The capacity of some major/minor priority junctions

by

R. M. Kimber
63 readings
Mean : 3.94 MN/m²

Values shown are estimated compressive strength (MN/m²) from projectile penetration

Fig. 19 PENETROMETER RESULTS: SERVICE TUNNEL FACE
(15th APRIL 1975)
Fig. 20 UPPER HEMISPHERE PROJECTION OF DISCONTINUITY ORIENTATION IN THE SERVICE TUNNEL AND BEAUMONT TUNNEL
At present, design calculations for the capacity of major/minor junctions are based on gap acceptance models which require the knowledge of the minimum acceptable time gap in major road traffic required by a minor road vehicle when joining the major road. Because this quantity is not easily measured, there is some advantage to be gained from the use of more direct methods. Traffic flow interactions have therefore been studied at five three-way major/minor priority junctions under conditions of heavy minor road demand, and the results analysed with the aim of developing simple capacity formulae.

**Definition of Capacity**

The adjacent Figure shows the six traffic movements possible in three-way junctions. The major road traffic has uninterrupted priority over the minor road streams, and thus the essential requirement in predicting the traffic performance of major/minor junctions is to be able to calculate the maximum flow capable of entering from the minor road (its 'capacity') for a given set of the four major road flows.

**Observations and Analysis**

Traffic following each of the six possible movements was counted on a minute-by-minute basis. Each count was subdivided into 'light' and 'heavy' vehicles. Observations were made under conditions of natural demand, and periods during which there was continuous queueing in the right-turning minor road stream (1-3) were used as a basis for capacity assessments. Naturally occurring fluctuations in the major road flows allowed the right-turning stream capacity to be estimated as a function of these flows. Capacity relationships for all five junctions were established, by linear regression techniques, in the form

\[ q_{13}^s = q_0 + a_1q_{23} + a_2q_{32} + a_3q_{31} + a_4q_{21} \]  

where \( q_{ij} \) is the vehicular flow from arm i to arm j, and \( q_{13}^s \) is the saturation flow (1-3).

**Effect of Traffic Composition**

The composition of major road traffic had no detectable effect on \( q_{13}^s \). Passenger car unit
factors for minor road heavy vehicles were site specific and offered little improvement (compared to a value of unity) in the accuracy of capacity prediction.

**Effect of Junction Features**

The coefficients $a_1, \ldots, a_4$ provide a measure of the inhibition of the minor road flow $q_{13}^S$ produced by the relevant major road flow; this inhibition in turn depends on certain features of the junction layout. The table summarises the results by giving the values of these coefficients pooled for all sites studied and shows how they relate to the junction geometry.

**Pooled coefficients for equation (1)**

<table>
<thead>
<tr>
<th>Major road stream</th>
<th>Coefficient</th>
<th>Pooled estimate (rounded)</th>
<th>Conditions for dependence</th>
<th>Approximate range of representation (vehicles/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2-3)</td>
<td>$a_1$</td>
<td>- 0.2</td>
<td>Two-way carriageway</td>
<td>$60 &lt; q_{23} &lt; 1260$</td>
</tr>
<tr>
<td>(3-2)</td>
<td>$a_2$</td>
<td>- 0.3</td>
<td>General</td>
<td>$60 &lt; q_{32} &lt; 1080$</td>
</tr>
<tr>
<td>(3-1)</td>
<td>$a_3$</td>
<td>- 0.3</td>
<td>No adequate major road left-turning facility</td>
<td>$60 &lt; q_{31} &lt; 720$</td>
</tr>
<tr>
<td>(2-1)</td>
<td>$a_4$</td>
<td>- 0.5</td>
<td>General</td>
<td>$60 &lt; q_{21} &lt; 300$</td>
</tr>
</tbody>
</table>

A value of 590 vehicles/hour is taken for the constant term $q_0$.

**A framework for capacity predictions**

In principle, equation (1) above, together with the appropriate coefficient values can provide a means for predicting the capacity of the right-turning minor road stream. The left-turning minor road traffic does not conflict with the major road flows $q_{23}$ and $q_{21}$, and the capacity relationship for $q_{12}^S$ should be of the form

$$q_{12}^S = q_0 + a_2 q_{32} + a_3 q_{31}$$

with $q_0$, $a_2$, and $a_3$ as before. However, values for the parameters of this equation could not be directly derived from experimental data, since the demand for this left-turn movement was not sufficient to saturate the minor road entry.

