*Discussion on Paper No. 6736**

Research into the relative merits of roundabouts and traffic-signal-controlled intersections

by

F. V. Webster, B.Sc., Ph.D.

and

R. F. Newby, B.Sc., F.S.S.

Mr H. N. Ginns (Assistant Chief Engineer (Traffic Engineering), Ministry of Transport) said that he felt that this useful and informative Paper gave information on the relative areas occupied by roundabouts and signal-controlled junctions which was clearly of very great importance in built-up areas where high land values were an ever-present problem to the highway and traffic engineer.

103. Mr Ginns would like first to comment on the formula $w_1/w_2 = \sqrt{(q_1/q_2)}$ which the Authors had suggested for determining the relative widths of the carriageways at a signalled junction. There was no doubt that the effect of using the square root relationship instead of the direct one as given in § 8 was to give more space to the more lightly trafficked road, and that seemed to be right from the practical angle. If the minor road was restricted in width at the signals, say to one lane, the effect could be that the one traffic lane would produce a long queue of vehicles and hence increase the time losses associated with getting such a queue moving on the appearance of the green signal. The green period for the minor road must then be set long enough to allow for that, and that was to the detriment of the major road.

104. The square root formula would often mean that the single lane on the minor road would be replaced by two lanes on the minor road, thus giving shorter queues and quicker clearance of the minor road. The saving in green time could be added to the major road green time, or used in reducing the cycle time. There were many signalled junctions where that approach would be of practical help. A widening of the minor road rather than the major road might be the simplest and the cheapest way of improving the capacity of an overloaded junction. There were, in fact, one or two junctions on the Great West Road where that sort of treatment could very well be applied.

105. The offset reservation for right-turners, dealt with in § 13, was extensively used in Canada and the U.S.A. where central refuges were noticeably absent from town streets, but there was reliance only on lane lines to effect the offset. The central refuges which were common in Great Britain were often an obstacle to adopting the offset laning for right-turners, but there must be many sites where the overall carriageway width was sufficient and where the offset effect could be achieved by shifting over the existing refuge by a few feet. He suggested that highway engineers faced with a right-turn problem at a particular junction should go over the site carefully with a tape to see whether, in fact, the apparently permanent central refuge—with its associated lamp-posts, of course—could not be offset by a few feet. He further suggested that at some such sites a slight relaxation on lane widths might be desirable

* *Proc. Instn civ. Engrs*, vol. 27, January 1964, pp. 47–76.

if, by that, one could squeeze in an additional lane for right-turners. The appropriate white lines would, of course, be used in association with the offset refuge.

106. As to the shape of roundabouts, he would, in passing, express his dislike of square roundabouts, however rounded the corners were. He would advise young designers that they should not be afraid of irregular or asymmetric shapes. He recalled many a case where the designers had reached an impasse solely because they were trying to work with a circle for the central island. The answer was often a heart-shaped, cam-shaped or similar central island. With really awkward layouts, it was often best to sketch in the basic shape freehand, subject, of course, to complying with basic dimensions for widths and so on.

107. In § 25 the Paper dealt with the 'give way to traffic from the right' rule, on which the Road Research Laboratory had done trials, which were now being followed up. Many had previously felt that that rule would not work. He had never been convinced before he had seen the experiment at the Quarry Hill roundabout in Leeds, which was one of the trial sites, but there was no doubt of the usefulness of the method. At least, it applied in the north, where perhaps the drivers were a little less thrustful than those in the south. It had the most curious effect of breaking the traffic up into platoons, and the vehicles then moved faster through the roundabout than they would otherwise have done.

108. The Ministry of Transport was extending the trials to 43 other sites in various towns, while the London Traffic Management Unit was doing so on 34 sites. The final decision on the adoption of that rule for all roundabouts would depend on the results of those extended trials.

109. He was very glad that the Paper once more called attention to the inadequacies of roundabouts in causing both delays and accidents. The 'English roundabout', as it was called abroad, should be regarded as an obsolescent device with limited uses. On busy roads roundabouts were quickly overwhelmed by the annual growth of traffic, and caused unnecessary delays. If further evidence was needed of that, one had only to consider that the Road Research Laboratory, in order to keep the traffic moving, were trying out signals, and when the signals failed to work, they had a policeman to bush a button and control the signals himself. On high speed roads, roundabouts were an obstruction and caused unnecessary accidents.

110. It was interesting to note that research was tending to show how small a field there was for roundabouts economically. For most busy junctions, grade separation, although much more expensive in the first cost, could be shown to be economically justifiable in savings in delays and accidents in the long run.

111. It was a common defect with many roundabouts that existing radii were small, especially the exit radii. The ideal exit was a tangential one. He suggested that engineers should review the many roundabouts with which they had to live in order to see whether they could, by small alterations to the lay-out, especially the exit lay-out, improve the capacity and flow characteristics of the roundabouts.

112. He felt that the Paper would be a standard work for all who were engaged in the design of signal-controlled and roundabout junctions, and he was sure that it would go on their shelves with the other standard works.

Mr A. J. H. Clayton (Divisional Engineer, Traffic Engineering Division, London County Council) said he wished to echo the last words of Mr Ginns, that the Paper would be very valuable in that it had gathered together a great deal of information about the design of intersections.

114. He had been very pleased to learn from the Paper that the Road Research Laboratory had now found that the priority rule at roundabouts, which he had seen previously, was a good thing. He hoped that Mr Ginns and his Minister would not take too long in confirming that view and introducing the rule officially. The

London County Council had suggested that to the Minister before the Highway Code was last revised, but the Minister had not seen fit to include it. Now they knew that what they had then thought to be true was true.

115. He wanted to deal with a particular point on which he felt he must join issue with the Authors. It related to their study of the relative amount of land used for widening compared with roundabouts. It was an interesting study, and he thought it was valuable, but he feared that it might be misleading, because in urban areas it was not the net square yards of land which cost the money but the properties that one had to buy.

116. From Fig. 14 which showed an intersection, it would be seen that while a roundabout would chop off the corners, widening would take frontages. Although the area might be the same for a widening as for a roundabout, or even less, the point was that the area was made up of properties which had to be acquired, and one found that it was necessary to acquire more properties in the case of a widening than in the case of a roundabout.

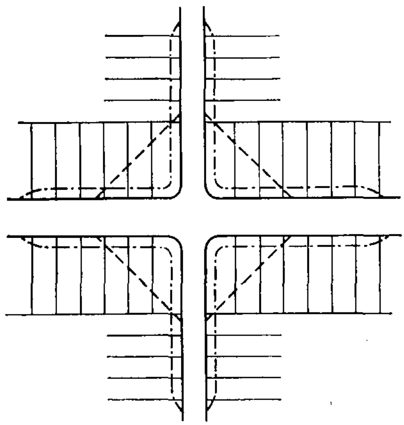


FIG. 14

117. A valuer colleague had very kindly prepared estimates of the alternative costs in a case where a roundabout was to be constructed in order to ascertain what it would be if a widening were carried out instead. Although one of the arms was to be widened anyway, it was found that, as near as could be within the limits of probable error, the cost was the same, about £1·3 million in each case. Although the area of land taken for the roundabout was a great deal more than for widening, the cost was about the same.

