paper on velocity against spacing, observed that in tests made with Mr. D. A. de C.

¹ Journal of Scientific Instruments, vol. 14, p. 396 ; December 1937.

Bellamy he had obtained a result similar to that suggested by Dr. Garwood, but with one important difference. He obtained a statistical cloud of points very thin at the top and coming down more and more densely to a fairly well defined edge, which clearly indicated the minimum distance that the particular driver could maintain at all the given speeds. The Author had referred to an inconsistency between different drivers; for any one driver there seemed to be a fairly well marked edge. With regard to the cloud of points that Dr. Garwood had mentioned, Mr. Adams thought that it would be fairly thin lower down and would run up to a dense distribution.

The Chairman observed that a good deal had been said during the discussion about the analogy between the laws of traffic flow and those of hydraulics, and one was attracted to that analogy when one set out to study the subject. He had been attracted also by Colonel O'Gorman's reference to taxicab-drivers, because he supposed that such drivers were the most level set of drivers in the country, and if one could rely upon all drivers having the same skill as taxicab-drivers the analogy might be more complete. In dealing with the matter of traffic-flow, however, one must take into consideration not only the varying skill and psychology of the drivers of vehicles, but also the difference in the performance of the vehicles. He was very sensible of the contribution which had been made to the study of traffic-flow by the engineers, past and present (of whom the Author was one), in the service of the Ministry of Transport. He sincerely hoped that when the war was over the engineers of the Ministry would be given a much greater opportunity than they had at present of making known their own knowledge and experience of the subject, and that their conclusions would be accepted by those in authority.

**** Mr. H. Alker Tripp** observed that he had read the Paper with much interest. From the practical point of view, however, he was doubtful as to the value of calculations of that character, because the computations were based (a) upon factors which were not constant, and (b) upon assumptions. In his view, when so many assumptions were needful, it would be simpler to work from actual census results and by continuous experiment.

There was, of course, the aspect of future development and the layout of new roads, but there again the same weakness was bound to be present, because the type of development, and the consequent traffic load upon any section, was so problematical. An aggregation of industrial undertakings might result in a local preponderance of heavy lorries and of tidal loads of pedal cyclists, whereas their absence would mean a faster flow of traffic, lighter in the aggregate and less tidal in character. That, of course, was elementary, but the permutations and combinations were so endless that he felt more and more driven to basing computations upon ascertained fact. In more propitious times, a considerable increase in traffic surveys would be

****** This contribution was submitted in writing.

valuable, for example, to ascertain the precise traffic-density which would cause a roundabout of given shape, size, and road-width to jam ; but he was afraid that that would not be practical politics at the present time.

The Author, in reply, said that he had deliberately confined his Paper to the calculations of traffic-flow principally at junctions, because the junction was the most important feature when traffic-flow was under consideration. He had not dealt with the flow of traffic through large areas, because he considered that that was an entirely separate subject.

In the matter of traffic planning, there was, unfortunately, a tendency for a number of the 45 million traffic experts in Great Britain to be included among those who had to deal with planning. It was regarded as one of the things about which everybody knew something, and therefore the planners considered that they could deal with it in addition to all the other multitudinous things they had to consider in town and regional planning. He had lectured to the students of one of the schools on traffic matters, but he thought that most of the schools regarded traffic planning as common knowledge. He considered, however, that engineers should ask that engineering principles should be applied to both road and rail traffic aspects of planning.

Recently he had been asked to advise a student town planner, and had been very interested to see the line that the student took. On the question of the flow of traffic through and round towns he assumed that if he put a route past the town that he was laying out the traffic would go past. The Author had explained to the student that if one wanted traffic to go past a town one had either to make prohibitory regulations, which were undesirable, or to make the route past the town not only better than the route through the town but also clearly better ; and, secondly, that very little traffic was through traffic. In a survey which he had carried out many years ago, he had found that only 10 per cent. of the traffic passing through the most congested part of Bond Street went from one end of the street to the other, and he thought similar conditions would be found in the cases of Oxford Street, the Strand, and other similar streets.

He welcomed Colonel O'Gorman's contribution to the discussion, because he considered Colonel O'Gorman might be regarded as the father of scientific traffic study. He did not agree, however, with the suggestion that the most economical spacing was one equal to the length of the vehicle. He thought that it would be found that the speed would be so low at that spacing that the number of vehicles that could pass a given point would be smaller than the number that would pass it at a greater spacing and a higher speed.

The density formula was rather of academic or general interest than of practical application to specific problems : that was why he had given it after his short dissertation on the fact that the number of vehicles per traffic-lane varied with something other than the type of traffic.

In reply to Mr. Herwald's question about the figure of 550 vehicles per

hour per traffic-lane entering Trafalgar Square from Whitehall, the Author had endeavoured to show that, whilst 550 vehicles per hour per traffic-lane entered Trafalgar Square from Whitehall, and not very far away, Broad Sanctuary carried practically the same number of vehicles of a similar type per hour per traffic-lane, but much more "congestion" appeared at Whitehall than in Broad Sanctuary. Two points arose in that connexion, namely, the intersection factor and the normal saturation density, which, for the type of traffic in question, as observed in Trafalgar Square, was 1,500 vehicles per hour per traffic-lane.

As a statistician Dr. Garwood had been able to help engineers in solving problems which were beyond the mathematical capacity of most engineers. The Author's observations on the Portsmouth road included the number of vehicles in different periods of time, determined by the police control. The number of vehicles in a bunch was plotted against the period. A definite tendency was evident for the number of vehicles to vary with the time, and he felt that it was justifiable to assume some consistency in the spacing of the vehicles, although the space between one vehicle and the next varied, he believed, purely in accordance with the opinion of a driver as to how near to the vehicle ahead he could safely remain.

With regard to the two alternative bases for the values of h in Mr. Adams' formula, it seemed to the Author that when a stream of traffic was flowing without much chance of it being disturbed by other factors, such as pedestrians stepping off the pavement, signals suddenly appearing, omnibus-stops, etc., such conditions as obtained on an arterial road on a Sunday night in peace time, drivers tended to follow the straight-line law, that was to say they tended to stay at such a position behind the vehicles in front that if one braked the driver behind could also brake without colliding. In towns, on the other hand, the tendency was rather for the distance to be slightly less than the braking-distance, which, of course, involved the first plus the second power of the speed. Very few opportunities existed for observing the relation between speed and traffic-density at speeds much in excess of 20 miles per hour, but on the Croydon by-pass he had observed 3,600 vehicles per hour in short bursts, and that number was very high, the spacing being 1 second.

He used the term "headway", in feet, to mean the distance from the nose of one vehicle to the nose of the next ahead, and in seconds, the time taken to travel that distance. Therefore the headway was made up of the length of the vehicle, plus a small margin so that the vehicles did not actually touch one another, plus whatever space might be needed in between.