Equations (1) and (3) refer to minor road streams using separate lanes. If a single shared lane only is provided the combined capacity $q_c$ is given by:

$$q_c = \frac{q_{12}^S \cdot q_{13}^S}{(1-f)q_{12}^S + f q_{13}^S}$$

where $f$ is the fraction of the minor road demand turning left. For design purposes it is necessary to allow some margin between the capacities $q_{12}^S$ and $q_{13}^S$ (or $q_c$), which represent fully saturated conditions and thus can involve considerable delays to minor road vehicles, and the 'practical' capacity. It is normal traffic engineering practice to design to a flow level which is 85 per cent of the absolute capacity.

An extension to the case of major/minor priority crossroads is suggested.

The work described in this Digest was carried out in the Traffic Systems Division of the Traffic Engineering Department of TRRL.

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<td>12</td>
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ABSTRACT

The Report describes traffic flow observations made at five three-way major/minor priority junctions under conditions of heavy minor road demand. The results have been analysed by linear regression methods to determine the extent of the interactions between the major and minor road streams. Variations in the composition of major road traffic had no detectable effect on the total flow through the junction; effects due to variations in minor road composition were slight only. The relationships between the major and saturated minor road traffic flows are represented by linear equations which allow the minor road approach capacities to be calculated. The results provide a framework for predicting the practical capacities of three-way junctions. An extension to the four-way case is suggested.

1. INTRODUCTION

Major/minor priority junctions are by far the most common of all road junctions in the UK. It is not easy, however, to predict their traffic characteristics — in particular the maximum attainable flows and the vehicle delays. For many existing junctions, where the traffic demand is low, such information is not essential but, for new junctions and for those where the traffic volume is expected to grow rapidly, it is very important.

The operation of a major/minor junction is usually described in gap-acceptance terms, in which minor road vehicles move into naturally occurring gaps in the major road streams. The specification of a minimum acceptable time gap and associated parameters allows the calculation of vehicle delays and capacity. However, although the gap-acceptance concept plays an important part in the description of vehicle interactions, there are several difficulties when the approach is used for practical estimates. The time gaps involved vary according to the circumstances; they are not easy to measure and the capacity and delay calculations are very sensitive to the values chosen. In addition, under heavily congested conditions, the process of simple gap-acceptance may be replaced by a more interactive one in which major road vehicles adjust their headways to allow minor road vehicles to enter. This makes the measurement of the effective time gaps extremely difficult and their significance uncertain.

This report describes an approach to the capacity of major/minor junctions based directly on traffic flows: it makes no attempt to relate them to the detailed vehicle-vehicle interactions involved. During the course of ‘before and after’ studies at a series of six public road sites, where the Local Authority was changing the control from major/minor priority to mini-roundabouts, an appreciable amount of flow/delay data has been obtained. The report presents the results of an analysis of the flow interactions at five of these major/minor...
junctions with the aim of producing capacity formulae for the minor road. These formulae provide some in-sight into the flow interactions in priority junctions generally, and provide the basis for some further analysis of flow/delay relationships.

Basic definitions and objectives are given in Section 2 of the report. Section 3 outlines the observations made at public road sites and Section 4 describes their analysis in terms of traffic flow interactions. The results are summarised and extended in Sections 5 and 6 to provide a more general representation of the capacity of major/minor junctions.

2. DEFINITIONS AND OBJECTIVES

Major/minor junctions have a complex hierarchy of priorities, both implicit and explicit. Figure 1 shows the six movements to be considered for a three-way junction. Each movement has associated with it a traffic stream and a corresponding flow, measured either in vehicles or passenger car units (pcu's) per hour. The major road streams have uninterrupted priority and can be regarded as the controlling flows. The left- and right-turning minor road streams give way to all of the major road flows, with the possible exception of the left-turning major road flows (3–1), and thus are the controlled flows.

The requirement, therefore, in designing major/minor junctions is to be able to predict the maximum flow capable of entering from the minor road for a given set of the four major road flows (with the left- and right-turning minor road streams treated either individually or combined depending on the number of lanes available to them). The capacity is attained, by definition, when the minor road demand is sufficient to produce the maximum flow into the major road. This occurs when the minor road is saturated, ie when there is continuous queueing.

The objective of the present work is to determine from observations of saturated minor road flows and the corresponding major road flows (a) which of the above priorities generate measurable stream interactions, and (b) how the capacity of the minor road can be quantitatively described in relation to the relevant major road flows.

3. OBSERVATIONS

3.1 Sites

Table 1 gives the location and brief details of the public road sites at which observations were made. Figures 2 to 6 show the geometric layout of each site.

