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8105 DISCUSSION

A new procedure for capacity calculations at conventional roundabouts

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Mr G. Maycock, Transport and Road Research Laboratory
The two methods of predicting the capacity of roundabouts[9] are on different bases. For conventional roundabouts, the capacity of an individual entry may be calculated, whereas for mini and small island roundabouts only the full capacity of the roundabout can be calculated, i.e. the total throughput of traffic at the roundabout when all arms are saturated. Work currently in progress at the Transport and Road Research Laboratory is aimed at producing a single design formula which will enable the entry capacities of all types of roundabout to be predicted. The Author's work on conventional roundabouts is the first step in a series of studies. Data collected on all types of roundabout are being analysed. About 80 sites have been studied and more than 10 000 minutes of saturated flow data at roundabout entries have been obtained. In 1976 a track experiment[15] was conducted which covered 35 geometric variants of offside priority roundabouts. Track experiment data cannot be used directly in deriving design formulae, but are valuable in establishing how entry and circulating flows are related, and how those relationships interact with the geometric variables.

41. The type of analysis being used at the Laboratory is that which the Authors describe as the linear model. So far no within-site variation of entry flow with circulating flow has been observed which cannot acceptably be described by a linear relationship. However, as part of the analysis procedure, which is being undertaken on behalf of the Laboratory by Halcrow Fox and Partners, alternative flow models, including the exponential model proposed by the Authors, will be examined.

42. The Authors arrive at a pcu value of 2·5–3. Philbrick[6] indicated that a value of rather less than 2 was appropriate for both entry and circulating flows. The difference may be due to the way in which the analysis was done, or to the use of different data bases. Later analyses at different types of roundabout indicate that a value of 2 is about right.

43. I agree (§ 29) that entry width is likely to be the most significant geometric variable in predicting capacity. (For offside priority roundabouts with flared approaches, the entry width will have to be a synthesized width which takes account of the flares.) Both in the Authors' analysis and in the analysis of Kimber and Semmens[15] of the same data, the weaving section width W proved to be a useful but not significant predictor for capacity. Guidance on those geometric parameters which contribute only slightly to capacity will be provided either through the use of standard designs, or by means of correction terms applied to the basic design formula.

44. The comparison of the interim DoE formula[9] with alternative models on the basis of mean weaving section capacities in Table 2 hides an important difference. The interim DoE formula does not have any traffic descriptive terms in it, and predicts a

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slope of entry versus circulating flow which is always unity. In practice, there are few roundabout entries which have an entry/circulating flow characteristic with a slope as high as this. The average is about 0·7. Thus, the interim DoE formula will overpredict at low circulating flows and underpredict at high circulating flows. Any model which predicts entry flow from circulating flow directly should improve the prediction of the within-site variation of capacity with circulating flow.

45. Regarding the Authors' proposed design procedures, I think it might be better to incorporate pcu factors directly in the calculation. Where it is known that the proportion of heavy vehicles in the roundabout flow is low, the use of a 10% margin as suggested, in addition to the 15–20% margin allowed for level of service, may be overgenerous. Reserve capacity is a very difficult concept to apply, particularly in the case of roundabouts, because the entries are interactive. Although the Authors' definition is very reasonable, an alternative in terms of the capacity which is reached at an entry if that entry flow increases to capacity with all the other entry flows remaining constant, may be more useful. This definition has the advantage that the 'virtual capacity' so defined is that which would be required for delay calculations.

Mr K. W. Huddart, Greater London Council

Are five-minute counts a true reflection of what is really happening in terms of creating a capacity assessment at a roundabout? At present at offside priority roundabouts certain entry flows can never get in, whereas at the original Wardrop type of roundabout before 1965 circulating flow locked up. I feel that perhaps attention should be given to the case when one particular entry flow cannot enter because another entry has a large directional flow for a prolonged period. Perhaps signalling could help, although it would have to be used with discrimination.

47. The safety of a roundabout has been shown to be dependent on the size of the central island[16,17] and so I was surprised that the Authors suggest that island diameter is of relatively little concern (§ 33).