118. For the record, at the peak hour that intersection dealt with 3800 vehicles/h and it was designed to accept a very considerable increase on that. The traffic on the two roads was about equal but rather tidal. The right-hand turns were on two opposite phases. They represented about 20% of the entering traffic on one road and about 8% on the other, or 10% of the total traffic in the intersection. The proportion involved was not high by any means.

119. Incidentally, he was not quite clear about how the percentage in Table 3 was worked out. Perhaps the Authors would clarify this. Was it a percentage of the traffic entering the road which took the right turn, or a percentage of the total traffic on the road?

120. He was convinced that one must work out each case on its merits. Even in the case of a widening, the most economical way was not usually to do it on both

sides of both roads. As Mr Ginns had suggested, it might be most economical to widen the side road. Therefore, several alternatives should be considered in order to obtain the best solution.

121. There were many other factors that decided economically and for other reasons whether a roundabout should be used. For instance, he did not think that the Authors' calculations took any account of the central islands. The central island of a roundabout in a town was of some value as an open space. The planners might even permit the area of the island being counted for density purposes for the development of land outside. That was done in one particular case in London, and it might well be done in other cases. They might even allow development on it. As a traffic engineer, one would rather that were not done, unless a completely underground access could be provided.

122. There were a number of other factors which affected the issue. In comparing the two cases, the Authors had assumed non-hooking right turns. (Mr Clayton would describe them as back-to-back turns.) He believed that to be the best way of handling right turns, although it was difficult to do it properly without some kind of channelization. They had not yet persuaded the police to agree to it, even with channelization. However, it would make a difference.

123. Mr Clayton suggested that the Author's conclusion (*c*) given in § 83 should read:

> Theoretical calculations have shown that land costs are not necessarily greater for roundabouts than for widening of the roads concerned to give equivalent capacity by signal control. Alternative schemes need to be prepared for each case to compare property costs, but the trend is in the direction of roundabouts when there are many right-turners (20–40% of the whole) and in the case of multiway intersections.

Mr H. C. Smith (Assistant County Engineer, Middlesex County Council) thanked the Authors for their Paper, which he said was a valuable contribution to traffic engineering information, and which many road engineers would find most useful. In view of that, he felt that he must raise certain points, for in his view the Paper was incomplete and, therefore, might be misleading.

125. With reference to Fig. 12, giving queueing delay curves, he wondered whether the Authors had plotted similar curves for automatic signal junctions. Using the data given in Table 3 and § 57, and plotting curves for 1:1, 2½:1, and 4:1 flow ratios, it appeared that with a flow into a junction equal to 60% of the capacity, the delay at signal junctions per vehicle on the major flow was from 4 to 11 times longer than delay at roundabouts, while the delay on the minor flow would be twice that of the major flow.

126. He wondered whether the Authors would agree that the figures given in Table 4 might be biased owing to the sample size for signal junctions being four times larger than the sample for roundabouts and also because they had used accident figures nearly 10 years old. He asked that question because a study of nine years' records ending December 1959, for 204 signal junctions and 59 roundabouts in Middlesex revealed an average annual accident rate per junction of 5·18 at signals and 3·4 at roundabouts. But in a comparison of 12 signal junctions and 12 roundabouts for the same nine years, and where flows, environment, including shops and so on, were similar common factors to each pair, the average accident per signal junction was 7·2, and for roundabouts 4·1. Yet, comparing those junctions for the three years 1960–62, the accident rates per junction were 9·7 for signals and 5·3 for roundabouts.

127. Quoting those results in terms of average annual frequency per 1000 vehicles/h inflow for all injury accidents over the nine years, the figures were 2·86 for signals and 1·67 for roundabouts. The figures for the three years 1960–62 were 2·96 for signals and 1·46 for roundabouts, reducing to 2·38 and 1·38 if pedestrian accidents

were excluded. The total three years' accidents were 349 at signals and 182 at roundabouts. For the record, it should be noted that traffic flow on the 24 junctions had increased between 1954 and 1961 by 46%—5%/a—with a corresponding increase in accidents average per annum over the whole county of 4·4%.

128. Referring again to Table 4, the results of a study of three-way roundabout junctions for the period 1954–56 at eight junctions with average inflows of 900–2000 vehicles/h gave a frequency per 1000 vehicles/h of all accidents of 2·18. There were only five pedestrian accidents in the three years although two of the junctions were adjoining stations and industrial works. The corresponding figures for four-way signals and roundabouts in 1954–56 taking the 12 samples of each type were: inflow 700–3000 vehicles for signals and 1100–3300 for roundabouts, frequency of all accidents 3·4 for signals and 1·9 for roundabouts.

129. The Authors would note that in the urban area of Middlesex the figures quoted were less favourable to automatic traffic signals than those in the Paper. Perhaps the Authors would comment on that.

130. In § 66 the Authors said that it would be misleading to compare the accidents at roundabouts with those at traffic lights because the two types were found in very different circumstances. To his mind, that was not necessarily so. Many towns had roundabouts in the centre of the town. That difference, he was sure, did not apply in the case of the 24 junctions to which he had referred.

131. From §§ 67–69 it appeared that 50% of the accidents at roundabouts involved one vehicle only. Was it, therefore, reasonable to assume that in a large number of the two-vehicle incidents one of the drivers was blameless? Perhaps the Authors would comment on that. Also, could they give the percentages of single-vehicle and two-vehicle accidents at traffic light junctions? In the example for 1960–62 previously referred to, the two-vehicle incidents at signal junctions were nearly eight times more than for single vehicles and nearly three times more than the two-vehicle incidents at roundabouts.

132. Mr Smith hoped that members would not take it that he was trying to fight the battle of roundabouts versus traffic-signal controlled intersections. He believed that the two were necessary jointly or separately. However, he agreed with Mr Ginns that where they could get grade separation, that was what they should do.

Mr N. Seymer (Planning Division, London County Council) said that he was speaking in a private capacity.

134. He would like first to comment on Dr Webster's remarks about the system which had been tried at Düsseldorf for indicating the speed at which one should approach a signal-controlled intersection. Herr von Stein, the traffic engineer responsible, had showed him the first installation about 10 years before, and he noticed that Herr von Stein was persisting with the system, so he at any rate thought it had some value. Dr Webster had stated that the tests at Crowthorne had shown no reduction in delay, but the vehicles used in those tests had all been small, light vehicles and Herr von Stein had told him that the main object in using the system was to keep the really heavy traffic moving—the heavy tractor–trailer combinations.

