The Paper, which was received on the 8th March, 1955, is accompanied by five sheets of diagrams, from some of which the Figures in the text have been prepared.

Discussion

Colonel Sydney Green (a Senior Civil Engineer, Ministry of Transport and Civil Aviation) observed that few engineers had very much doubt about the theoretical capacity of an unobstructed traffic lane carrying vehicles proceeding at uniform speed. Most of them would probably agree that in practice drivers tended to drive closer than they should to the vehicle in front and he would not quarrel with the adoption of the lower figure which the Author had given in Fig. 1. It left a margin for drivers to mend their ways. The difficulty was that vehicles were not uniform, and so far Colonel Green had seen no suggestion that British roads generally—including motorways—should be restricted to vehicles having a minimum speed or that vehicles should keep to their own lanes at all times. If, therefore, vehicles in line were capable of speeds ranging from 20 to 70 m.p.h., how much extra road space should be allowed for them to leave their lane and overtake, in order to avoid a procession at a speed dictated by that of the slowest vehicle? There appeared to be a wide difference of opinion on that subject. For example, Hutton had stated¹⁶ that a reasonable capacity for a unidirectional unobstructed two-lane carriageway might safely be taken as 1,000 vehicles/hour/traffic lane, which was tantamount to 2,000 vehicles/hour on the one lane and an additional lane provided for overtaking. During the discussion on Hutton's Paper Colonel Green had registered some doubts about the acceptance of that as the basic capacity for motorways, since 2,000 vehicles/hour on a two-lane carriageway, with speeds ranging from 20 to 70 m.p.h., might well take on the form of a procession based on the speed of the slowest vehicle. The present Author advised that the number of vehicles per lane which ought to be adopted for a motorway was 400 per hour, so that, with 800 vehicles/hour on a two-lane carriageway, there would be an average speed of 40 m.p.h., against 33 m.p.h. for 2,000 vehicles/hour on a two-lane carriageway.

There then, in Colonel Green's view, lay the crux of the problem. In his view new roads, and particularly motorways, should obviously offer average journey speeds higher than did the roads which they relieved.

The examination of the information now available was not made easier by some of the terms which the Author had used, as, for example, "congestion." The Author's definition of "working capacity" was

¹⁶ T. E. Hutton, "The Design of Motorways." Proc. Instn Civ. Engrs, Part II, vol. 2, p. 701 (Oct. 1953).

given as "the volume of traffic which, under the normal conditions of that road, can pass through it without material risk of congestion and at a journey speed reasonable for the type of road." Colonel Green would prefer the definition to be "the flow which produces the minimum acceptable average journey speed," the emphasis being on "acceptable." If by "congestion" the Author referred to the condition at the commencement of the broken line in Fig. 4, it should be emphasized that difficulties arose long before that point was reached.

It might well be, however, that the Author had used some information given by Wardrop (see reference 6, p. 672), who had stated that in a traffic flow of 225 vehicles/hour/lane (450 on two lanes), he had observed that the desired overtakings, with that small flow, were 1,090/mile/hour. Moreover, the number of desired overtakings varied as the square of the traffic, so that if the traffic was doubled the desired overtakings increased four-fold. It was easy to see that if the traffic on the two lanes increased from 450 to 2,000 vehicles/hour there would be a good deal of frustration, and perhaps an appreciable increase in the number of accidents.

On p. 657 the Author had stated: "A road which does not allow fairly free overtaking is overloaded." What did he mean by "fairly free" and what did he mean by "overloaded"? It would seem that the answer might lie in the acceptance of a ratio between actual overtakings and desired overtakings. It was not of course possible to design roads which would allow every overtaking that was desired, but a measure of them had to be provided; what did the Author regard as "fairly free"?

Colonel Green did not entirely agree with the Author's decision to abandon the word "safe" and substitute "working" in relation to capacity in order to avoid confusion with the question of road safety. He felt certain that there was a relation between capacity and safety up to the point when vehicles settled down in line ahead, and he thought that that was borne out by national statistics. For example, about 42% of all accidents on de-restricted roads in Britain occurred on straight stretches, and a considerable number of them involved vehicles proceeding ahead, whilst about 10% arose from manoeuvres which came under the heading of overtaking. There was need, therefore, for more information on the subject.

On p. 653 the Author had pointed out that capacity, speed, safety, and economy were closely inter-related. Capacity at an intersection could often be materially increased by eliminating right-hand turns, which often meant that the vehicles concerned had to go longer distances. Capacity was thus increased at the expense of extra journey time.

On p. 660 the Author had stated that in all cases where there was a speed limit the average speed should lie below the speed limit if it was rigidly observed. It would be interesting to know whether, in the Author's opinion, if a speed limit of 45 m.p.h. were introduced on an unrestricted road, the effect of the introduction of that limit would be to alter materially

the average speed, and what corresponding increase in capacity would result.

Colonel Green made it clear that the views he had expressed were his own and not necessarily those of the Department to which he belonged.

Mr W. F. Adams (a Senior Civil Engineer, Ministry of Transport and Civil Aviation), said that the Author in opening had invited "guesses," but he himself would prefer the word "speculations."

The Author, in dealing with the reduction in capacity with angle of weave, had assumed a straight-line form which was very convenient for a first approximation, but had also discussed the question of a driver allowing a safe distance between himself and the driver in front. That idea could be extended into two dimensions, and in the weaving area of a roundabout it might be assumed that a driver, in addition to allowing a clear space in front of his vehicle, would allow a clear space along each side. That driver was weaving in a stream of traffic with another driver who also allowed clearance areas in front and at the sides. The assumptions might be made that those clearance areas were the same for all drivers, that all drivers were driving at the same speed, and that the areas did not vary through any other circumstance. (Those were all assumptions—which was why Mr Adams used the word "speculations.") It was then fairly easy to show that, given those assumptions, weaving capacity was related to the non-

weaving traffic capacity of the road according to $\frac{1}{1 + K \tan \frac{1}{2}\alpha}$. That was speculation and should be tested by results. The number of results by which it could be tested was small, and more information was wanted.

Mr Adams then referred to the capacity of roundabouts. He thought that there had been a complication introduced into the problem, both in the Author's analysis and in that of others, through thinking of the problem in terms of the traffic capacity of unit lane-width of weave. The Author himself had referred to the possibility that the traffic flow on a road might increase in step form with the width of the road, but had discarded it in that context, so that when dealing with roundabouts he had not taken it into account. The Author's analysis was in terms of traffic per lane. Engineers were not primarily interested in that, but in the total traffic carried by the weave. It was interesting to see, therefore, what the results were if the Author's data were re-plotted in terms of the total traffic instead of traffic per lane.