48. The amount of traffic taking the last exit before the one which was being considered in the analysis had a positive effect. Could this be helped by a lane lining system so that traffic that is about to take an exit can be better identified by entry traffic? Would this affect capacity? If traffic leaving a roundabout could be identified and directed into one lane to a greater extent, would this have any effect similar to that shown by the Transport and Road Research Laboratory at a small roundabout where the capacity could be increased by segregating all left-turning traffic into a separate lane?

49. Presumably when the original Wardrop formula was created, it was done by a similar technique of observing capacity in various sections of roundabouts all over the UK, and presumably the formula was designed to fit those observations. If the offside priority rule as applied to conventional roundabouts has caused a loss of 20% capacity, is it a real loss or is it that previous locking up has a greater impact in day to day terms than the theoretical capacity?

Mr Maycock

An experiment was carried out in 1975 to study the combination of traffic signals and the priority rule at a roundabout. The results were not very conclusive. One of the difficulties in attempting to make comparisons involving signals and roundabouts, is that the two control systems are so different. A roundabout is a first come, first served system, whereas a traffic signal—with segregated turning lanes particularly—is less flexible in the allocation of capacity to turning traffic. Further work is needed to define under what circumstances a combination of signal and priority would be useful.

51. Evidence on the basis of conversions from one form of control to the other seems to suggest that more accidents occur at traffic signals than at roundabouts. However, few studies have attempted explicitly to take traffic flow and junction operation into account, and current research is aimed specifically at identifying the difference between traffic signals and roundabouts on dual carriageways, used to control junctions

which are doing an identical traffic job. This research, which is being undertaken by Southampton University, also covers the safety of all types of roundabout design on class A and B roads.

Mr M. Kruppa, Greater London Council

Were there any zebra crossings on any of the roundabouts the Authors studied? If so, was there any correlation between the zebra crossings and the capacity of the roundabouts?

53. For the standard entry lane to a roundabout, where is the entry width taken? Just by the stop line there might be four cars stored two or three car lengths, but not more. This could affect the higher figures obtained for the shorter periods.

Dr R. J. Salter, University of Bradford

The scatter of observed values of mean entry and circulatory flows shown in Fig. 5 is typical of many observations of priority junction performance when a relationship is sought between two parameters, however significant, of the traffic flow.[18] When an attempt is made to explain the scatter in terms of additional parameters, difficulties are usually experienced in the amount of data required and the complexity of any valid relationships which may be derived. There is also the additional problem that once complex relationships are established the independent variables require to be accurately determined for use in a predictive situation. The result has been a move towards simpler generalized formulae for predicting capacity.

55. However, there is an intuitive desire to incorporate gap acceptance criteria into both capacity and delay relationships for roundabouts, for this is their mode of operation. It could be expected that the use of a gap acceptance parameter would allow the effect of illumination of roundabouts and the effect of entry angle to be considered as these factors influence the gap acceptance value.

56. Gap acceptance is a complex operation and it is by no means certain that it can be represented by a simple mean value. In research carried out at the University of Bradford it was noted that its effect on delay, and hence capacity, was considerable. In a comparison of observed delays and those obtained using a computer simulation model it was noted that the observed delays were underpredicted when a single value gap acceptance was used, were more closely predicted by a distribution of gap acceptance and most closely predicted by the use of two differing distributions—one for lag acceptance and the other for gap acceptance.

57. Capacity is most usefully expressed in terms of the flow which produces a maximum desirable value of average delay.

58. The observed conflicting effect of section width may be due to differences in the use of the circulating area. The assumption of random flow in the circulating area implies a freedom of movement through the section which may not be realized. Work at the University of Bradford is investigating the factors which influence the characteristics of traffic flow through the circulating area.

59. Using a computer simulation model of traffic flow at a conventional roundabout developed at the University of Bradford it was noted that when the circulatory flow Q_1 varied between 750 and 1300 vehicles per hour and Q_2 was operating at capacity, then the average delay per vehicle would be approximately 60 s. As the distribution of simulated delays had a standard deviation in the region of half the mean delay, it appears reasonable to assume an average delay in this region represents saturated conditions. A simulation model of a small roundabout with flared approaches indicated shorter delays in the region of 45 s when at capacity operation.

