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**CAPACITY OF SINGLE-LEVEL INTERSECTIONS**

by

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# CAPACITY OF SINGLE-LEVEL INTERSECTIONS

## ABSTRACT

Full-scale experiments on the Road Research Laboratory track and on public roads have shown simple and economical ways of improving the capacity of, and reducing delays at, single-level junctions of a given size.

With any method of control the highest capacity in a given area was achieved with a layout providing the greatest width for each movement particularly at the point of entry into the junction.

At 4-way intersections with traffic signals the best results were obtained with non-hooking right turns and cycle times shorter than one minute.

With the priority-from-right rule the highest capacity was obtained with a marked deflection of the traffic to the nearside on entry and a very small roundabout central island.

The track experiments at 4-way symmetrical intersections with symmetrical traffic demand have shown little difference in the capacity obtainable with the best traffic signals or offside priority arrangements.

The public road experiments at 3-way, 4-way and 5-way junctions, previously controlled by traffic signals or conventional roundabouts, have shown improvements ranging from 20 to 35% within the same outer kerbline. This was achieved with a roundabout central island smaller than one-third of the circle inscribed within the outer kerbline and entrances brought forward to afford a greater width.

## I. INTRODUCTION

As well as being the location of the majority of accidents, single-level junctions are the main bottle-necks of road networks and the cause of most delays. This is particularly true in towns because the roads there are more heavily loaded and the junctions closer together. It is also in towns that the difficulty and cost of making the junctions larger or of building them on several levels are the greatest.

At the same time it is apparent that the existing area occupied by junctions is not always efficiently used for moving traffic even when the junctions are saturated. This is true at junctions of all types whether controlled by traffic signals, roundabout or major/minor priority system. The introduction of the 'Give way to traffic from the right' rule at roundabouts in Great Britain<sup>(1)</sup> in 1966 made a significant contribution to the operating efficiency of roundabouts, but there is still further scope for improvement.

Much effort is therefore being given at the Road Research Laboratory to finding ways of making better use of the area available at junctions in order to increase their capacity. The research is mainly empirical by means of full-scale experiments on the Road Research Laboratory's test track and on public roads.

## 2. TRACK EXPERIMENTS

The track experiments carried out so far<sup>(2)</sup> have all been at the right-angle intersections of two two-way roads of equal width.

These intersections were laid out with movable road furniture and vehicles were driven through them from each approach according to rules made clear to the drivers by the layout, signs, markings, and written and verbal instructions. The test drivers were members of the public who came with their cars in answer to press advertisements. Buses were also included in some tests. A test in progress can be seen in the aerial view shown in the photograph.

After passing through the intersection each driver was given a signal to turn left, go straight ahead or turn right, at his next passage through the intersection. During the tests queues were maintained in all the approaches by transferring vehicles from one arm to another when necessary.

The main criterion for comparing different intersections is their full capacity, defined as the total discharge of vehicles through the intersection from queues in all approaches, ie, when the intersection is fully saturated. This criterion has been adopted because the condition of full saturation can be most consistently reproduced in successive tests and the corresponding full capacity is less dependent on the pattern of traffic demand than the capacity under lower degrees of saturation. Furthermore, full capacity, as defined above, is the most relevant and important quantity at real junctions on overloaded networks.

The many factors which can affect the capacity of junctions, such as size, shape, internal layout, method of control, proportion of turning movements, etc. were represented for convenience by ten parameters which were varied one at a time through their useful range in successive tests.

The parameters concerning the size were the basic road width and the area of widening, defined as the area of intersection outside the basic cross formed by the two intersecting roads. Seven different shapes of outline were compared for one particular area of widening. The methods of control included different forms of priority, mainly the offside priority\*, and traffic signals with hooking and non-hooking right turns with cycle times varying from 16 to 64 seconds.

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\* 'offside priority' means giving way to vehicles from the right in countries with the left-hand rule of the road (or giving way to vehicles from the left in countries with the right-hand rule of the road).

To detect possible interactions between different parameters, the variation of one parameter had to be repeated for different sets of values of the others, but in the time available so far, only a limited number of such variations have been possible.

The capacity was assessed by counting the vehicles leaving the junction every minute by each exit, where the greater separation between successive vehicles makes counting easier and more accurate than on entry. To reduce the possibility of undetected errors, counting was done by three independent methods:

1. push-button, telemetry, computer,
2. hand-tallies, pencil and paper
3. cine-record.