In Fig. 10 Mr Adams, for simplicity, had plotted only the points from the Author's Table relating to three- and four-lane roads. The widths for the points actually plotted ranged from 30 to 44 ft, and the indication was that all those roads were carrying traffic according to a similar "mechanism" and with approximately the same relation between saturation volume and weave angle. Mr Adams had plotted also the Author's own formula for a three-lane weave and his formula for a four-lane weave, and again the

lesson seemed to be obvious. With regard to that group of points, Mr Adams said he would not like to guess whether they represented a three-lane weave at 1,200 vehicles/lane or a two-lane weave at 1,800 vehicles/lane; he did not think that enough was yet known about it. The indication was, however, that from 30 ft to 44 ft the roads were carrying weaving traffic by a similar process. There was one point for a two-lane road which

FIG. 10

would lie towards the bottom of the graph and indicated that the road must be carrying traffic by a process involving a lower limit of capacity, and there were other points where the capacity was higher than for the 30- to 44-ft group.

He had also plotted by a dotted curve the results given by taking the above tangent formula and putting $K = 1$. He did not know what K should be. The data available was not sufficient to show whether that or the Author's form was to be preferred. He gave that as a present to those who were now active in exploring the traffic capacity of roundabouts, and he hoped that it might help them.

Mr J. Collett Dickinson (Senior Engineer of Messrs Preece Cardew and Rider, Consulting Engineers, London) remarked that he was probably approaching the problem from the wrong angle, but he looked at it from the

point of view of a road user and not a road designer. At present he paid a great deal of money to the Road Fund and in petrol tax, and the reason for his interest in the question was that he did not consider that he was getting value for money.

He was firmly of opinion that a purely mathematical approach to any complicated problem was the right one, and therefore he approached the matter purely on an algebraic basis and with complete ignorance of the road problem as such. In approaching it algebraically, it must be admitted that the basic equation, the spacing of vehicles, was of the form $H = L + KV$. He put KV instead of $1.47r$ because he wanted to refer to the factor r later. He would like to call attention to what happened when there was a cross-roads, over-saturated or under-saturated. With under-saturation, probably the front vehicle waited for the whole period of the red and some vehicles got through without a stop. At saturation, every vehicle was stopped for the period of the red light and at over-saturation some unlucky people were stopped for a red, a green, and another red, plus their accelerating period in every case. At over-saturation, therefore, some unfortunate people were stopped for three times as long as they should be. His question to the Author, therefore, was why build more traffic lanes to bring in vehicles which it was not possible to get rid of, and why spend public money in so doing?

That question of saturation was very important. The other day Mr Dickinson had found himself at the end of a 4-mile line of vehicles, bumper to bumper, trying to get over a cross-roads. Those vehicles, though on a major main road, had been strung out in a single line.

Applying the basic formula to which he had referred, he came to the conclusion that if the vehicles lined up in a single lane at a cross-roads the ratio between the saturation of the traffic lane and the number of vehicles

that got away took the form of $\left(1 - \frac{A}{R}\right) \left(\frac{KV}{2L + KV}\right)$. If they lined up in two

lanes, the first bracket remained the same and the second became $\frac{\frac{1}{2}L + KN}{\frac{3}{2}L + KN}$.

That would get away 1.32 times as many vehicles as the other, and with three lanes it would be 1.45 times as many vehicles.

That introduced a question of road manners. The man who so placed his car at a cross-roads as to prevent other vehicles lining up in two lanes was wasting about 20% of the road in front.

In the formula which he had given, A was a loose term which he called the get-away period of the vehicle, and R was the period of the traffic lights, when they were equal. That seemed to lead to a paradox. The larger R was the nearer to unity became the first expression, which led to the paradox that the longer the R period the more vehicles got through but the slower the journey. It seemed to point to that, and he would welcome the Author's comments. Turning to the factor r , he was aware that $r = 1$ was

used in the Highway Code, but the Highway Code had been drawn up from the point of view of Safety First. Many people had been tested on the police reaction-machine, and his recollection was that a reaction time of $\frac{2}{5}$ sec was good, $\frac{3}{5}$ sec average, and $\frac{4}{5}$ sec poor. Why then should they tolerate the presence of people on the road whose reaction time was 1 sec? He would like the Author's views on whether roads should continue to be built for inefficient drivers.

Dr R. J. Smeed (Deputy Director (Traffic and Safety), Road Research Laboratory) said that many definitions had been put forward by engineers working on the subject of capacity, and he was glad that the Author had come fairly close to accepting the definition first put forward by the Road Research Laboratory, namely, the traffic flow which resulted in the minimum acceptable journey speed. That was not quite the Author's definition; the Author defined capacity as the volume of traffic which could pass at a reasonable journey speed and without material risk of congestion. Dr Smeed thought that the additional words "without material risk of congestion" were not necessary unless the Author was going to demand very low acceptable journey speeds, but, like Colonel Green, he would like to ask what the Author meant by "congestion" in that connexion.

The Author had cast some doubt on the reasonableness of some figures which Dr Smeed had given in a Paper⁵ in 1949 and made certain calculations based on those figures and deduced a curve for them in Fig. 1. Professor Lighthill, in a recent Paper,¹⁷ had given some reasons for believing that the curve of what the Author called "density" and Dr Smeed called "flow," plotted against speed as was done in Fig. 1, was not of the shape there shown. Professor Lighthill believed that it rose and then went down again, and, if his conclusions were accepted, it was not possible to accept the method of calculation which the Author had adopted. It seemed a pity that the Author, having cast doubt on those figures, should then arbitrarily obtain another curve without adequate data and call the resulting curve the theoretical capacity. It was the use of the word "theoretical" which seemed regrettable to Dr Smeed.

The Author talked about the use of the mode and the mean in some figures which Dr Smeed had given.⁵ Those figures had been obtained by measuring time intervals between vehicles following one another as closely as possible, both with ordinary vehicles on the road and with vehicles driving under controlled conditions on a disused airfield. The Author pointed out that under most conditions the two sets of measurements gave identical results. The Road Research Laboratory preferred the airfield results for the cases where they differed, because on the road it was not always certain whether vehicles were trying to follow one another as

¹⁷ M. J. Lighthill and G. B. Whitham, "A theory of traffic flow on long crowded roads." Proc. Roy. Soc., Series A, vol. 229, p. 317 (10 May, 1955).

closely as possible. For that reason an arbitrary method had to be used to reject data when the mean was used for obtaining maximum capacity. The use of the mode overcame that difficulty, and on the airfield the mode had been the same as the mean.