Dr Ashworth and Mr Laurence

Mr Maycock's discussion shows clearly the place of our work in relation to the Transport and Road Research Laboratory's research into roundabout capacity prediction. Mr Maycock makes the point that the evidence at present available does not suggest any

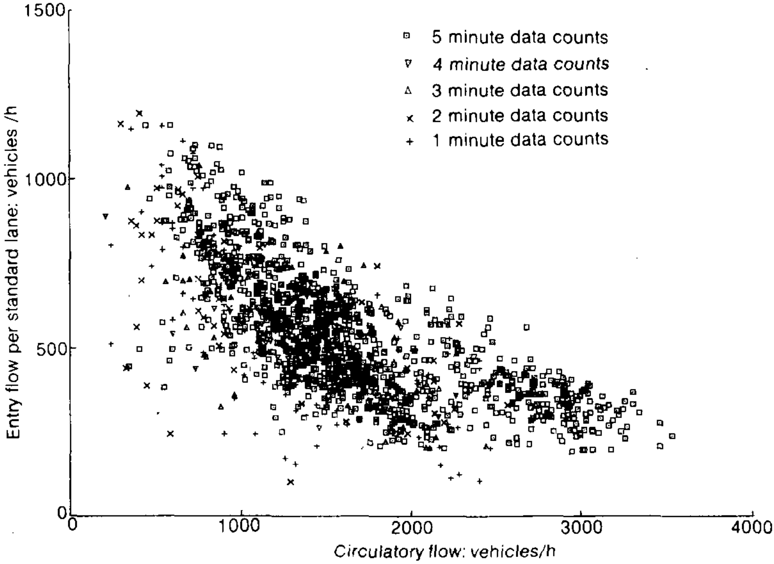

Fig. 10. Scatter of data observed at all 42 sections

significant curvature in the relationship between entry flow and circulatory flow. We accept this as far as the section mean values are concerned, but if the individual data points are considered the relationship appears to be concave upwards (Fig. 10). Although this curvature may not be significant in practice, a curved relationship implies that the entry and circulatory flows are not uniquely interchangeable as components of total flow, and ideally a prediction formula should recognize this effect.

61. We think Mr Maycock is correct in attributing the difference in pcu values between the Transport and Road Research Laboratory and our analyses to a different data base and a different method of analysis. Apart from Philbrick's data[6] including the five-minute observation periods where entry queueing was continuous for only four minutes, which we had deleted, his analyses were based only on data from our initial 21 sections. Also, in deriving an average pcu value for heavy vehicles in § 20, we included only values from the 14 sections which showed a significant relationship between the percentage error in prediction and the percentage of heavy vehicles in the entry flow. The average pcu value from all 42 sections studied was 1·99.

62. Mr Maycock suggests that it might be better to incorporate pcu factors directly in the calculations rather than use the design procedure in the Appendix with corrections for large proportions of heavy vehicles. The design procedure was presented in this way to follow the practice reflected in recent technical design memoranda.[9, 19, 20] We agree that if the effect of heavy vehicles on entry flows can be determined precisely it would be better to allow for this directly by using pcu values in the calculations.

63. We also agree that Mr Maycock's suggested alternative reserve capacity definition may be more useful in certain cases. The method presented in the Paper was based on procedures such as described by Webster and Cobbe[21] who identified the entry which will reach capacity first by assuming a uniform rate of traffic growth on all approaches. If traffic flows and turning movements do not increase uniformly throughout the junction, this procedure has to be modified.

64. Mr Huddart asks if five-minute counts provide a true reflection of operation

when assessing roundabout capacity. The five-minute duration was chosen principally for convenience in data collection. Short counts, such as those lasting one minute, will result in more points on a plot of entry flow against circulatory flow, but will show more scatter because of the effect of greater variations in driver behaviour likely in a short interval. By adopting a five-minute duration we were aiming at a compromise. We think that a five-minute duration provides a realistic assessment of operation. The data in Fig. 10 show that there were few occasions where the circulatory flow reduced the entry flows to less than 250 vehicles/h per lane, indicating that it is unusual for the entry flow to be severely restricted by a high circulatory flow over time periods of five minutes or longer.