### 3. RESULTS

Because of possible experimental errors no undue significance should be attached to single results but the trends shown by a number of consistent results are probably true. Also conditions in the track experiments differed from those on public roads in several respects: full symmetry of layout and traffic operation, drivers' briefing and concentration, absence of pedestrians, appearance of layout, etc. The value of the experimental results is therefore not so much in the absolute capacities observed but in the relative efficiency of different arrangements. Furthermore it was not possible in the time available to test all the better arrangements in all the different shapes of outline. It is therefore quite likely that the capacity observed in some of the outlines could be improved more than in others. The order of merit shown in Figure 1 should not therefore be taken as accurate in detail but as an indication of a trend which is probably true.

From all the tests carried out it is evident that a major factor affecting the capacity of an intersection is the effective width of entry from each road. This is not unexpected because the intermittent discharge from a saturated road into a junction clearly has to be on a front much wider than the basic road in order to provide a similar capacity. This basic principle serves as a guide in the experiments on junction capacity and in the development of improved junction designs where many factors have to be considered to make the principle effective.

Some of the main experimental results can be seen in Figures 1 and 2.

The eight intersections shown in Figure 1 are on roads of the same width of 9.8 metres. The small intersection on the left has a small area of widening of  $32 \text{ m}^2$  formed by a kerbline radius of 6.1 metres, and the other seven intersections of different shape have the same large area of widening of  $1550 \text{ m}^2$  equivalent to a kerbline radius of 42.7 metres, in different shapes of outline. The capacity values shown are the highest obtained with the respective methods of control in each outline.

The highest capacity with traffic signals and with the off-side priority respectively was virtually the same and was obtained in the same shape of outline shown in Figure 2. The widening consisted of an asymmetrically-tapered flare at a slope of 1 in 4, providing much more width on entry than on exit.

In general it seems that vehicles, starting from a wide front on entry can be merged through a narrow exit without difficulty or congestion if the rate at which their passage is narrowed downstream from the stop-line or give-way line is no greater than the rate of widening up to that line.

The differences between the highest capacities obtained with traffic signals and the off-side priority respectively in the different outline shapes were usually not large compared with the effect of some other parameter variations. The differences were particularly small in the three best shapes. This is supported by an apparent resemblance in the rhythm of operation where the best traffic signal systems ie, with fairly short cycles, appear to excite a natural frequency in the change-over of right-of-way similar to that under the off-side priority system. However, traffic signals have shown some advantage in the parallel-sided approaches while the off-side priority showed some advantage in the widely-flared approaches.

With traffic signals, the highest capacity in a given outline was usually achieved with a cycle-time shorter than 1 minute, non-hooking right-turns and a lane or channel for the right-turners guiding them to the right side of the road axis before entry (ie off-setting the 'centre' line, see Figure 2). With hooking right-turns the capacity was usually lower by about 10 per cent or more. The signal cycle time giving the highest capacity tended to be lower as the flare on the approaches became wider and shorter.

With the offside priority several track experiments have shown that the capacity of roundabouts of conventional design, ie with a fairly large central island and a relatively narrow circulating road around it, could be improved by reducing the diameter of the central island to about one-third of the diameter of the circle inscribed within the outer kerb-line of the roundabout. With a further reduction of the central island and no positive means of deflecting vehicles to the nearside, vehicles tended to form a nucleus of congestion around the small island which could reduce the capacity. This seemed to be due to drivers' difficulties in observing fully the offside priority in this situation. However, by deflecting the traffic to the nearside on entry this congestion could be prevented and the capacity could be increased still more by reducing further the diameter of the central island to almost nothing.

Thus it seems that, in some circumstances at least, the function of a normal roundabout central island of helping the circulation by separating opposing movements can be performed more efficiently by a suitable deflection of the traffic to the nearside on entry. Like the central island this deflection also serves to control the speed of entry to a safe level. This important aspect of design will be studied in more detail in future experiments.

The highest capacities obtained in intersections of different size regardless of shape, internal layout and method of control, can be related approximately to the dimensions by the following simple formula:

$$q = k (\Sigma w + a)^{1/2}$$

where  $q$  is the capacity in pcu/h

$k$  is an efficiency coefficient which happens to be about 100 pcu/h/m for the highest capacities  
 $\Sigma w$  is the sum of the basic road widths in metres used by traffic in both directions to and from the intersection

a is the area of widening in square metres, ie the area within the intersection outline including islands if any, lying outside the area of the basic cross-roads.