The Author completely rejected the use of data obtained under controlled conditions on an airfield. Dr Smeed regretted that, because important results could be obtained in that way which could be obtained in no other way. It was always true that such results should be looked at with special scepticism and should be accepted only if they agreed with whatever measurements could be taken on the road, but they had used that method in several different types of investigation and in all cases full agreement had been obtained. Dr Smeed considered, therefore, that controlled experiments on an airfield were useful and he had every confidence in the further use of the method.

There were two questions which he would like to ask. The Author talked about the capacity of a lane but did not clearly specify what a lane was. It was necessary to know the width of a lane and so on, and perhaps the Author would be more specific. He believed that the Author had some views on the necessity for a reservoir of capacity for storing standing vehicles, and it would be of interest if the Author would say something about that.

Mr Nigel Seymer (Editor of *International Road Safety and Traffic Review*), who prefaced his remarks by stating that he spoke in a purely private capacity, said he proposed to confine his remarks entirely to the section of the Paper on roundabout capacity, which he regarded as the most important part of the Paper, in view of the fact that the Author was employed by the London County Council, which was the highway improvement authority for London, and nearly all the major improvement schemes for London roads involved the construction of very large roundabouts.

As the Author himself said, roundabouts took up a great deal of space, and land in towns was extremely expensive. According to *The Surveyor*, the scheme which had been adopted for a roundabout at Hammersmith Broadway would cost £300,000 more than a solution involving the use of signals. Mr Seymer questioned whether the roundabout was in fact preferable to the signal solution, quite apart from the fact that it was considerably more expensive; in fact he thought it was desirable to be a great deal more certain than was the case at present, before launching out on such a programme, so that all the roundabouts proposed for numerous major intersections, such as St Giles' Circus, Hyde Park Corner, Marble Arch, Victoria, and so on would be value for money.

That question was bound up with roundabout capacity. The Author admitted that more research was necessary on that subject. Mr Seymer was glad to hear that and wished that the Author's superiors had been of the same opinion nearly 4 years ago, when Mr Seymer and Mr Andren had been given a hearing by a sub-committee of the London and Home Counties

Traffic Advisory Committee, on which the L.C.C. was represented, when they had strongly urged that research should be undertaken on roundabout capacity before the schemes for Hyde Park Corner and Marble Arch were finally approved. They had been told in effect that no such research was needed and therefore 3 years had been wasted; it was only in the past 4 months that such research had been undertaken.

The Author's statement that, except for O. K. Normann, other investigators did not appear to have published definite conclusions on roundabout capacity was surprising. Mr Seymer would like to refer to three Papers which had been published in other countries. One of those Papers was by the Dutch engineer Volmueller,¹⁸ and in that the definite conclusion was reached that the very largest roundabout would not have more than double the capacity of the very smallest, and that the maximum theoretical capacity of one side of a large roundabout would be 2,400 vehicles/hour, in terms of passenger car units. A more recent theoretical study had been made by a German engineer, Dr Grabe,¹⁹ who had reached the conclusion, among others, that in the case of a six-armed roundabout—and the Hyde Park Corner roundabout would have six arms—the maximum number of vehicles which should enter from one of those arms during one hour should not exceed 650, whilst the maximum capacity of any one side of such a roundabout would be 2,520 vehicles/hour, again in terms of passenger car units, and regardless of the dimensions of the roundabout.

The third and more interesting Paper on that subject had been presented by Shrope,²⁰ who had stated that with the two weaving streams approximately equal in volume the maximum capacity on the longer sides of a particular roundabout, which were about 200 ft long, was about 1,900 vehicles/hour, again in passenger car units.

The present Author said that "the entering traffic density must be light enough to allow the traffic to flow with natural gaps so that the circulating streams can weave with it. A density of half saturation for a short length of the approaches is probably suitable." Mr Seymer accepted that qualification, with which it would be hard to quarrel; but it was hard to reconcile it with the theory of roundabout capacity expounded in the Paper and especially with the suggestion that, although there were no reliable data available, the maximum capacity of a weaving space should be put at not less than 5,000 vehicles/hour.

The Americans had never maintained that it was impossible for weaving

¹⁸ J. Volmueller, "*De Capaciteit van Verkeerspleinen*" (Capacity of roundabouts). *Wegen*, No. 429 (Aug. 1951). (In Dutch, with summary in English.)

¹⁹ W. Grabe, "*Leistungsermittlung von nicht lichtsignalgesteuerten Knotenpunkten des Strassenverkehrs*" (Capacity calculations for road junctions not controlled by signals). *Forschungs Arb. Strassen.*, New series, vol. 11. Kirschbaum Verlag, Bielefeld, 1954.

²⁰ E. B. Shrope, "Testing a traffic circle for possible capacity." *Proc. Highway Res. Bd.*, vol. 31 (1952), p. 415.

volumes to exceed 1,500 vehicles/hour; that was regarded as a desirable maximum, but it could be exceeded, and it had been. R. L. Fisher, at the Highway Research Board meeting in 1948,²¹ had quoted figures obtained for a 10-min period on a weaving section in New Jersey which was nearly 400 ft long and 50 ft wide, where the weaving volume was 2,856 vehicles/hour and the total flow through the weaving area 4,770 vehicles/hour. The Americans, however, did not regard such conditions as satisfactory and would certainly not deliberately create them, yet that, or something like it, was what was planned for Hyde Park Corner.

The Americans did not deduce from that, however, that a separation of levels was indispensable where the volumes exceeded the capacity of a roundabout. On the contrary, Mr Bellis, of the New Jersey State Highway Department, had stated that it was possible for a signal-controlled intersection having proper design of channelization to carry considerably more traffic than a traffic circle. Some of the solutions which Mr Bellis had applied to intersections in New Jersey were described in a recent article.²² Two of them were based on the principle of directional channelization, of which Mr Bellis claimed to be the inventor. Mr Seymour suggested that that solution could very properly be applied both at Hyde Park Corner and at Marble Arch, and he hoped that that possibility would be considered before a final decision was made.

Mr S. J. Chamberlain (Assistant Secretary, Traffic Branch, New Scotland Yard) said that the Metropolitan Police were anxious that the fullest possible information should be obtained in relation in particular to traffic densities in roundabouts and weaving in roundabouts. They had had a good deal of experience of the working of roundabouts but there were still some things which astonished them. The Author, Mr Adams, Colonel Green, and himself had all studied the question at great length, but there was still much to be discovered about roundabout design.