135. Mr Seymer showed a film he had taken some 10 years previously of traffic weaving capacity on a weaving section 40 ft wide and 240 ft long in Parliament Square, Westminster. Mr Andren's analysis gave the following results for the two longest shots (47 s each):

	Total inflow, veh/h	*Weaving*	*Weaving flow, veh/h*
Shot 1	2790	56%	1560
Shot 2	2540	71%	1800

These results were similar to design capacities for weaving sections recommended in America and Germany but lower than the Wardrop formula would give.

136. Mr Seymer showed a slide taken from the roof of the Arc de Triomphe in Paris several years ago. It showed the complete seize-up of the Place de l'Etoile. This was not exactly a roundabout as the term was understood in Britain: there were not weaving sections, but there was a large circular area of road space, about 12 lanes wide. The offside rule applied, so that drivers coming into the roundabout had priority over those trying to get out of it. The British were on the right track with the nearside priority rule. The French had since cured the problem. They had installed signals on all 12 approaches to the intersection, grouped in phases, and that stopped too much traffic coming in during any single period.

137. Another slide showed a much more orderly arrangement in Germany. There were three lanes in each of the main road approaches to the intersection and only two lanes in the exits: one of the approach lanes was intended for left-turning traffic at the intersection. That might be considered a novelty in Britain, but it had been done in Germany many years ago. The junction had a central divider, and the intersection was well marked with lanes and arrows.

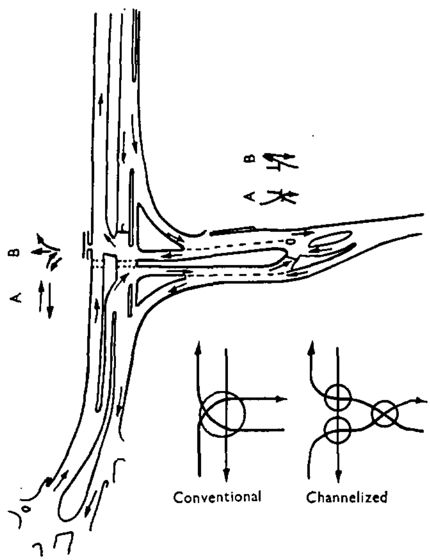


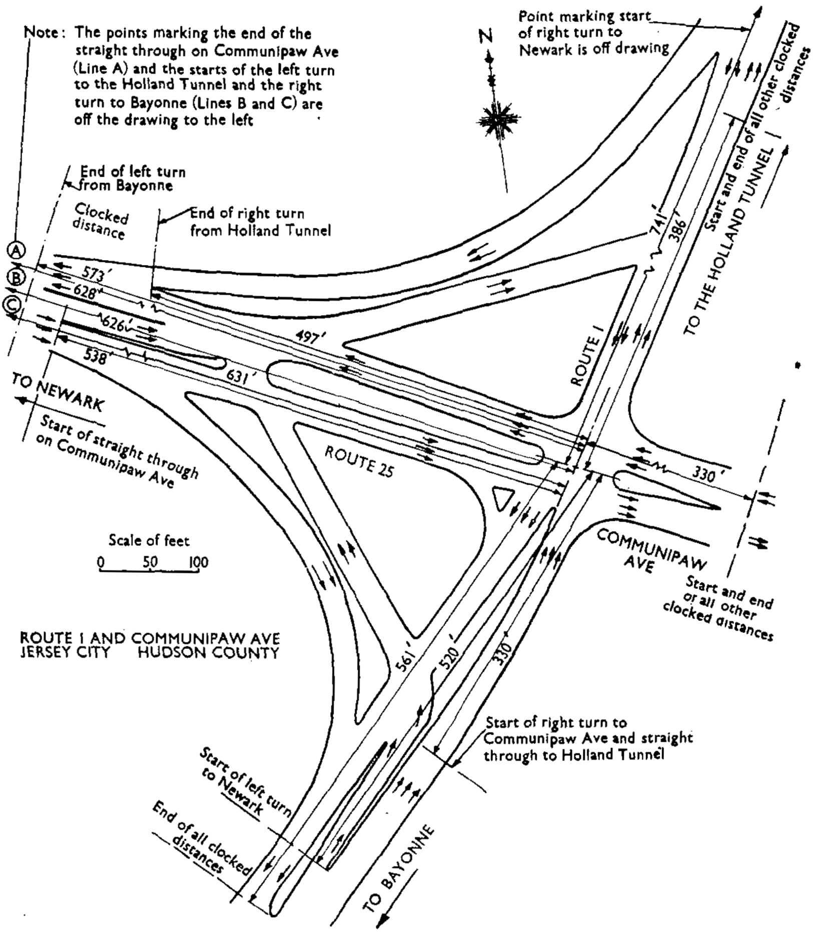
FIG. 15: SWEDISH SUGGESTION FOR A T-JUNCTION

138. Fig. 15 showed a Swedish suggestion for possible application of the directional channelization arrangement at a T-junction—one could imagine the junction at the foot of Big Ben—where with a normal layout one had two right-turn movements conflicting with the straight-on movement and three phases were necessary if they were heavy movements. With the proposed layout, there was just a two-way conflict at each of three points. That was the directional channelization principle but it looked as if it took up a great deal of space although at a junction where there were three conflicting flows each of 1500 vehicles/h, one would need one lane for the straight-ahead movement and one lane for each of the 'outside' movements; and, with the conventional arrangement (since each flow could run for only a third of the cycle) three lanes for each of the turning movements and three lanes for the straight

ahead movement were necessary. With 'directional channelization', each flow required only two lanes.

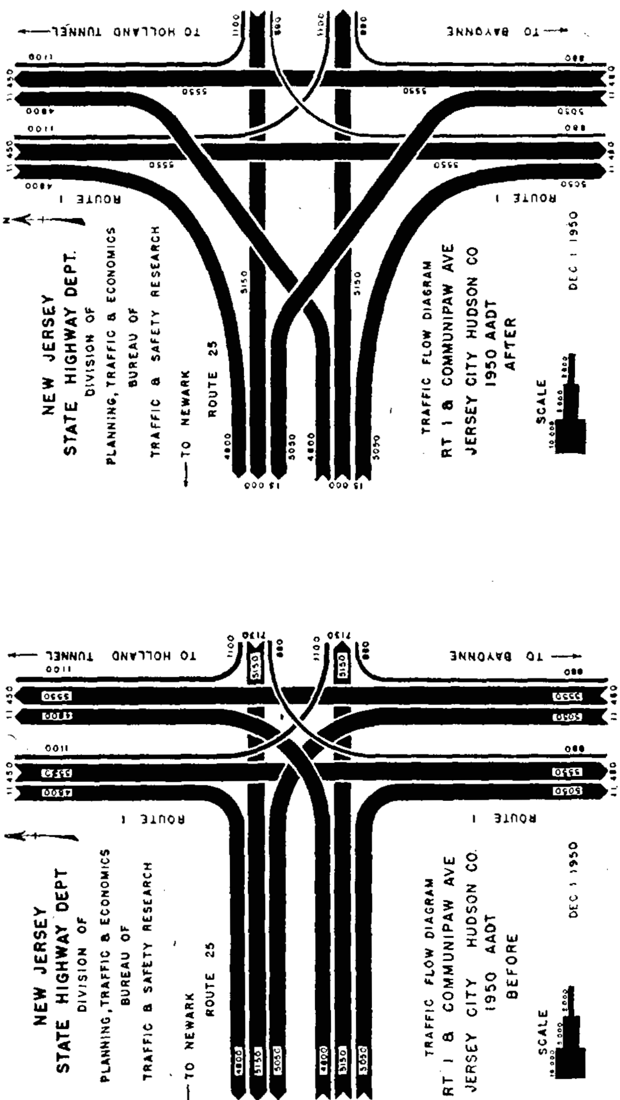
139. It was true that the oblique cross-over represented a design problem. It could not be too oblique, although it could be a great deal more oblique than some people might imagine. Mr Clayton had said that cost depended not just on how much land one took, but on what land one took. It might be that one could more easily get extra width at a point 300 or 400 ft down the road, although one could not cheaply widen part of the road nearer the intersection. That could be a good solution.