The capacity given by the above formula with  $k = 100$  can be regarded as the potential capacity obtainable in a given size of intersection under the almost ideal conditions of the experiment and an optimum kerb outline. At most junctions on public roads the capacity to be expected would be appreciably lower, ie  $k < 100$ .

#### 4. EXPERIMENTS AT JUNCTIONS ON PUBLIC ROADS

The design principles evolved from the track experiments have now been tried in experiments on public roads at three important junctions of three, four and five roads respectively<sup>(3)</sup>. A similar procedure has been followed at the three sites:

1. 'Before' observations of flow, delay and degree of saturation before any change of layout or method of control.
2. Removal of all islands, bollards, etc, to provide a large unobstructed area within the outer kerblines.
3. Tests of the full capacity of different layouts marked with movable road furniture, (and of different methods of control at one site) each test with similar observations as before.
4. Choice and establishment of a permanent layout.

As in the track experiments the full capacity was taken as the free discharge of vehicles through the junction from queues in all the approaches. This condition of full saturation was reached naturally during peak periods at the three junctions in the 'before' conditions. However, when the capacity was increased by improvements in the layout, full saturation could be achieved only by holding up the traffic for a short time in the approaches and then releasing it all at once to permit short measurements of the flow while the full saturation lasted. This procedure was repeated several times for each layout and the average discharge during all the periods of full saturation was taken as the full capacity of the layout.

The first experiment was at a three-way junction in Peterborough, previously controlled by traffic signals. After testing different layouts with different sizes and positions of the central island the arrangement shown in Figure 3 with a 3 m diameter central island in an inscribed circle diameter of 29 m was found to give the highest capacity, 4700 pcu/h against the full capacity of 3700 pcu/h previously observed with the traffic signals.

Observations of journey-times showed that the average delay – the difference between actual journey-times under different levels of flow and the average free-running time of unimpeded vehicles – was reduced to less than half at all levels of flow. This was estimated to represent an annual saving of about 50000 vehicle-hours.

The zebra crossings were installed temporarily for the experiment and one of them has since been made permanent. Initially some pedestrians claimed that it was more difficult to cross the road with the roundabout than with the previous traffic signals, but a detailed analysis of the time-lapse cine-record has shown that average pedestrian journey-times were in fact shorter with a roundabout. The difficulty seemed to be due to the change of procedure, affecting mainly older people, and to pedestrians having to make their own decision when to cross the road instead of being guided by the traffic signals. Eventually after a few months all road users, pedestrians as well as drivers, were reported to be satisfied with the overall improvement.

An earlier study of five junctions where traffic signals had been replaced by roundabouts or vice-versa, has shown that the risk of injury accidents, particularly of pedestrian injury accidents, was appreciably smaller at roundabouts than at signalled junctions<sup>(4)</sup>.

The second public road experiment was at a five-way roundabout in Cardiff shown in Figure 4. The former egg-shaped island, about 30 metres across, was eventually replaced by a small island 5 metres in diameter within an inscribed circle diameter of 46 m and the capacity was increased by nearly 25 per cent.

Two main problems were encountered there. Drivers seemed unwilling at first to spread out into the new wider entrances provided. The other more basic problem was the number and variety of conflicting movements which seemed to restrict the benefit of the extra area offered. Although the final layout shown in Figure 4 has overcome to some extent the above difficulties, further study of these problems, particularly the second, is called for.

At these junctions in Peterborough and Cardiff the mini-roundabouts which gave the best results in the experiments have been made permanent and have now been in operation for 18 and 12 months respectively. Precise accident records before and after the introduction of the mini-roundabouts are not available but, according to the Local Authorities concerned, neither junction had a high accident rate before the experiments and there has been no significant change since then.

The third experiment was at a four-way roundabout in Hillingdon about 20 km west of London on a main radial road. The site was made available for the experiment at a suitable intermediate stage during a conversion from roundabout to traffic signals.

A wide variety of arrangements were tested including traffic signals with hooking and non-hooking right-turns and different cycle times, and roundabouts with different sizes of central island and different designs of entrances. Because of the number of major changes of layout and method of operation, relatively less time was left available to optimise, and to accustom drivers to, each basic arrangement.

In the event the arrangement which gave the highest capacity – about 35 per cent more than the original – was a roundabout with a 15 metre diameter island in an inscribed circle diameter of 46 m. The fact that the optimum size of central island in this case was much greater than at the other experimental sites may have been due to an incorrect design of the entrance deflection in conjunction with wider roads than in the other cases. This is also a matter needing further study.