Sometimes a large roundabout did not work very well, yet a small one worked astonishingly well. The roundabout at Lambeth Bridge had proved extremely satisfactory, but he doubted if any of them understood the reason for that. There were two other roundabouts which looked very odd and which had been put in largely as a stop-gap measure to deal with traffic attracted to the 1951 Exhibition on the South Bank, and they had proved very effective. He referred to the Westminster Bridge—York Road roundabout and to the York Road—Waterloo Road roundabout. Not only had those two roundabouts vastly improved the traffic conditions but they had carried an increasing volume of traffic with a safety factor appreciably greater than that which obtained with the previous traffic

²¹ R. L. Fisher, "Weaving traffic." *Proc. Highway Res. Bd*, vol. 27 (1948).

²² "Directional Channelisation applied to Hyde Park Corner." *Rds & Rd Constr.*, vol. 33, p. 139 (May 1955).

arrangements, which had been controlled in one case by signals and in the other by a police officer.

Mr Chamberlain remarked that any information which his organization could obtain which was both factual and practical would be of great help, and they would be glad to assist in any investigations which were being undertaken.

Mr D. A. de C. Bellamy (formerly a Senior Engineer, Ministry of Transport and Civil Aviation) remarked that no one seemed to understand either the object or the design of a roundabout. The object of a roundabout was to reduce the speed of all vehicles to a common level and to compel the drivers to follow the proper paths to achieve perfect weaving. The Author had explained that two streams had to cross each other at the weaving point, and only a certain quantity of traffic, which Mr Bellamy would call x , could pass through that point (see Fig. 11).

If the quantity of traffic to be dealt with was greater than x it would be necessary to provide more points for it to get through and have the sort of arrangement shown in Fig. 12. Each of those points would take x , so that provision had thus been made for a quantity $2x$ in a double weave. For larger quantities a triple weave would be necessary to take up to $3x$.

The straight-sided roundabout to handle a single weave, which was the first type to be introduced, was compact and aerial photographs showed that it worked as it was designed to work. With double and triple weaves it was necessary to have longer weaving sections and wider carriageways, with resultant loss in the control of traffic.

The value of x depended on the number of vehicles which could pass a point in an hour. The most usual method was to measure headways at various speeds. He and Mr Adams, with the Author's approval, had made some tests in the early 1930s. The headways measured at any speed covered a wide range, as indicated in Fig. 13, since there was a wide diversity in the temperament of different individuals.

In the majority of cases the curve fitted was a second-degree polynomial and the question arose: through what points should the line be drawn? The Americans had approached the problem statistically and argued that the line should be drawn through the means or modes. They had obtained very high values which were subsequently found in practice to be unworkable and eventually they had decided that 1,500 vehicles/hour was a suitable design figure.

Mr Adams had suggested that the dots at the top represented the more cautious people, and that if a line were drawn through them, as shown in the diagram, it would give a safe figure—"safe" being used not necessarily in the sense of road safety but in the sense of a figure which could not be exceeded without involving the designer in difficulties.

Speaking from memory, the equation they had obtained was:

$$H = 17 - 1.47V - 0.035V^2$$

The constant term gave the headway as the speed approached zero. The linear term gave the distance covered in 1 sec, and appeared frequently in such equations. One second was very near the average value of a person's reaction time measured on a choice-distraction method, so that

FIG. 11

FIG. 12

FIG. 13

FIG. 14

the second term represented the distance travelled during the driver's reaction time, whilst the third term was the distance travelled during braking.

Dividing $5,280V$ by that equation gave the number of vehicles that would pass at various speeds and gave a curve of the type shown in Fig. 14.

The maximum of 1,800 vehicles/hour occurred at about 20 m.p.h. It fell sharply to zero at decreasing speeds, but never fell below 1,400 vehicles/hour for speeds above 20 m.p.h.

In Britain a figure of 1,500–1,800 vehicles/hour had always been taken, but the higher value should only be used where the island could be provided of a size, and with the radii, to permit a speed of about 20 m.p.h. to be maintained. Where the speed was likely to be higher, or where there was the possibility of checks reducing the speed, the lower value should be used.

The earlier roundabouts, which were about 110 ft square with 30-ft-radius corners, gave a speed of about 15 m.p.h., so that only about 1,500 vehicles/hour could be passed through the weave. In addition there would be left-turn and right-turn streams, so the capacity of the weaving section would be greater, probably about 1,800 vehicles/hour, but as the Author had said, it depended on the distribution.

According to the last figures Mr Bellamy had seen, the Lambeth Bridge roundabout was working at about 1,820 vehicles/hour and about 1,400 pedestrians/hour. If the volume of traffic increased much more the roundabout would fail. The Neasden roundabout had already had to be removed, the weave at the time of the heaviest traffic being 1,600–1,650 vehicles/hour and pedestrian flow about 600 per hour. Various reasons had been suggested, one of them being that the proportions of buses, perambulators, and pedestrians were too high.

In a test under working conditions in another roundabout, while traffic volumes were rising to a peak, satisfactory working had been observed for weaves of up to 1,500 vehicles/hour, which had progressively deteriorated as the weaves approached 1,800 vehicles/hour, when traffic had been brought almost to a standstill.

For design purposes a weave of 1,500 vehicles/hour should not be exceeded.

Mr J. G. Wardrop (Traffic and Safety Division, Road Research Laboratory) commented on the Author's reference on p. 661 to a formula worked out by the Road Research Laboratory for congested urban streets. That gave the total traffic as a function of the width of the road and the speed of the traffic. The Author took as an example 20 m.p.h. as a desirable speed, and in his formula (7) gave T (total traffic) = $330 \left(\frac{w - 19}{10} \right)$,

interpreting the 19 as a deduction for standing vehicles. It must occur to anybody, however, that that was rather a large deduction for standing vehicles, even though they were on both sides of the road. It was dangerous to interpret constants which occurred in a purely empirical formula of that type, based on observation, in terms of some physical quantity as a deduction for standing vehicles. It would be safer to say that the 19 was a deduction for standing vehicles and other factors. When taking a different

speed a different deduction was obtained, which did not mean that the standing vehicles had altered in width.

The Author went on to consider the results found in London on which that Road Research Laboratory formula had been based, and which gave rather low flows per lane, of the order of 500 to 600 vehicles/hour, and suggested that those flows were low because of the effect of the intersections. Mr Wardrop thought it was true that but for the effect of the intersections those flows might be much higher, but the relation between speed and flow which the Road Research Laboratory had found and which was given in the formula, and which related to the sections of roads between intersections, was valid, and had the flows been higher the speeds would have been lower still. The fact that the intersections controlled the traffic did not affect the validity of the relation between speed and flow between the intersections. It was well known of course, that intersections were the main cause of congestion in cities.