140. A four-way junction in New Jersey where it had been necessary to solve the problem of two left-turn movements resulting in a three-way conflict was shown in Fig. 16. Those concerned had thought of building a roundabout, and they could



Courtesy: Roads and Road Construction

FIG. 16: PLAN OF FOUR-WAY INTERSECTION, NEW JERSEY



Courtesy: Roads and Road Construction

FIG. 17: NEW JERSEY INTERSECTION BEFORE AND AFTER 'DIRECTIONAL CHANNELIZATION'

have done so on the land available. Probably according to the Wardrop formula that would have had sufficient capacity, but on the basis of the United States' standards, those concerned reckoned that it would not have enough capacity. So they had applied the 'directional channelization' principle. They had short-circuited the left-turn movements.

141. Fig. 17 showed the flow diagram 'before' and 'after'. Previously, there had been a three-way conflict at one point. The 'after' picture showed it spread out. This had been done many years ago, and it seemed to work satisfactorily.

142. Another example from New Jersey was given in Fig. 18. The situation was much the same. Previously there had been a heavy left-turn movement in the direction indicated. That movement had been given another path. It now moved 'back to back' with traffic in the other direction, with only a narrow dividing island. The system worked well. The crossing between the two movements was fairly oblique; but it still worked quite satisfactorily, and had done so for a number of years.

143. An attempt to apply the same principle to one of Britain's major and rather more complex intersections was illustrated in Fig. 19.

144. Fig. 20 showed what the morning peak-hour flows would have looked like applied to that layout at Hyde Park Corner. This had been a possibility, but it could not be done now, and he would not suggest that it should be; but this kind of solution was worth considering elsewhere.

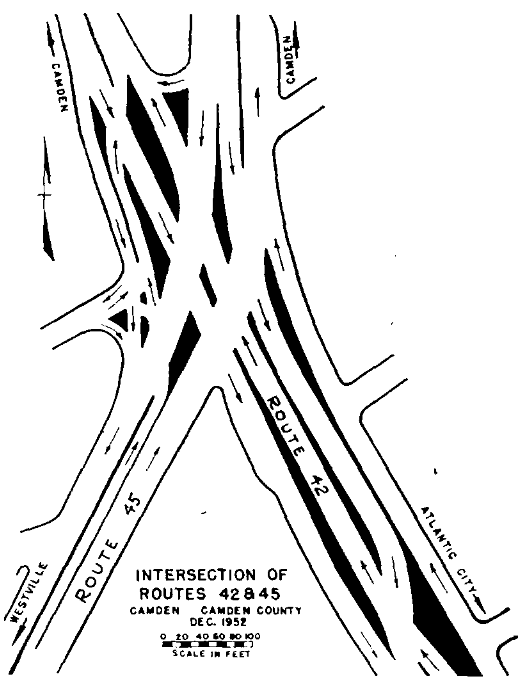


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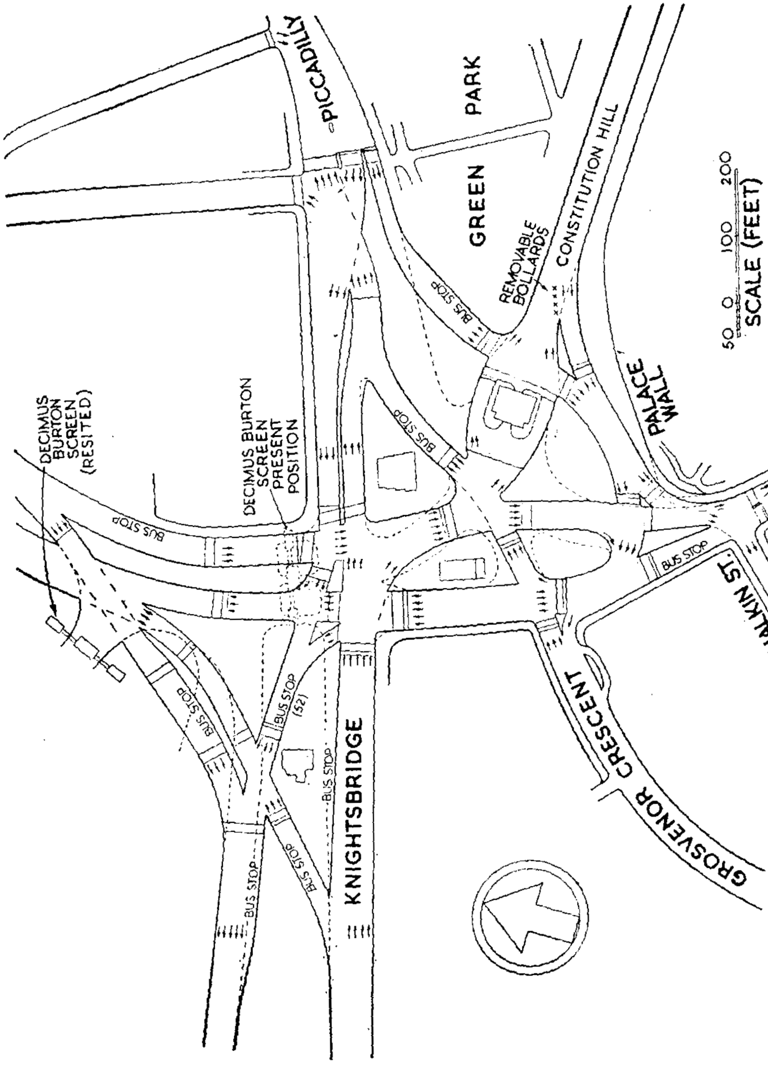
FIG 18: A FURTHER EXAMPLE FROM NEW JERSEY