The flow of pedestrians at Hillingdon was much heavier than at the other junctions, particularly across the wide roads. To minimise interference between vehicles and pedestrians at these crossings, several intermediate refuges were placed across the mouth of these roads and this measure seemed to be effective.

The original plan to instal conventional traffic signals with widened approaches was in due course completed after the experiment and is reported to be working well although no detailed comparative assessment has yet been made.

The highest capacities obtained with the experimental designs at the three sites can be compared with the best obtained on the track by means of the efficiency coefficient  $k$  in the capacity formula given earlier. A maximum  $k$  value of about 100 was obtained in the track experiments whereas it was about 90 at the three-way junction in Peterborough, 65 at the five-way junction in Cardiff and 70 at the four-way junction in Hillingdon. The above differences are not surprising considering the differences in shapes, number of roads, crossing movements, pedestrian movements, etc., which are not taken into account in the simple formula.

## 5. CONCLUSIONS

While much more research remains to be done to find out how various types of junction can best be treated and how to predict their capacity, the results already achieved show that the new design techniques can offer substantial improvements in capacity in a given area at a small fraction of the cost of improving the capacity by conventional methods.

The main aspects of the new techniques are:

1. Fuller exploitation of the offside priority which can provide a capacity comparable to the best traffic signal systems.
2. Shape and layout of junction to provide more width for the different movements, particularly on entry, and separation of opposing hooking movements.
3. Non-hooking right-turns and fairly short cycle times at signalled cross-roads.

Since junctions are the main bottle-necks of road networks, the potential economic benefits of the new techniques are considerable.

## 6. ACKNOWLEDGEMENTS

The Road Research Laboratory wishes to acknowledge the help and cooperation received from the Peterborough, Cardiff and Hillingdon Authorities during the full-scale junction experiments.

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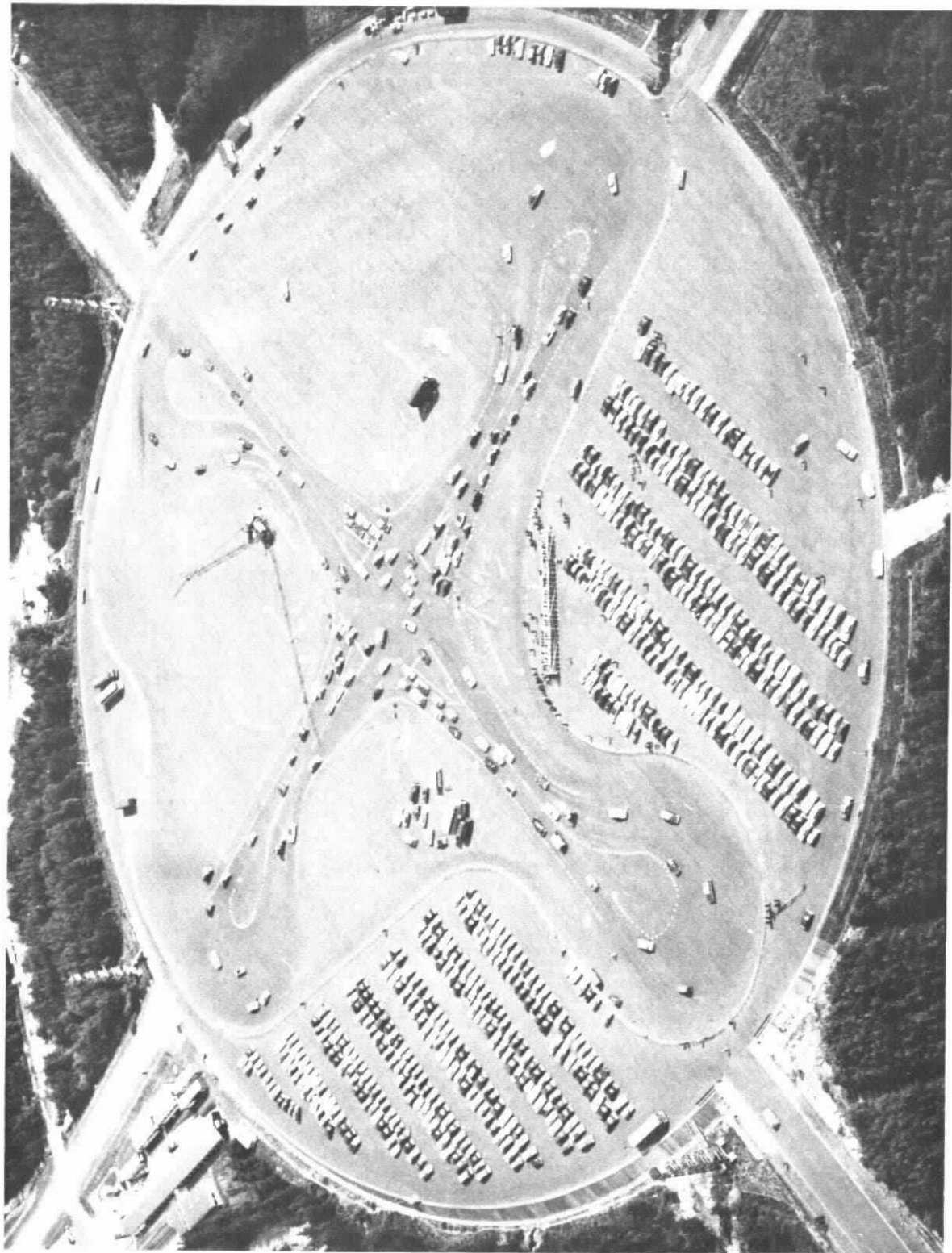