On p. 663 the Author commented on the "effective go period" for traffic signals and mentioned that there might have been some confusion in the definition of that quantity given in his earlier Paper.⁹ Mr Wardrop confessed to having been always rather puzzled by the definitions in that earlier Paper, because in fact the Author gave two and Mr Wardrop could never see how they were connected. In the present Paper, however, the Author had plumped for the one in which the "effective go" time was the actual green time of the signals plus one amber period and minus a quantity to allow for the starting-up delay, which could be measured, and a quantity to allow for the variation in the number of vehicles arriving in a green period. That additional allowance seemed to Mr Wardrop to be a matter of judgement and he would prefer something which could be calculated or measured in some way. The Author gave some figures on p. 663 for the value for the lost time which had to be subtracted from the green-plus-amber period, namely, 8 sec for fixed-time signals, 7 sec for police control, and 6 sec for vehicle-actuated signals, but did not explain how he arrived at those figures. It would be interesting to know how he did so.

The Author had not mentioned the work which the Road Research Laboratory had done to discover what allowance should be made at traffic signals for the variation in the arrivals of vehicles. They had found it quite satisfactory in most cases to assume that the arrivals were at random. They had made use of an artificial model of traffic, and in fact had used the electronic computer at the National Physical Laboratory to provide that model. Delays had been measured under all conditions of traffic flow and signal timings likely to be found. As a result of that work it was possible to make an exact allowance for the effect of random arrivals on delay and then decide how the signals should be adjusted to give the minimum delay and what was the acceptable value for capacity.

Some of that work had already been described in the Annual Reports of the Road Research Laboratory, and a Paper would be published shortly in

which Dr Webster would describe the work. Tables would also be published of delay. The work should give a definite answer to the question so far as fixed-time traffic signals were concerned, and, since vehicle-actuated traffic signals behaved similarly when the traffic was heavy, the results had some relevance to them as well.

Turning to the question of roundabouts, about which there had been a great deal of discussion already, it had been said that more research was needed on the subject and the Road Research Laboratory agreed with that view. One reason why there had not been as much research as there should have been was that the subject was a difficult one. To use observations on existing roundabouts, as the Author had done, was always risky, because there were so many factors which affected the capacity; not merely the weaving angle, but types of traffic, exact dimensions of entries to the weaving sections, and so on. It was difficult to take all those factors into account when using a relatively small number of existing roundabouts, each of which had probably some very characteristic features.

Recently, therefore, the Road Research Laboratory had carried out some artificial airfield experiments, in which they constructed a layout in the form of a figure of 8, the bar of the figure of 8 being made to represent the weaving section of a roundabout. The dimensions of that weaving section were large, the length being generally 200 ft and sometimes 300 ft. The weaving angle was of the order of 45° for the 200-ft length and 27° for that of 300 ft. The width of the weaving section was varied from 30 ft to 60 ft, and the entry widths on the left and right from 20 ft to 50 ft. The proportion of traffic weaving—i.e., the two weaving movements which crossed in the centre of the weaving section—varied from 60% to 100%, and in one or two of the tests the ratio of the traffic in the two weaving streams had been as great as 9 : 1, the 9 being sometimes in one direction and sometimes in the other. The tests had been carried out on part of the airfield at Northolt and had occupied 2 days.

With regard to the results of the tests, they had found that with mixed traffic (10% of buses and 12% of medium and heavy commercial vehicles) and 60% of weaving traffic the maximum flow was 925 vehicles/hour per 10 ft of the weaving section. That was achieved when each entry width had been the same as the width of the weaving section itself. That meant for instance that when the weaving section was 50 ft wide they could get 4,600 vehicles/hour through it if 60% were weaving. With a width of 60 ft the figure was about 5,500 vehicles/hour. When the entry widths were reduced to about 70% of that of the weaving section the maximum flow was reduced by 13%. It had been found that one weaving vehicle was roughly equivalent to $1\frac{1}{2}$ non-weaving vehicles, which was not quite what the Author had assumed. Also, one bus was equivalent to rather more than three cars. Lengthening the weaving section from 200 ft to 300 ft increased the capacity by about $6\frac{1}{2}\%$. They also found a surprisingly large number of accidents during the tests. Some might have been due to

the artificial nature of the tests, but they suggested that weaving under those conditions, with large weaving sections, was a difficult and risky business. There was a real element of danger and the possibility of accidents had to be considered when discussing the design capacity of large roundabouts.

Mr Wardrop then showed a short film of the tests which he had described.

Mr C. P. Andren (Chartered Civil Engineer in private practice), asked whether the Author would agree that his term "working capacity" had in fact the same meaning as the term "practical capacity" used by American traffic engineers. Mr Andren did not suggest that the actual figures given in the Paper should be the same as those given by the Americans for "practical capacity" in any particular case, because it was well known that the same results were not obtained from similar measurements of traffic flow made in Britain and in the United States. Traffic conditions, the type of traffic, the proportion of commercial vehicles, and so on were very different in the United States.

A few years ago Mr Andren had had occasion to compare what he might call the "practical capacity" of a London signal-controlled junction (where the vehicles were getting through without undue delay and with no backlog of waiting traffic) with the American "possible capacity" of that junction determined by the method given in the "Highway Capacity Manual." He found that his flow measurement was 40% in excess of the American "possible capacity."

The Author had mentioned some work done at University College on the relation between carriageway width and number of lanes in London streets, and Mr Andren showed a few slides dealing with that study, which had been made by J. C. Elliott some years ago. The observations had been made of entering vehicles at thirty-one controlled junctions in central London during peak conditions. The relation found was that $N = 0.0804W - 0.0274$. As the Author had stated, that gave an effective lane width of $12\frac{1}{2}$ ft.

That effective width, which took into account the different sizes of vehicles and habits of drivers, could be used in the formula given by Mr Wardrop which related total flow and carriageway width as followed:—

For a running speed of 15 m.p.h., $T = 48(W - 6) - 430$

then if Q = flow per running lane in v.p.h.,

L = width of a running lane in feet,

P = width of two parking lanes in feet,

then $T = Q \frac{(W - P)}{L}$ and from Wardrop's formula $\frac{Q}{L} = 48$ and $\frac{QP}{L} =$

718, so that if $L = 12\frac{1}{2}$ ft, as had been found by Elliott,

$Q = 600$ v.p.h. per lane and $P = 15$ ft.