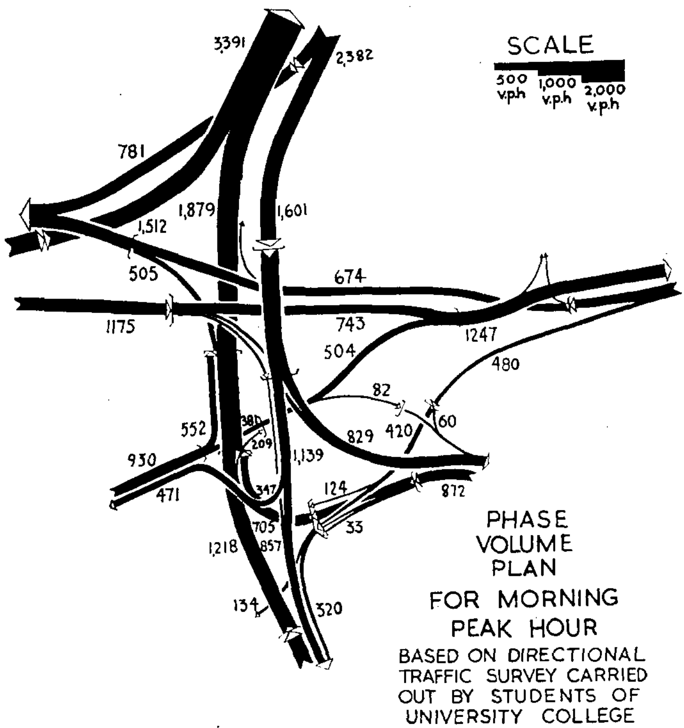
Courtesy: Roads and Road Construction

FIG. 19: HYDE PARK CORNER PHASE VOLUME PLAN

145. In an article[25] published in 1955 describing this scheme, he had quoted Mr Thomas Macdonald, formerly Commissioner of Public Roads in the U.S.A. He wrote: 'Experience is a great and important teacher; but repetitions without critical analysis of even a proven course may wear a rut so deep that other and perhaps more desirable courses are lost from view.' The roundabout had worn a deep rut in Gt Britain, and there was a danger that other and possibly more desirable courses were being lost to view.

146. He wished to quote the following letter from the late Professor-Ing. Feuchtinger:

> 'If the preference for roundabouts in your country is indeed such a great one, then I believe it is necessary to clear up between the experts a question which has got no answer by the Northolt test, namely, how great shall be the difference between possible capacity and practical capacity? The possible capacity is measurable, and has been measured in Northolt. The practical capacity is not measurable but can only be fixed. If anybody does not believe the correctness of the American figures and the figures according to Grabe and Friedrick, then —as a second step after Northolt—quite a lot of roundabouts with heavy traffic have to be tested under practical conditions. Only in this way can it be found out where the limit of the practical capacity has to be fixed, and a very interesting task for international co-operation, too. But so long as this very heavy work is



Courtesy: Roads and Road Construction

FIG. 20: PROPOSED NEW LAYOUT FOR HYDE PARK CORNER

not done, I for my part can only recommend to keep to the figures out of the U.S., those of Grabe and Friedrich, and even under the most favourable conditions not to exceed a design capacity of 1800–2000 vehicles per hour.'

147. Mr Seymer had another sentence to quote which gave the principle of directional channelization. It was: 'The very essential of traffic regulation consists in the distribution of pressure and the prevention of its accumulation at any one point.' The date when that was written was 1877.

Lt-Col. A. Borlase (Chief Engineer, Cwmbran Development Corporation) said that he had already addressed a question to the Authors, in connexion with a rather intractable problem in the new town of Cwmbran, in Monmouthshire. It was really an issue of making another attempt at designing a town centre after almost failing at the first attempt.

149. In Cwmbran they had the case of a one-way street system in the commercial centre adjacent to the major north and south road and the traffic went into a three-way T-junction. Coming from the north, the traffic would be about 1700 vehicles/h in about 15 or 20 years' time. From the south, the traffic figure was almost equal to that—1758 vehicles/h. The one-way traffic systems joining the main road traffic would add about 2300 vehicles/h at peak flow, which occurred at about 5 p.m.

150. There had been a little difference of opinion of whether the whole of the traffic coming round from the north and joining the north–south road should be filtered into the weaving lane. The proportion of this traffic wishing to go north was 18%. The amount of traffic which would continue going south but turning right on the one-way system was about 25%. Consequently, it left 57% of the homeward-bound traffic actually using the T-junction roundabout. He would like the Authors to say whether they thought it would be justified to turn the 18% of the traffic away from the junction itself, if possible by providing a separate filter lane.

151. With regard to § 11 of the Paper, he certainly concurred with the principle of regimentation of traffic at junctions, if only to correct the Indian-file user, to which one speaker had referred. What views had the Authors on the extent of surface marking in order to school drivers to utilize to the full the weaving and merging facilities provided? He wondered whether the Authors had any suggestions to put forward and whether trials had been carried out. He believed that there had been trials at Portsmouth, but he was not sure.

152. With regard to § 14, what did the Authors mean by the expression 'exceptionally high' in reference to right-hand turning traffic?

153. The Authors stated in § 16: 'For this reason it is preferable to round off considerably the corners of a square roundabout.' The meeting had already had a dissertation on that. He would merely say that he would prefer to have roundabouts to suit the general flexibility of flow. It was flexibility that was needed and he considered that the statement by the Authors was a very cogent one.

154. In § 17, the Authors referred to channelization, with which he absolutely agreed. However, he would be glad if they would say something about the phrase 'islands should be made as large as possible'. Presumably length came into that rather more than width.

155. In § 24 reference was made to signal-control at roundabouts and the use of a detector loop presumably going through some counter. He wondered whether more information was available on the use of that technique, since, although it was not necessary at the moment, one had to look ahead.

156. Contributors to the discussion had already spoken about 'give way' signs referred to in § 25. The Paper stated that they had led to an appreciable increase in the capacity over police control and that in certain cases locking had been virtually eliminated. This was not at all surprising. He believed that the 'give way' sign was to replace the 'Slow major road ahead' sign. He would like to know whether

it was to be made mandatory, and whether the Authors had any information about how the sign could be used even for experimental purposes.

157. With reference to § 35, it seemed that the gap of x seconds for right-turning traffic would depend on the speed of through traffic. Did not the Authors think that 5 seconds might well be too low in certain circumstances—if signals were used, of course?

158. One thing which he had noticed about the Paper was that the Authors seemed to deal exclusively with the capacity of the road junction and that little, if anything, was said about the adequacy of the highway capacity for vehicle queueing. It was a question not only of the number of lanes that one presented to the signal but what he called the stacking distance behind which was also rather crucial.

159. He wished also to add his congratulations to the Authors for a very fine contribution to traffic engineering.

Dr T. P. O'Sullivan (Partner, Messrs T. P. O'Sullivan & Partners) said that he proposed to raise one or two points about roundabouts and traffic signals, and he wondered whether he could have some comments from the Authors, and, if they thought fit, they might conduct some further researches.