PLATE 1 Full-scale traffic experiment, Road Research Laboratory  
Test Track, Crowthorne  
Neg. No. R66/67/12

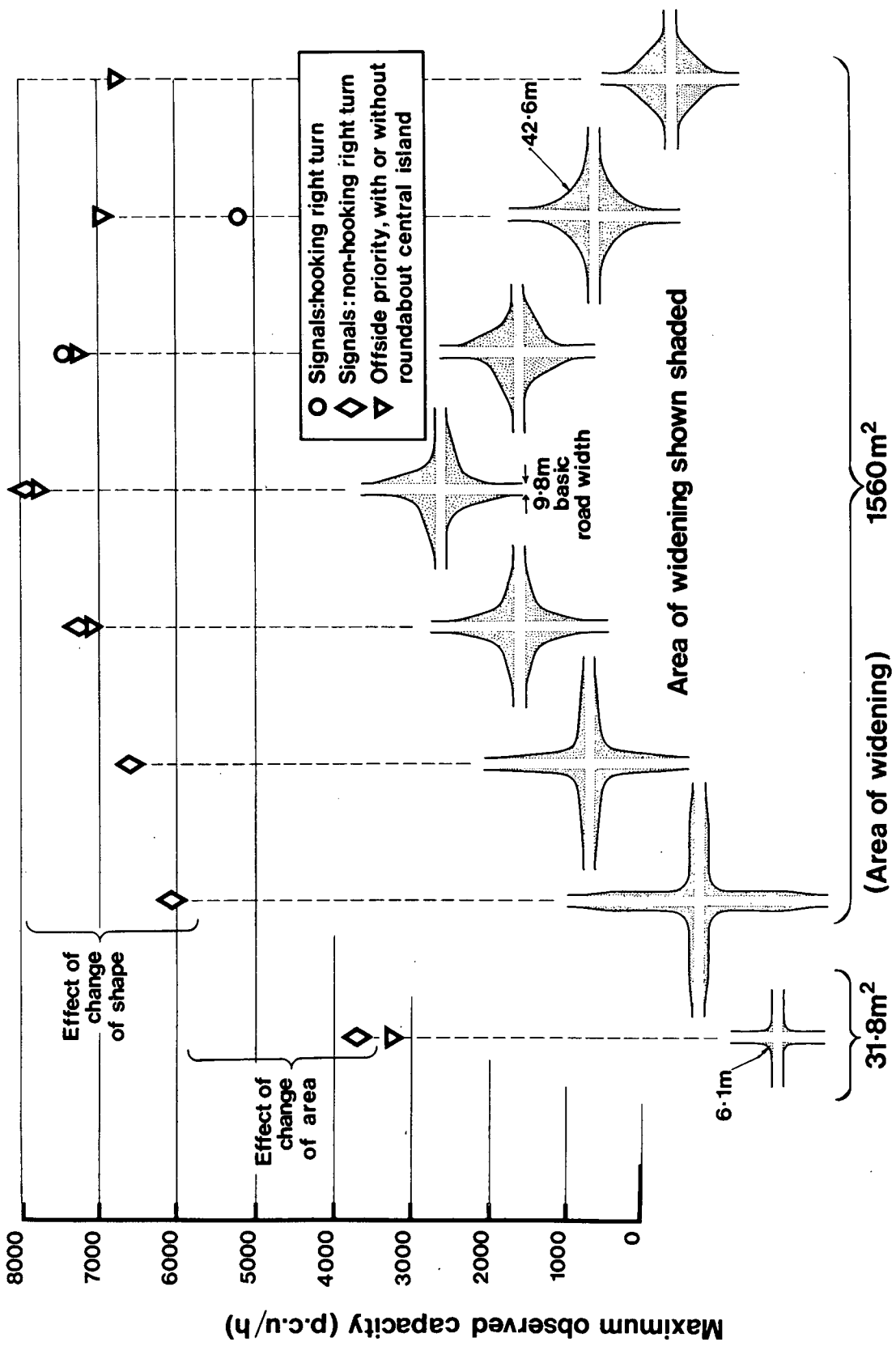


Fig. 1. EFFECT OF AREA AND SHAPE OF WIDENING FOR THE