The Author had stated that Wardrop's formula gave very low densities; perhaps an assumed lane width of $12\frac{1}{2}$ ft and a running speed of 15 m.p.h. might be nearer to actual conditions in central London.

Following Elliott's investigation, a map of the 1937 peak-hour densities in central London had been prepared by the late R. B. Hounsfield. It showed that routes carrying more than 550 v.p.h. per lane were exceptional. The most striking case, in which the density was over 1,000 v.p.h. per lane, was along the Victoria Embankment, with no side turnings on the river side and few intersections to the north. In other words, the conditions there approached those which might be expected on an urban free-flowing road. A few other cases of very high densities occurred at sudden narrowings of carriageways and also under very highly controlled conditions, as in Oxford Street.

Turning to the subject of roundabouts, Mr Andren had used the Author's formula for the calculation of the capacity of one side of a roundabout to find the effect on the capacity of a change in assumed lane width where the carriageway width and maximum weaving angle remained fixed.

From $T = 1,200 N \left\{ 1 - \frac{\alpha}{90} \left(1 - \frac{4}{3N} \right) \right\}$, it could be shown that if $T1$ was the total flow assuming $N1$ lanes and $T2$ was the total flow assuming $N2$ lanes, then $T1 - T2 = 1,200 \left(1 - \frac{\alpha}{90} \right) (N1 - N2)$, and if the corresponding lane widths were $L1 = 10$ ft and $L2 = 12\frac{1}{2}$ ft, then $T1 - T2 = 24W \left(1 - \frac{\alpha}{90} \right)$.

In other words there would be a change in the capacity value in every case except where $\alpha = 90$.

Mr Andren had then considered the effect of changing the assumed lane width from 10 ft to $12\frac{1}{2}$ ft in a capacity calculation for the much publicized roundabout design for Hyde Park Corner. Students of University College had measured the morning peak traffic there recently, and he had redistributed those volumes on the projected layout.

It appeared that the volume on the north-east carriageway between the new road and Piccadilly would be 3,250 v.p.h., plus traffic which now went down Hamilton Place—perhaps another 500 v.p.h. The capacity of that carriageway calculated by the Author's method would be about 4,440 v.p.h. Neglecting the Hamilton Place traffic altogether, that would give a reserve capacity of 1,200 v.p.h. to cope with future traffic increases. The effect of assuming a $12\frac{1}{2}$ -ft lane-width would reduce that reserve capacity to 450 v.p.h.

The police censuses at Hyde Park Corner from 1949 to 1954 showed that there might be an increase in traffic there of $33\frac{1}{3}\%$ in the next 20 years. What would the Author consider to be a reasonable growth figure to use in the design of such a junction in central London?

"The Design and Layout of Roads in Built-up Areas" suggested that no side of a roundabout should carry more than 3,000 v.p.h., and that a 33½% increase should be allowed for over the future volumes for design purposes so that the system would never be loaded to more than 75% of its ultimate capacity. Did the Author agree with that, or had he some other factor to suggest?

Finally, Mr Andren showed two photographs of Hyde Park Corner taken on the morning of the survey. One showed the approach from Knightsbridge with five lanes of entering vehicles, the flow being 1,260 v.p.h.; and the other the Constitution Hill entry, one lane wide, where the flow at that time was 1,070 v.p.h., although no entering vehicles were visible.

Dr G. Charlesworth (Traffic and Safety Division, Road Research Laboratory) said the Paper was valuable since it expressed the views of a practising traffic engineer—a man who had the actual job of handling traffic. For the research worker it was useful to know of the practical points which arose and how they were dealt with. The Author had covered many important and interesting matters, but Dr Charlesworth did not agree with all that he said and in parts of the Paper the Author did not give enough factual basis for his comments.

On p. 653, and elsewhere in the Paper, the Author referred to engineering judgement. Dr Charlesworth hoped that it would not be long before the need for engineering judgement was reduced, because the more factual the business of roads and traffic could be made the better it would be. On p. 653, for example, the Author said "The relation between material risk and reasonable speed must be a matter of engineering judgement." It should be possible to reduce that to an economic basis and find a more satisfactory way of dealing with it.

In the last paragraph on p. 658 the Author said "For practical purposes it may be said that differences in the flow in opposite directions in undivided carriageways do not affect the capacity per lane." Observations which the Road Research Laboratory had made indicated that the speed of traffic in one direction on a two-way road was influenced more by the amount of traffic in the same direction than by that in the opposite direction—probably about twice as much. Taking the road as a whole and considering the average speed of all the traffic, he thought it could be said that the Author's statement was reasonably correct.

With reference to Fig. 4, Dr Charlesworth showed a graph (Fig. 15) relating average speed of traffic to total flow. The figures for dual carriageways had been obtained 5 years ago and the average speed, which was that of all vehicles, was lower than it would have been had the results been obtained today; but it would be noticed that the curve stayed quite flat up to (with a width of 2×30 ft) nearly 3,000 vehicles/hour. There was not much evidence of falling off in speed with increasing flow there, but the Author's curve for the motorway fell all the time.

On p. 659 it was stated that "It should be appreciated that a limit is placed on the practical capacity so long as one slow or stationary vehicle is a possibility. In the case of a two-lane one-way carriageway, as soon as the fast stream is forced to pass a slower vehicle it is reduced to one lane." On p. 660, however, under "Standing vehicles," he said "An occasional standing vehicle is not sufficient to reduce the capacity below the value given above." Dr Charlesworth was puzzled by the apparent

FIG. 15.—SPEED AND FLOW ON RURAL ROADS

inconsistency between those statements. In the same paragraph, dealing with standing vehicles, the Author said "A rough rule is to assume for each side a progressive loss of the capacity of a lane from nil at ten standing vehicles per mile to total loss at a hundred per mile." Such observations as the Road Research Laboratory had taken suggested that the first standing vehicle, at least on two-lane carriageways, had the biggest effect proportionately. On one section of the A5 road it had been found that the presence of one standing lorry reduced the average speed of traffic by $6\frac{1}{2}$ m.p.h. That meant a loss of capacity. Similarly with gradients; the Author said "Gradients lower the speeds of vehicles"—with which he would agree—"but do not materially affect working capacity." With the latter statement Dr Charlesworth did not agree, because a reduction in speed reduced working capacity. The same was true of pedestrians. Pedestrians crossing the road slowed down the traffic and therefore reduced the capacity. Table 2 gave some results of delay to pedestrians

crossing free-flowing traffic, but did not give their source. Under "Intersections" he said that "Fixed-time signals have the maximum loss even if set to give the minimum delay at maximum traffic." It would be interesting to have the Author's comments on that in relation to linked systems of fixed-time lights. For instance, Oxford Street worked during the day as a fixed-time system—did that have the maximum loss?