161. When did a roundabout become a one-way traffic scheme? That interested him very much. There were some wonderful one-way traffic schemes in towns. Was it that if one had a block of buildings in the middle it was a one-way traffic scheme and if one had nothing in the middle it was a roundabout?

162. He also wondered whether the Authors could tell them something with regard to the traffic-carrying efficiency and accident proneness of a roundabout. It was surely extremely dependent on the type of roundabout. If it was something approaching a one-way traffic system or if it was a tiny circle or square, they were very different cases, and it seemed very hard to generalize between the purpose of a roundabout and the traffic and safety factors of a roundabout versus traffic signals without knowing something about what the roundabout was like. Obviously, the larger the roundabout, the greater was the facility for weaving and so forth.

163. The question of possibly just having red and green lights for traffic signals had been mentioned. He had the misfortune to travel past one or two traffic light crossings where immediately the green changed to amber, the amber came on with red. It was a terrifying experience when one was going at maximum speed. As the amber came on with the red, all the drivers went on. The drivers did not wait for the green. Why could they not have the green and red lights only? Green and red would then slow down the traffic, and red would stop it. That subject might be outside the terms of reference of the meeting, but he felt that it might be given consideration. Quite apart from that, in relation to the question of capacity of traffic signal crossings and the safety factors, the time ratio as between the changes of signals was a factor, and it was something which should be defined. Perhaps the Authors could give their views.

Mr G. B. Parker (Traffic Engineer, Messrs W. S. Atkins & Partners) said that surely the difference between a roundabout and a one-way street system was that in the weaving section of a roundabout the approaching driver was already concerned with crossing the other traffic stream, but in the one-way street system his concern with crossing it tended to arise within the street.

165. The theoretical operation of a roundabout seemed to depend on the driver being concerned with weaving within the section and not at its entrance. If weaving occurred at the entrance, one tended to get primarily a crossing action. He would like to ask the Authors: When was a weaving section not a weaving section but a crossing section? Very often it worked out as a crossing section and if crossing was efficient—and he would like to know what research had been done by the Authors

into the capacity of crossing sections—could one not save space and avoid long weaving sections which were never used as such?

166. The idea of a weaving section resulted in the term 'space sharing'. It had been pointed out that the use of both signals and 'give way' signs tended to increase the capacity of a roundabout. Both those methods really turned a 'space sharing' junction into a 'time sharing' junction, with platoons of vehicles going through in turn. When signals were installed at a roundabout, the idea was that at peak hours the roundabout would operate with signals and, therefore, would be 'time sharing', and that at off-peak hours the signals would not be in use, with the advantage that drivers were not delayed unnecessarily.

167. One had to be realistic about such things. How long should the off-peak hours last? He went through a junction every day where it was stated that the traffic signals would be in use during the peak hours only, but even in the off-peak hours the traffic signals were usually still working. If the lights were required nearly all the time, the junction could surely be improved in design by being made a proper signalized, channelized junction.

168. Concerning 'give way' signs, he would object to the idea of a general rule being imposed. As had already been pointed out, roundabouts varied in shape and had different functions. Surely, where many roads of equal importance came together, a 'give way' sign was more appropriate than where the junction was of a very major road with a relatively minor road. There a roundabout might merely be a device to separate the turning movements and give a median reservoir space for minor road vehicles.

Mr L. A. Laffan (Assistant Senior Engineer, Chief Engineer's Dept, London County Council) said that some years ago he doubted the accuracy of Dr Webster's theory that wet weather reduced the capacity of a roundabout by 10% and for a year he took observation on a weaving section. His research led to no significant result because it seemed never to rain in England. In fact, in a year, he found there were only 30 days when it rained during the morning peak while he was carrying out the experiment.

170. However, one thing which emerged was that that weaving section would run at 105% Wardrop. At this level it was very congested, but ran fairly easily at 100% Wardrop, and very easily at 95% Wardrop.

171. The results were taken over a year and were based on about 250 observations. He thought that that was sufficient to prove that any doubts which had been cast on the accuracy of Mr Wardrop's formula were quite unjustified.

Mr W. D. Hadfield (Senior Engineer, London Traffic Management Unit) said that, very appropriately, the discussion in the Institution had been largely on engineering, but outside in the street, where they had to work, a great many people were lay people; also it was lay people who controlled our governments, both national and local. In a practical world, these had to be dealt with. While some of the tools which had been described were perfectly satisfactory in the hands of skilled people, they were not always well used by lay people.

173. He had seen literally hundreds of applications for traffic signals, but he had yet to find an application for the removal of traffic signals, although the accident situation at the signal junction might be very poor; in London he had known signalled junctions with as many as 40 personal injury accidents a year, but nobody asked that those signals should be removed.

174. A difficulty about finding the safety value of traffic signals was that very commonly a junction was not as good as it might have been before the signals were installed there. When one installed signals, one not only controlled traffic but did a number of other things. Thus the signals gave a very positive and clear indication of the presence of the junction both by day and by night; also generally they removed

standing vehicles from the junction. If accident records were studied for junctions without signals, it was found that those factors often appeared to be contributory causes. Examples were 'Slow' signs which were not lit at night, and 'Halt' signs where vehicles were allowed to stand close to the junction on the main road, so that a driver trying to emerge from the halted position in the side road could see only the roof of an approaching car over the top of the standing vehicles.

175. When he enquired why these simple things could not be done before installing signals (which would delay traffic and bring their own accident potentials), the answers often contained the idea that they would cause local trouble, particularly in removing standing cars, whereas drivers naturally parked further back from a signalled junction. Sometimes, it was difficult to escape the thought that the local or national politician who might become involved in the relevant discussions was less concerned with the best method of improving the accident and traffic situation than in attaining what would be most popular with local residents, i.e. signals. Hence one must be careful in making technical tools available to people who might not fully understand them, but might never the less use them to advance their own aims.

The following contribution was received in writing:

Mr A. C. Dick (Assistant Traffic Engineer, City and County of Newcastle upon Tyne) wrote that it stated in § 39 that lost time could vary from 0 to 7 s with an average of 2 s. Could the Authors elaborate on this and say whether it was true that a 'good site' (see definition in Table 2) had a shorter lost time than a 'poor site'? The value of lost time assumed became very critical when calculating the reserve capacity of, say, an existing two-phase fixed-time signal with concurrent ambers. A calculation of the reserve capacity for an existing traffic signal installation gave the result set out in Table 7. As could be seen, the practical reserve capacity varied from 0 to 30% which would give a variation in expected life of approximately 0–5 years.

TABLE 7

Lost time per phase, *s*	Practical reserve capacity, %	Ultimate reserve capacity, %
0	30	45
1	26	40
2	22	35
3	17	30
4	13	26
5	9	21
6	4	16
7	0	11

The Authors, in reply, expressed their gratitude for the many useful suggestions. Mr Ginns' comments on the use of the square foot formula for approach widths at signal-controlled intersections and on the use of off-set central refuges were helpful and practical.