65. However, there are cases where entry capacity is insufficient, and extensive queueing occurs upstream. The northbound exit at junction 34 (Tinsley Viaduct) on the M1 suffered this problem with traffic queueing back from the roundabout on to the M1 itself. Traffic signals operating only during the morning peak were installed at the roundabout entry and removed the problem.[22] A similar problem on the M4–A355 junction was successfully overcome by using a left filter lane.[23]

66. Mr Huddart comments on our statement that central island radius does not appear critical (§ 47). We recognize that central island diameter is particularly important in roundabout safety. However, this is mainly true in small-island roundabout design, where the island must slow down approaching traffic and prevent a clear run through the junction. In conventional roundabouts—the subject of the Paper—island diameter is usually much larger than the minimum required from safety considerations. § 33 was intended as a comment on the effect of central island radius on section capacity, which does not appear critical in this context.

67. The suggestion of a lane lining system to help entering traffic identify vehicle paths within a roundabout, and thus possibly improve entry capacity, has been tried in practice. Bennett[4] made suggestions on these lines, and a spiral lane marking arrangement was in use in August 1972 at the Plough roundabout in Hemel Hempstead before the Transport and Road Research Laboratory experiments which started there in May 1973. We are not aware of any published data on the effects of these markings, and can only assume that—because they are not used more widely—they have been only limited in their success.

68. Mr Huddart wonders whether the 20% loss of capacity apparently resulting from the change to offside priority operation is a true loss. We consider that it is—providing the original form of operation did not lead to locking. The public road trials of the Wardrop formula[8] show that the observed capacities were on average 85% of those predicted. It was also suggested then that 80% of the predicted value should be used as a practical value to allow for the effects of interaction between sections and adverse weather conditions.

69. Figures 3 and 4 show that most of the data are well below the observed = 80% predicted capacity line. This suggests that the introduction of the offside priority rule has led to a reduction in weaving section capacity. In practice this is not true, because under the original form of operation roundabouts frequently became locked when flows neared capacity. This caused capacity to fall substantially below that predicted by Wardrop. In this context, introduction of offside priority operation has been beneficial,[24] for although the theoretical capacity may have been reduced, it can now be achieved continuously, unless the roundabout is affected by traffic conditions downstream of the exits.

70. In reply to Mr Kruppa, there were zebra crossings on or near the entry to several of the sections studied. However, at all these sections there was little or no observable effect on traffic movement caused by pedestrians using the crossing. This followed from the criteria initially laid down for site selection, as we wanted to eliminate this variable from the data in order to simplify the analyses. In practice, it is likely that higher pedestrian flows would adversely affect entry capacity and some allowance should then be made for this factor.

71. Entry width was taken as the perpendicular distance from the intersection of the offside kerb (or white line marking the offside limit to the entry) and the give way line to the nearside kerb (e_1 in Fig. 1). As there was no appreciable flaring on any of the entries studied, this was a measure of the upstream road width which determined the rate of arrival at the give way line. Where flared approaches are used this measurement would be misleading and an effective entry width would have to be determined.

72. Dr Salter comments on the use of a single gap acceptance parameter in the formula. While it is likely that introducing a more complex relationship would explain more of the variation, it would be a move away from a simple formula which is easy to use in practice. There could also be problems in determining the values of any additional parameters required to apply the formula to predict capacities of proposed roundabouts. Unless relationships were determined linking such parameters with section geometry or traffic movements, the designer would have difficulty in selecting suitable values. It would also be necessary to determine values at existing roundabouts before reserve capacities (however defined) could be calculated.

73. As we wanted to examine capacity prediction at a large number of different sections in a short space of time, it was felt impractical to collect additional data on gap and lag acceptances. Our work therefore was concerned principally with explaining observed variation in section flows in terms of geometry and flow parameters; we did not examine explicitly gap acceptance behaviour at the give way line.

74. Dr Salter raises an interesting point in suggesting that the conflicting effect of section width may be due to differences in the use of the circulating area. It is certainly possible that the position of the circulating vehicles across the circulatory width e_2 could affect the entry flow. This was partly investigated by the within-section analysis of %RT in the circulatory flow, but we could not look at this in more detail as we had no data on lateral positioning of the vehicles in the circulatory flow. The analyses which were perfomed did not reveal any evidence of such an effect.[10, 14]

75. We accept that the assumption of random arrivals in the circulatory flow may not always be valid, but it seems a reasonable assumption for the larger layouts with longer sections.

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