Finally, Dr Charlesworth wondered whether the Author could say a little about the application of his results in practice. Some mention had been made already of that, but it was important to see how the particular problems in London were being tackled. The Author had been working on that matter for many years and had wide experience. What sort of increase in capacity and increase in speed did he expect from carrying out some of the works mentioned in the plan proposed in 1951?

*** * Mr C. L. Champion** (a Superintending Engineer, Ministry of Works) observed that the flow of traffic considered as a fluid was subject to remarkable laws which were the statistical result of countless actions of individual drivers whose behaviour was more complex than that of the molecules of a normal fluid. It was known that in the flow of a compressible gas through a restriction, a critical flow might be reached which could not be exceeded. In the case of road traffic the critical or saturation flow was an unstable state, and if actually reached might lead to a rapid reduction of speed and a very low flow.

Mr Champion had noticed a number of cases where it seemed likely that local road improvements were actually causing delays by encouraging the saturation of "bottle-necks" beyond them, since after a check the rate of flow in the improved section might greatly exceed that which the following section of road was able to accept. It appeared that that difficulty could be reduced by some form of traffic control on improved sections before "bottle-necks" to ensure that the capacity of the latter was not exceeded. That could consist of a simple counting device, counting the traffic during (say) $\frac{1}{2}$ -min intervals and actuating a traffic signal if the required density was exceeded. Although that would involve some delay to drivers at the signal, under suitable circumstances the total journey time could be greatly reduced. As an example of what might be done, the Author mentioned that to obtain the maximum flow in a roundabout the density must be reduced to perhaps half saturation in the approaches.

There was no doubt that in years to come traffic conditions were likely to get worse rather than better so Mr Champion hoped that it would be possible to carry out an experiment to determine whether a reduction of journey time at peak hours could be obtained in that manner.

The Author, in reply, said the film which had been shown had been very interesting, and, allowing for the fact that the camera had run at

*** * *** This contribution was submitted in writing after the closure of the oral discussion.—**Sec.**

half speed, it gave an idea of what 5,000 vehicles/hour looked like when weaving. He had had the pleasure of watching those experiments. As with all experiments of that type, there had necessarily been a degree of artificiality. He knew from the discussions which he had had with the Road Research Laboratory that that was not disputed. On the other hand, he regarded the experiments as extremely valuable and as the only way of tackling the problem of going beyond existing experience. The engineer was always trying to do that. If, for example, today's knowledge had been available 29 years ago, roundabouts would never have been tried in London, and London would have been the worse for it. Some of them could recall what Hyde Park Corner and Trafalgar Square looked like when they had been channelized. (It had not been called that in those days, but that was what it amounted to.)

In the film the particular feature which he had noticed was the strong tendency of the drivers in the experiment—and it occurred also in very heavy weaves in practice—to get their weaving over early. That was a good thing to do, but, if it could not be done early, it was better to do it late instead of stopping, as some drivers did. In practice, in a freely flowing roundabout he believed that weaving would be easier than the experiments had indicated.

The Americans were wealthy and could afford to have fly-over junctions. There had been a tendency recently, however, to regard roundabouts as belonging to the past. It was most undesirable in engineering to talk of certain things as having been completely outdated. Engineers must use reinforced concrete when it was best in the circumstances, taking economic aspects into account, and steel when steel was the right material to employ. The same argument applied to roundabouts, signals, and fly-overs.

Mr Seymer referred to a figure for the extra cost of a roundabout at Hammersmith Broadway compared with the use of signals. That should not be taken seriously, because it included the extra cost of buying property for the fly-over scheme which might be undertaken one day. That would cost at least £1,000,000 more, and he thought that at the present time there were better ways of spending £1,000,000.

The Author regretted that as usual the limitations of a Paper and the lack of available facts made it difficult to give a full factual basis for all the ideas put forward,

He agreed with Mr Charlesworth that the more factual the information on traffic became the better, especially if it was available in a convenient form to the engineer. That would not reduce the need for engineering judgement. The engineer had always needed to go ahead of research and would always do so. There were also factors such as availability of funds, property costs, amenities, etc., which could not be covered by formulae.

On the terms used the Author agreed with Dr Smeed that "theoretical capacity" was inappropriate since the curve was by no means based on theory. A more suitable term would be "practical saturation density."

The Author deliberately used such vague expressions as "congestion," "fairly free," and "overloaded" since it was a matter of judgement when those conditions were reached, and the judgement would depend on considerations beyond the reach of research technique. By "working capacity" the Author had in mind that which a competent engineer would recommend his clients to regard as satisfactory. Whilst in the case of unobstructed free-flowing roads that depended very largely on the range of speeds desired by drivers and the speeds actually attained, the capacity was the primary consideration. In the case of intersections and the like, whilst again the possible flow was greater when greater delay was accepted, a point was rapidly reached where the delay increased to an inordinate extent and the practical capacity was reached just before that point.

A number of useful contributions to the discussion were made on the question of the capacity of a weaving space. Mr Adams's method, using the two-dimensional approach throughout the range, was more precise than the Author's although, as would be seen from Fig. 10, there was not a great deal of difference between the two lines. There still appeared to be some difference of opinion as to the effect of the width of the weaving space; Mr Adams and Mr Bellamy suggested that perhaps it had no direct effect whereas the general opinion and experience appeared to be that additional width, provided it was not at the expense of the weaving length, did increase capacity. That was supported by Mr Wardrop. The Author was aware of the opinions¹⁸⁻²¹ referred to by Mr Seymer, but did not regard them as giving any new information about the relation between the dimensions of a roundabout and its capacity; those opinions of the maximum capacity of a weaving space were clearly at variance with experience not only in Britain but, as quoted by Mr Seymer, in America. The "laboratory" experiments at Northolt gave valuable information for a limited range at the upper end of the scale, showing that volumes of traffic in excess of 5,000 v/h could be handled. As to the circumstances in which it was desirable or not to rely on weaving for handling such volumes, that depended on many factors again outside the limits of research technique. Mr Wardrop quite properly did not give any formula to correlate his results. They did not give any information regarding the effect of weaving length since only a very limited number of observations were made at the 300 ft length. They gave valuable information, however, on the effect of the ratio of the traffic actually weaving. In the light of that information the Author wished to withdraw his equations (13) and (14) (which were based on American information) and substitute $K = \frac{8}{9}(1 + \frac{1}{2}p)$, where p denoted

the proportion of weaving traffic to the total traffic. Otherwise the results at Northolt appeared to give support to the Author's formula.