178. An example of the accident risk at roundabouts on high-speed roads was the clusters of accidents at the terminal roundabouts of motorways. Signals also presented a hazard on these roads and the Road Research Laboratory had done much work on the development of a traffic signal for such circumstances. Accident studies had shown that substantial reductions in the number of accidents could be achieved through relatively small improvements to the road lay-out, as mentioned by Mr Ginns.

179. The Authors felt that it would be beneficial to make the priority rule at roundabouts general and they awaited with great interest the results of further trials at other roundabouts.

180. With regard to Mr Clayton's suggestion that the area calculations for roundabouts and signal-controlled intersections might be misleading, the Authors agreed that each case should be treated on its merits and that widening the approaches for signal control might often consume more properties and cost more money than cutting off the corners (see Fig. 14) for a roundabout, even if the extra areas involved were the same. However, the reverse could be true in other circumstances. The use of results from experiments involving statistical data could only indicate trends and what would be likely to happen on the average if a particular course of action were taken. Such results were nevertheless of great value, and in particular the area calculations for a range of roundabouts and traffic signals had indicated some very interesting and in some ways surprising results. For example, to many people it seemed inconceivable that an intersection controlled by traffic signals could occupy as much land as a roundabout, or even more, but this was in fact the case when the proportion of right-turning traffic became very high.

181. Concerning the percentages of right-turning traffic in Table 3, each figure in the column headed 'Overall' was the percentage of all traffic entering the intersection which turned right. In the case of the five-way junction (a major fork with a minor road crossing it), it had been assumed that all the traffic which forked right from the single stem was right-turning as well as traffic which turned right on to and off the minor road. This method of designating the traffic movements tended to give rather high percentages of right-turning traffic compared with those at the other types of intersections considered. It was interesting that for this type of intersection, roundabout treatment became preferable to signals, on area considerations, at higher right-turning percentages, as shown in Fig. 11.

182. Dr Webster agreed with Mr Clayton that, in deciding what was the best type of intersection for a particular location, all the appropriate factors should be included in the economic assessment. Not all these could readily be evaluated, but if a value could be placed on the amenity aspect of a central island of a roundabout, account should be taken of it.

183. With regard to Mr Clayton's suggested amendment to conclusion (*c*) in § 83, it was felt that the original wording should be retained because it gave in simple language the basic results of the calculations which had been made. Conclusion (*e*) provided the suggestion that a complete economic assessment was really required and that would take into account the actual costs (property as well as land costs).

184. The Authors were grateful for Mr Smith's detailed comments. Many calculations of delay had been made for traffic signals and he was referred to the Road Research Laboratory Technical Paper No. 39. They could not agree with his comparison of the delays at roundabouts and traffic signals—in the particular cases quoted in Table 3 the delays for the two types of treatment were of the same order.

185. With regard to Mr Smith's reference to the results given in Table 4, the differing samples did not introduce any bias, but a result based on a small sample was subject to a greater degree of uncertainty than one based on a large sample. The interesting feature of the results in Table 4 was the linear correlation between inflow and accidents, rather than the numerical values of the calculated accident rates. The method was certainly crude and the data too old to permit a direct comparison of traffic signals with roundabouts, a procedure advised against in § 66. Mr Smith's matched results, which were later and more relevant, showed much lower accident rates for roundabouts than for traffic signals. They also suggested that lower speeds (as a result of higher flows) might account for the lower accident rates at signals in London as a whole than in Middlesex.

186. Perhaps some drivers became innocently involved in two-driver accidents at

roundabouts only after the accident had occurred. The frequency of such occurrences was not known; the same consideration would presumably apply to some extent to multi-vehicle accidents anywhere. The percentage of one-vehicle and two-vehicle accidents at traffic signals was known for Gt Britain as a whole for fatal and serious injury accidents. In 1961, 46% of such accidents at traffic signals on roads with a 30 or 40 mile/h speed limit involved one vehicle only.

187. In reply to Mr Seymer, the Crowthorne experiments on speed advisory signals had shown that under light and moderate flows the signals resulted in a substantial saving in stopping and starting and this agreed with Dr Webster's impressions of traffic in Düsseldorf. No change in delay had been observed in Crowthorne, though the traffic had consisted of 10% heavy vehicles, and not just light vehicles as Mr Seymer had suggested. As drivers grew used to the system and learned what to do, it was possible that a saving in delay could be achieved. However, under saturated flow conditions no change in capacity was found and the change in the proportion of vehicles stopping and starting was very low.

188. The film shown by Mr Seymer was interesting and it was not surprising that the flows were lower than the practical capacities as given by the Wardrop formula; the weaving sections appeared unsaturated. Figs 15–20 showing the channelized junctions were also of interest. For some reason channelization schemes were not adopted in Gt Britain as they were in many other countries including the U.S.A., although the signalized junctions which had been compared with the roundabouts in the studies reported in the Paper became simple channelized schemes when there were many turning vehicles and the capacity was high. The points of conflict were not separated as was done in some of the schemes shown in the Figures. It would be necessary to recalculate the areas of some of the signalized junctions, (*a*) with all the conflicts in one place, and (*b*) with the points of conflict dispersed, each point being controlled by a simple two-phase controller, to ascertain whether that method of channelization was beneficial in respect of the amount of land used for a given capacity.

189. On the question of the difference between the possible (as measured at Northolt) and the practical capacities, the latter were given in § 47 as 80% of the measured values at Northolt. Fig. 9 showed that the practical capacity as defined would underestimate the real capacity in about three-quarters of the cases.

190. Concerning Lt-Col. Borlase's description of the particular intersection at Cwmbran, it was not a simple case of whether or not to filter off the 18% of the traffic going north. Strictly, an economic assessment of the alternatives should be compared, which would mean calculating the area of carriageway required to accommodate all the traffic including the left-turning traffic and also the area required when the left-turning traffic was filtered off. The effect on delay should also be estimated. Other factors also affected the economic assessment, but it would be interesting to see whether the cost of the extra carriageway required for the filter was offset by the savings in delay.

191. The regimentation of traffic at junctions was common at signals and the improvement in orderliness alone was valuable. From the point of view of preventing accidents, measures which promoted uniformity of traffic behaviour were on the whole of benefit. So far as capacity was concerned, the width of lane was important. It was possible that if the lanes were less than 10 ft wide there would be an improvement in capacity compared with having no lanes, but if the lanes were wider than 10 ft there might be a reduction in capacity. However, the wider lanes would undoubtedly offer better driving conditions than the narrower ones and a compromise was usually made. It was a different matter where roundabouts were concerned. The only scheme which the Authors knew of was at Portsmouth, where the approaches to a roundabout were marked so as to give one lane for each direction of movement. There had been good reports of the scheme from local users but the Authors had no evidence of its effect on capacity. It might not be possible to gain

much extra capacity by regimenting the traffic within a weaving section because weaving, by its very nature, necessitated the changing of lanes. The Road Research Laboratory was proposing to carry out some experiments on channelization lanes within a roundabout at the Research Track at Crowthorne.