SAME BASIC ROAD WIDTH

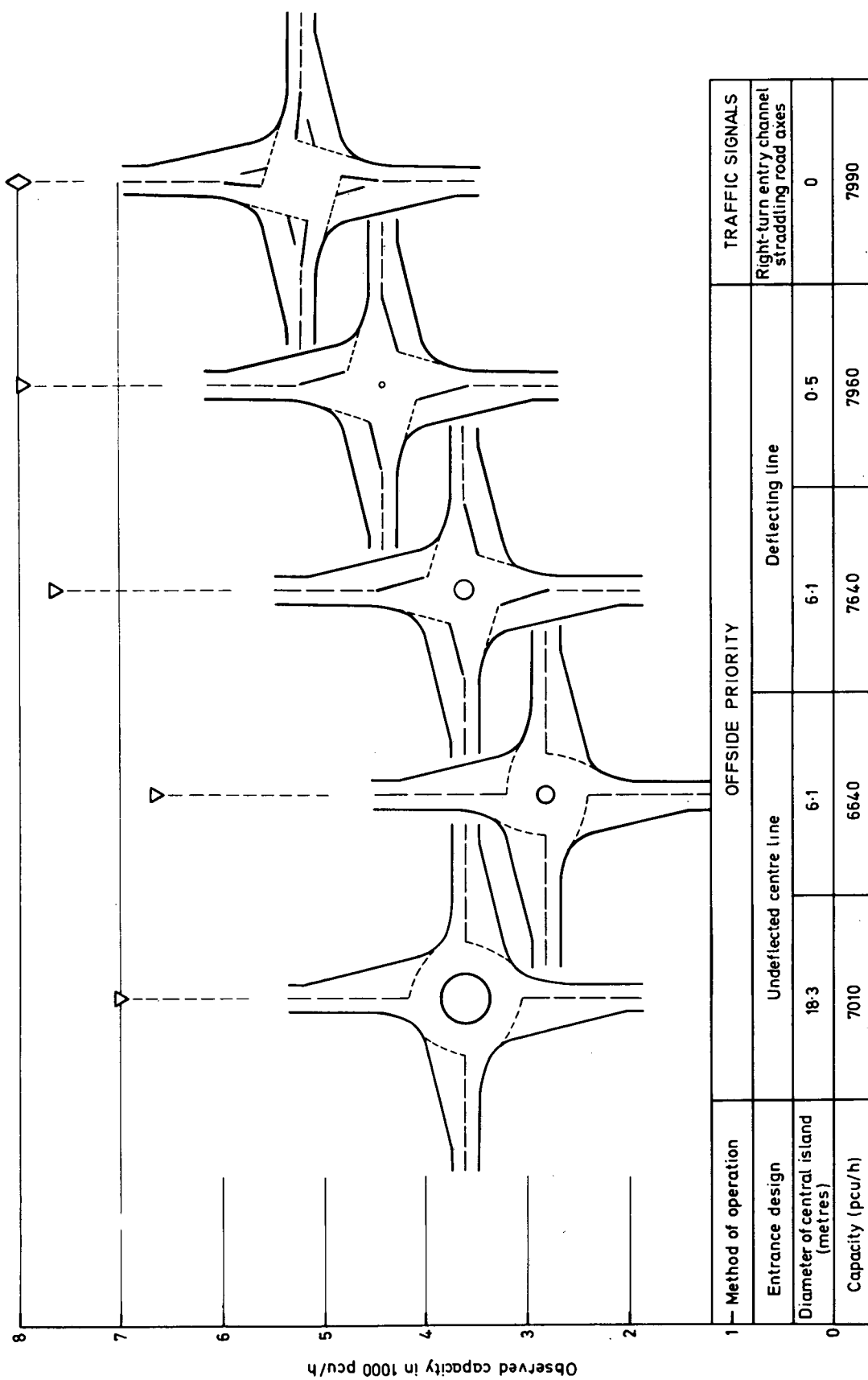
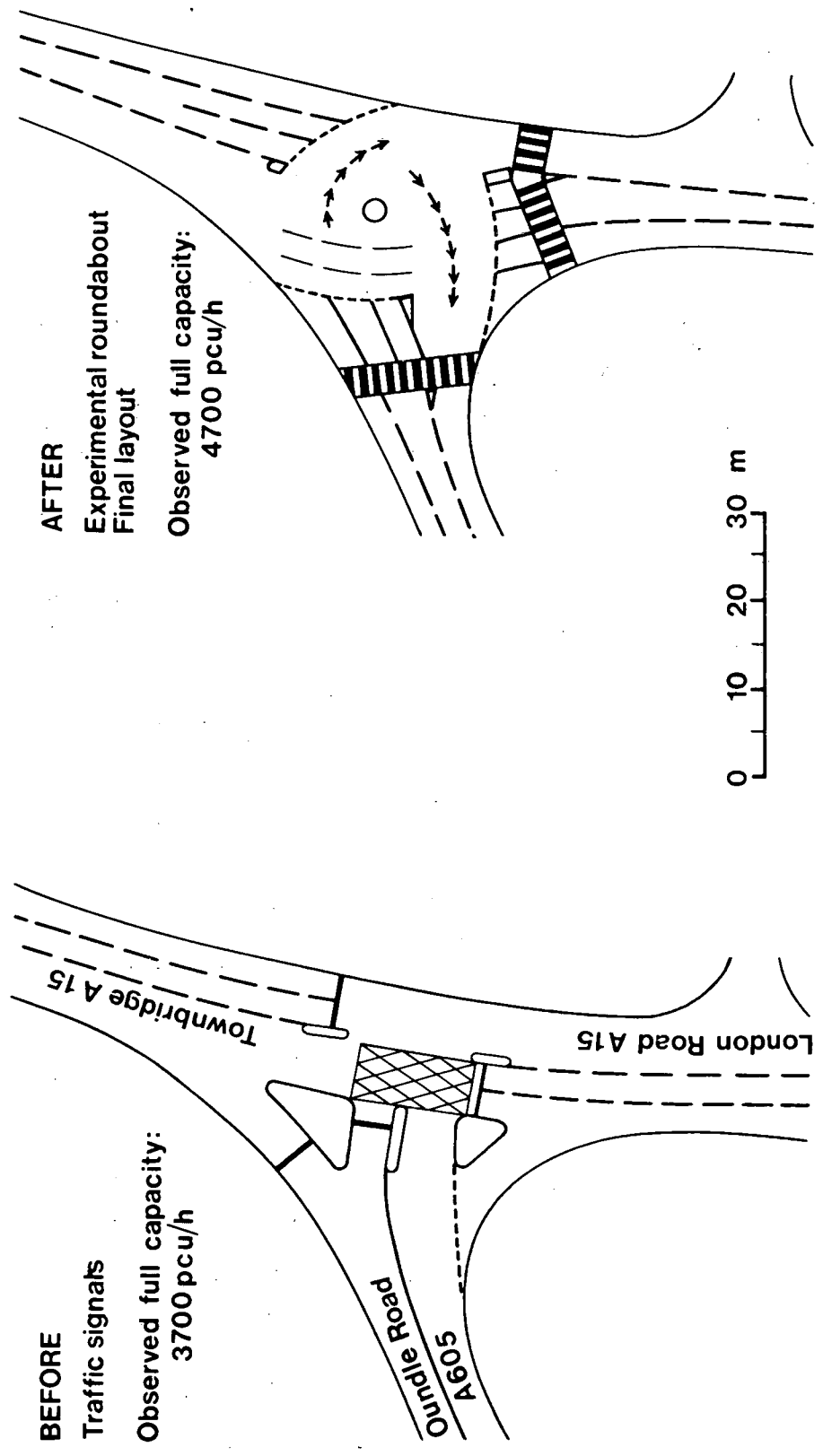