Presumably Mr Bellamy's figures for the Lambeth Bridge roundabout related to the weaving traffic only since the total peak flow on that intersection was well over 4,000 v/h.

Mr Seymer appeared to be under the impression that there was some prejudice in favour of roundabouts as opposed to other methods of control. The Author was convinced from experience and theoretical considerations that a properly designed roundabout had greater traffic capacity than an ordinary signal-controlled intersection. The Author had recommended the use of channelization for certain types of intersection at a discussion at the Institution about 10 years ago. Members could see, however, the absurd complications which arose from endeavouring to apply the channelization principle to an intersection with many approach roads, in the layout for Hyde Park Corner published recently.²² There were eight roads entering Hyde Park Corner, that meant fifty-six streams of traffic to channelize. Some simplification by weaving was possible, in fact the arrangement at present in use reduced the actual cuts to four. A roundabout was the final simplification. The channelized intersections in New Jersey seemed to take up as much space as a roundabout.

A closer examination of equation (8) of the Paper would show Mr Dickinson that the capacity of controlled intersection increased with the cycle and therefore with the delay. He would also see that the capacity of a road entering a signal intersection was proportional to the width of the carriageway and not in the ratio given by him. It was worthwhile widening roads since that increased their capacity, particularly at signalled intersections. The Author agreed with Mr Dickinson that drivers with substantially greater than the average reaction time ($3/5$ sec) should not be on the road. Nevertheless those were test figures and a driver could not be expected to maintain such a degree of alertness throughout a long drive, much of it perhaps in dense traffic. We did not design for the breaking stress of a material and we should not design for the limiting capacity of a driver. That to some extent also answered Dr Smeed's point and explained why the Author had scaled down the saturation density below what might be possible if every driver could drive continuously at the "model" spacing. The Author was also in close agreement with Dr Smeed on the value of "laboratory" experiments of the type carried out on an airfield. His particular objection to the experiments on minimum headway lay in the fact that the following driver must know, at least subconsciously, that he could avoid collision by pulling out to one side or the other, which would not be possible in a fully loaded road. The Author suggested a uniform value for the saturation density in relation to speed (Fig. 1) after it had reached 2,000 as a compromise between curves (A) and (B). It was now generally accepted that the value did not drop very much after reaching a maximum.

On the point raised by Col. Green as to safe capacity there was very little data except that in similar circumstances accidents were approximately

²² "Directional channelization applied to Hyde Park Corner." *Roads & Road Constr.*, vol. 33, p. 139 (May 1955).

proportionate to flow. There seemed to be some evidence that high density with high speed led to a greater increase in serious accidents. On the basis of some data given from the Netherlands ²³ accidents appeared to rise more rapidly after the point of 3,000 vehicles/lane in 24 hours was reached or say 200 v/h/l. Equation (2) of the Paper would give a theoretical limit of safe capacity if suitable values were inserted but the Author did not consider that of practical value.

A 45-m.p.h. speed limit would have no material effect on capacity since most vehicles would have less than that speed if the road were loaded to capacity.

In answer to Dr Smeed and others, the Author explained that by a traffic lane he meant the width required for one line of the kind of traffic expected at the speed considered. Normally that would be 10 ft in urban areas. In spite of Mr Elliott's observation (quoted by the Author and Mr Andren) the Author would not recommend taking 12.5 ft as the value unless a larger value was taken for the density per lane. Engineers were used to thinking in terms of such units as tons/sq. ft, and vehicles per hour per lane was a useful unit even if the value had to be varied to suit the different cases. There were no lanes of traffic as such when weaving but it was useful to keep to the unit of 10 ft. The proportions of the types of vehicle should be specified. It was not possible, as thought by the Traffic Branch of the Board of Trade in 1909 and apparently, according to Mr Seymer, still thought on the Continent ²⁴ to reduce the traffic to "passenger-car units." The effect of larger and slower vehicles was not a simple function although it was sometimes necessary within narrow limits to make such an allowance for want of better information.

In reply to Dr Smeed it should be pointed out that the question of reservoir space for standing vehicles was dealt with briefly on p. 670.

The Author agreed with Mr Wardrop that the constant 19 ft in equation (7) represented other factors as well as the space occupied by standing vehicles, but suggested that the formula was in a form more easily understood than Mr Wardrop's form.

In answer to Mr Wardrop the Author said his lost-time deduction to get the "effective go-period" was chosen to give, for fixed-time signals, answers agreeing with observations including Mr Wardrop's. The variations for police control and vehicle actuation were, however, only suggestions. He felt that to use such a method was preferable to the American practice of using "vehicles per minute of green," since the latter made the capacity independent of the cycle.

Mr Andren's question on prediction of future increases in traffic was rather outside the scope of the Paper, but the Author suggested that to attempt to forecast by extrapolation from censuses taken during the past

²³ "Accident Facts and Their Use." Int. Road Safety and Traffic Rev., vol. 3, No. 1, Winter 1955, p. 18.

²⁴ See p. 680.

5 years was as dangerous as any form of clairvoyance. With limited resources it appeared important not to spend large sums on doubling the capacity of one intersection in a town where other intersections forming part of the same road system were near their limit of capacity, which could not be similarly increased. It was better to spread available resources.

The Author had no data for 3×2 dual carriageways but the figures quoted by Mr Charlesworth only amounted to 500 v/h/l, very much less than the 2,000 v/h/l suggested by some as the capacity of a motorway at high speeds.

There was no inconsistency between pp. 659 and 660. On p. 659 the Author explained why saturation density on all lanes was not practicable, whereas on p. 660 it was pointed out that when density had been reduced to allow for overtaking a single standing vehicle would not materially affect capacity although it was agreed the speed would be reduced at that point. Similarly with a gradient.

Table 2 was based on Table 1 and the method evolved by Adams.³

It was not possible to deal in detail with the application of the principles given in the Paper to individual cases, but the Author affirmed that those principles had been used appropriately when considering the design of road improvements in London.

Holding back the traffic some distance from an intersection as suggested by Mr Champion was not likely to do much, if anything, to improve conditions. If there were n vehicles per hour wanting to pass through the intersection, holding them back for $\frac{1}{2}$ min and then releasing them again at intervals would still leave n vehicles per hour to go through the intersection. The fact that they arrived in rather dense blocks of traffic might, in some circumstances, make things much worse, although the tendency in built-up areas for traffic to be broken up helped the working of a roundabout.