192. The amount of right-turning traffic was described as 'exceptionally high' in § 14 if it needed so much green time for it to pass through the intersection in single lane that there was too little time left in the cycle for the efficient movement of the other streams.

193. With reference to the statement in § 17 that 'channelization islands should be made as large as possible without encroaching on the desired paths of vehicles', traffic did not always use the space which was available. If there was no island or only a very small one an effective island had to be assumed for the purpose of estimating the effective length of the weaving section and the entry widths and it was suggested that the limits of the desirable paths of vehicles entering and leaving the weaving section should be drawn on the plan and this would outline the effective island. This procedure could be adopted also in designing a roundabout to give a first approximation to the design of channelization islands. It was interesting to inspect certain junctions when it had been snowing; the tracks of vehicles left well-defined 'islands' in the snow.

194. In reply to Lt-Col. Borlase's request for more information on the use of congestion-detectors in conjunction with signals at roundabouts, the Authors stated that the technique had been very successful in eliminating the locking of a roundabout at which it had been installed. The equipment was now commercially available and an article describing it was being prepared for publication.

195. With regard to the use of the 'Give Way' sign at roundabouts the Authors did not know whether it would be made mandatory, but it would be difficult to enforce; it was hard to say how much compliance with the sign was necessary for the most efficient working of a roundabout. For experimental purposes, apparently, at several sites the 'Give Way' sign would be used but at others the 'Give Way to Traffic from Right' sign, as at Millbank and Leeds, would be used.

196. The Authors had used a figure of 5 seconds as the minimum gap in the opposing traffic stream through which a right-turning vehicle, waiting at traffic signals, might pass; that was based on very scanty information. In many circumstances it would be too low but they felt that, on average, it was not far out.

197. The space for queueing at signals had been taken into consideration when dealing with the design of signal approaches and also when comparing the areas occupied by roundabouts and traffic signals. Formulae and tables had also been produced for estimating the maximum queue length in the average cycle and also the critical queue which will be exceeded only once in 20 cycles and in 100 cycles. The latter information was contained in Road Research Laboratory Technical Paper No. 39.

198. In reply to Dr O'Sullivan's question as to when a roundabout became a one-way traffic scheme, the Authors suggested that it did not really matter how one defined a particular system. Obviously, if the weaving length became far greater than that necessary solely for weaving, the road would tend to be classed as a one-way street. There seemed, indeed, to be a tendency to refer to a system with buildings in the centre as a gyratory system and to one without simply as a roundabout, but size probably had something to do with it, as in most cases the systems with buildings in the centre were much larger than those without.

199. The Authors agreed that much more research was needed into the effects on capacity and accidents of factors such as the shape and size of the central island and the width and entry angles of approach roads.

200. With regard to the problem of concurrent ambers, on the latest controllers there were at least two seconds from the beginning of the amber of the phase losing

right-of-way to the beginning of the red/amber of the phase gaining right of way, and the interval could be lengthened as necessary for safety. That was a better method than eliminating the amber and red/amber altogether. The effect on capacity of varying the length of the interval could be assessed quite readily with the rules given in the Paper.

201. The experimental omission of the red/amber phase of traffic signals had been studied in a number of towns. It was found that the general effect was to reduce the capacity of the intersection by about 6%; fatal and serious injury accidents were reduced by about a quarter but the number of slight injury accidents was not affected by the change. Omitting the red/amber increased the separation in time of the two conflicting phases and was equivalent to increasing the inter-green time; the result was of even greater benefit (see § 79).

202. In reply to Mr Parker, it would appear that the shorter the weaving section, the more it became a crossing section. In the Northolt experiments, tests were made with a policeman controlling the two entering streams and it was found that this increased the capacity of the weaving section by about 10%. The film shown by Mr Seymer indicated that weaving tended to take place at the beginning of the weaving section, but a good deal of weaving also took place later on in the section. The length obviously had some effect on the operation of the weaving section and, in fact, observations indicated that if a weaving section was lengthened the capacity was increased, although for a given increase in area greater benefit (as far as capacity was concerned) was obtained by widening rather than lengthening. Length also contributed to reducing the risk of locking by providing a reservoir for traffic temporarily unable to enter the following weaving section. The Authors had found that the capacity of large weaving sections (greater than 4000 veh/h) agreed with values deduced from the Northolt tests, whereas for smaller weaving sections observed values were about 85% of the Northolt values.

203. Regarding the use of signals at roundabouts, the Authors agreed that consideration should be given to redesigning a junction when conditions were such that the signals were required to be operating for nearly a whole day. Estimates should, however, be made of the expected gain in capacity because it was possible that in some cases the cost of redesigning might not be justified by the gains.

204. In some cases it might be detrimental to traffic flow to have a priority rule at all roundabouts but this possible disadvantage would have to be weighed against the many gains likely to result from a universal rule. If a general rule were in operation, signals together with a congestion detector, or alternatively two-level treatment, might have to be used at those roundabouts where it was particularly important to favour certain streams.

205. Concerning the effect of weather on the capacity of a roundabout, the 10% rule had emerged from the Northolt experiments, where measured capacities were 10% lower during tests in the rain. Mr Laffan's measurements of capacity at a particular weaving section were interesting and provided further confirmation of the validity of the Wardrop formula.

206. The Authors thought that Mr Hadfield had made an interesting point about the use by lay people of the kind of results given in the Paper, but they felt that in practice little could be done about it.

207. In reply to Mr Dick's question on lost time, the Authors considered that because of the variability of lost time observed it was very difficult to pick out definite trends. One would perhaps expect that 'good' sites should have lower lost times than 'poor' sites but one could envisage many cases where this would not be so.

208. The Authors agreed that the value of lost time assumed affected the value of reserve capacity, particularly if concurrent ambers were used, and they recommended that where possible lost time should be measured at the same time as saturation flow so that the best estimate of lost time for the particular site was obtained. Since concurrent ambers were possible only on the older controllers, the situation quoted

by Mr Dick would arise less frequently in the future. The inter-green period with new controllers had a minimum of 4 seconds, thus increasing the lost time per cycle by at least 2 seconds, and in many cases it would be much more. Thus, inaccuracies in the starting delay component of lost time would have a reduced effect in the future. Mr Dick had given a range of lost times in Table 7 from 0 to 7 seconds (the widest range recorded by the Authors) to show the possible range in estimated reserve capacities. However, any traffic engineer should be able to tell by inspection whether the lost time was exceptionally short or long. Thus, the resulting error in assuming a lost time of 2 seconds (or a different value if the engineer had reason to believe this to be so) was unlikely to be more than about 10% and probably would be much less.

Reference

25. N. Seymer. 'Directional channelization' applied to Hyde Park Corner. *Roads and Road Construction*, vol. 33, May 1955, p. 139.