Fig.2. EFFECT OF VARIATION OF INTERNAL LAYOUT AND METHOD OF OPERATION IN 'BEST' OUTLINE SHAPE



Full capacity= Total outflow while there are queues in all approaches

Fig. 3. PETERBOROUGH JUNCTION EXPERIMENT - OCTOBER 1968

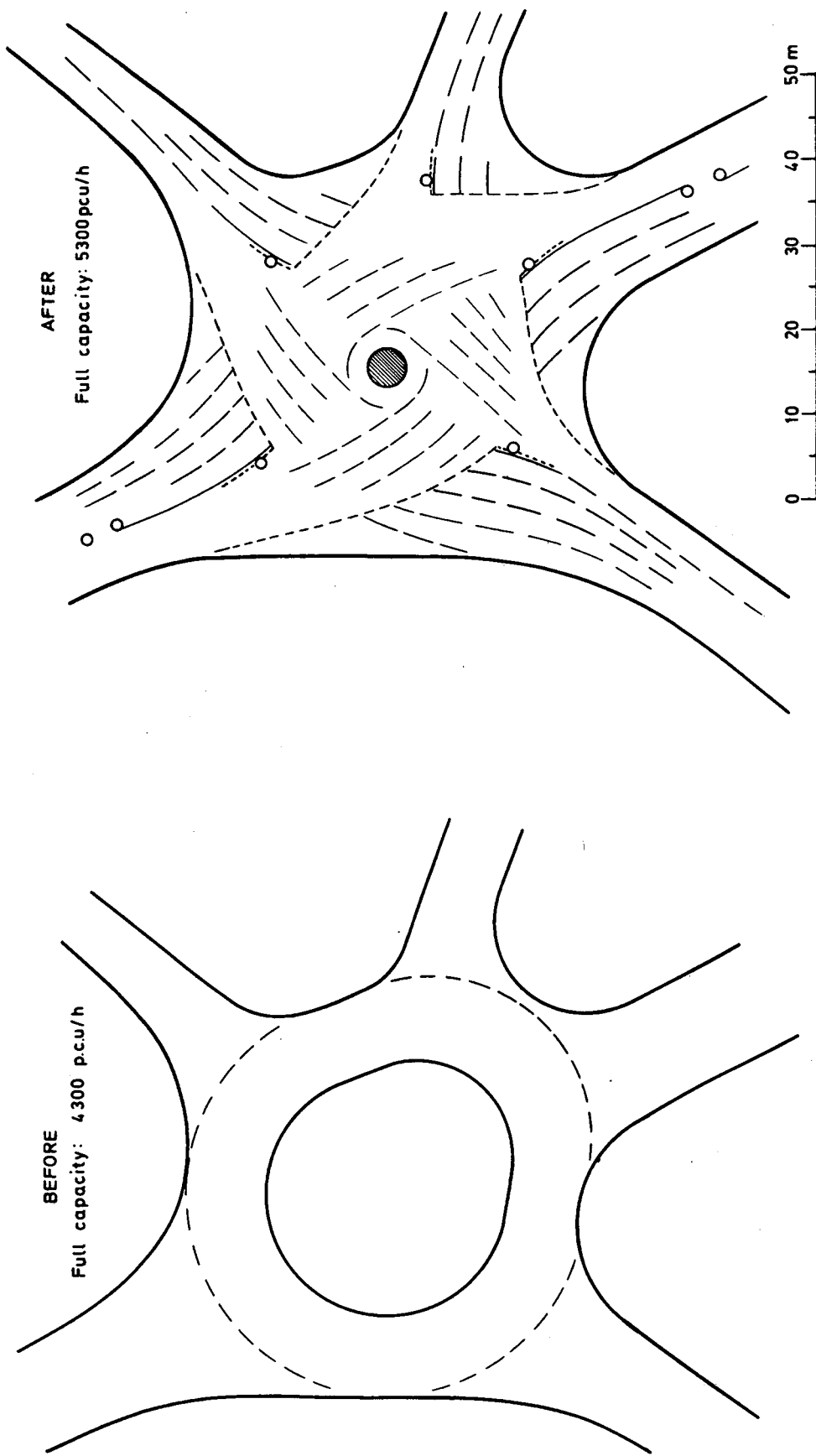


Fig. 4. CARDIFF ROUNDABOUT EXPERIMENT - MAY - JUNE 1969

Printed at the Road Research Laboratory, Crowthorne, England.

## ABSTRACT

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