3.2 Patterns of Demand

Site observations were made at various periods of the day during both peak and off-peak conditions. The overall patterns of demand are shown in Table 2; these relate to the periods used for capacity assessment, ie those during which the minor road demand was saturated.

All sites were treated as three-way junctions. Observations at site 5 were confined to the 'T' junction formed by Ruscote Avenue and the A423. The traffic flow on the fourth arm of site 3 (St. James Avenue) was negligible.
3.3 Data Collection

Ideally, in order to establish the minor road capacity relationships, the saturation minor road flow should be measured for each condition of major road demand. However, public road observations are necessarily limited to those combinations of flows which occur naturally. In these circumstances a compromise must be achieved in the measurement of vehicular flows following the various movements through the junction. If averages are taken over too long a period (e.g., ten minutes), the range of flows available under conditions of natural demand is very restricted, whereas, for very short periods, fluctuations due to individual vehicles cause considerable scatter in the observations.

The present approach has been to measure the flows following each of the six movements shown in Figure 1 on a minute-by-minute basis, each flow count being classified according to vehicle type: vehicles with 3 or 4 tyres were designated 'light', and those with more than 4 tyres 'heavy'; 2-wheeled vehicles were omitted from the counts. A record was also made of the periods during which queueing was continuous on the minor approach. Minute-by-minute fluctuations in the natural demand of the major road flows produce corresponding fluctuations in the saturated minor road flows, and it is these fluctuations which have been used to describe quantitatively the capacity of the minor road.

4. ANALYSIS

The analysis has two aspects. The first is the determination and quantification of the dependence of the minor road capacity flow on the four major road streams. The second is an investigation of possible effects due to traffic composition. In the following $q_{ij}$ (1) represents the flow of light vehicles following the movement from arm i to arm j in any minute. Similarly, $q_{ij}$ (h) is the flow of heavy vehicles.

4.1 Stream interactions and capacity

The junction layout at all sites allowed separate discharge of the minor road streams ((1–2) and (1–3)) at the give-way line. Although the road space available for separate lanes at the approach was more constricted in some cases than others (particularly at site 4), this did not seem to inhibit 2-lane discharge. The right-turning movement was consistently saturated, and it was primarily because of capacity limitations for this...
### TABLE 2

Turning movements by class (1 = light, h = heavy) as percentages of total junction throughput

<table>
<thead>
<tr>
<th>Site</th>
<th>1–2</th>
<th>1–3</th>
<th>2–3</th>
<th>3–2</th>
<th>3–1</th>
<th>2–1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>l</td>
<td>h</td>
<td>l</td>
<td>h</td>
<td>l</td>
<td>h</td>
</tr>
<tr>
<td>1</td>
<td>0.2</td>
<td>0.0</td>
<td>27.5</td>
<td>6.8</td>
<td>16.0</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>2.6</td>
<td>0.4</td>
<td>10.0</td>
<td>1.8</td>
<td>31.8</td>
<td>3.9</td>
</tr>
<tr>
<td>3</td>
<td>5.8</td>
<td>0.1</td>
<td>20.0</td>
<td>4.8</td>
<td>14.8</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>10.9</td>
<td>0.3</td>
<td>19.6</td>
<td>0.3</td>
<td>27.2</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>2.3</td>
<td>0.0</td>
<td>11.2</td>
<td>0.0</td>
<td>38.7</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Mean flows during all periods of saturated minor road demand (vehicles/hour)

<table>
<thead>
<tr>
<th>Site</th>
<th>Minor road</th>
<th>Major road</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>513</td>
<td>973</td>
</tr>
<tr>
<td>2</td>
<td>375</td>
<td>2158</td>
</tr>
<tr>
<td>3</td>
<td>434</td>
<td>979</td>
</tr>
<tr>
<td>4</td>
<td>433</td>
<td>958</td>
</tr>
<tr>
<td>5</td>
<td>187</td>
<td>1201</td>
</tr>
</tbody>
</table>
movement that the conversion to mini-roundabout operation was undertaken. The left-turning minor road
demand was generally slight and saturation was rare in this case.

Gap-acceptance treatments of the capacity of a minor road stream as a function of the ‘straight-
through’ major road flow from the right predict a non-linear relationship of the form shown in Figure 7.
Owens has shown that capacity predictions made by such relationships using measured gap-acceptance
parameters agree with direct capacity measurements to well within the limits set by the variability of the data.
However, typical flow data do not by themselves support any curvature and linear approximations provide
no worse a fit to the data than the gap-acceptance expressions. The largest errors due to an assumption of
linearity are likely to arise near the intercepts on the major and minor stream flow axes, and, since the region
of interest is usually somewhere between, such errors are probably not very serious in practice.

The present data have therefore been analysed by linear multivariate regression techniques. For the
moment, the light and heavy vehicle flows are summed for each minute and the simple vehicular totals used.
Thus \( q_{13} = q_{13}(1) + q_{13}(h) \) etc. Alternative treatments are discussed in Section 4.2, where the possible effects
of variations in traffic composition are considered. In fact, the use of the simple vehicular totals is found to
be the most appropriate choice.

Since the right-turning minor road flow was always saturated and flowed independently of the left-
turning flow, its dependence on the major streams could be directly determined by fitting to the data the
equation

\[
q_{13}^s = q_0 + a_1q_{23} + a_2q_{32} + a_3q_{31} + a_4q_{21} \quad \ldots \ldots \ldots (1)
\]

(The flow \((1-3)\) is written \(q_{13}^s\) to denote that it originates from a saturated stream). An example of the
regression results compared with flow data is shown in Figure 8. Table 3 shows the values obtained for the
coefficients at the five sites studied. Each indicates the degree of coupling at any particular site between \(q_{13}^s\)
and the relevant major road stream.

| TABLE 3 |
| Regression analysis of vehicle flows. Values shown are statistically
| significant at the 5% level or better, except that marked *, which is
| significant at the 10% level. Standard errors are given in brackets. |

| Dependent | Site | Regression | Coefficients |
| variable | | constant | | |
| \(q_{13}^s\) \(\text{equation (1)}\) | | (vehicles/hr) | | |
| 1 | 637(27) | -0.26(0.05) | -0.28(0.04) | - | - |
| 2 | 560(34) | - | -0.32(0.03) | - | - |
| 3 | 594(28) | -0.27(0.05) | -0.39(0.04) | - | -0.47(0.12) |
| 4 | 532(32) | -0.15(0.05) | -0.41(0.07) | -0.12(0.07)* | -0.52(0.08) |
| 5 | 331(40) | -0.09(0.04) | -0.12(0.05) | -0.54(0.10) | - |
i. The 'straight-through' major road streams
Except for site 2, the 'straight-through' major road flows $q_{23}$ and $q_{33}$ are both important in determining $q_{33}$, the coefficients $a_1$ and $a_2$ being in the region of -0.2 and -0.3 respectively. At site 2 there was local dualling of the carriageway at the junction so that vehicles turning right out of the side road could do so in two distinct movements, by sheltering in the central reserve. This 'decoupling' of $q_{33}$ is reflected by the absence of any dependence of $q_{33}$ on this element of main road flow: $a_1$ is not significantly different from zero. In contrast, the dependence on $q_{32}$ is still well-defined. There is some suggestion of a similar effect at site 5 where there is a central 'ghost' island; $a_1$ is very small in this case ($-0.09$).

ii. The right- and left-turning major road streams
In effect $a_4$, which corresponds to the movement $(2-1)$, is only determined for sites 3 and 4 where right-turning major road traffic constituted an appreciable proportion of the total junction throughput; for these it takes values of around -0.5. For the remaining sites, $q_{21}$ was less that 4% of the junction throughput and was too small for $a_4$ to be determined. This reflects only the lower effective sample size and does not imply any fundamental difference between sites in the effect of $q_{31}$ on $q_{13}$.

The left-turning major road traffic does not compete for road space with the minor road streams and might therefore be expected to have little effect on them. However, the distinction between approaching major road vehicles about to turn left $(3-1)$ and those proceeding straight on $(3-2)$ may not always be clear to traffic waiting to emerge from the minor road, and some inhibition of minor road vehicles may result.

It is not easy a priori to say whether or not $q_{13}$ should depend on $q_{31}$, and at first sight the analysis does not seem to throw much light on the problem: although $q_{11}$ is appreciable in all cases, sites 4 and 5 show a dependence, whereas sites 1, 2 and 3 do not. However, the $(1-3)$ corner radii of the junctions seem to be relevant; they are 70, 35, 25.5, 15.1 and 11.5 metres for sites 2, 1, 3, 4 and 5 respectively, so that the inhibiting effect occurs only for the tightest corners. This implies that the nominal left-turning lane at site 5 was ineffective, whereas at site 3, where there was no such marking, the separation of left-turning major road traffic was still effective. Clearly the dependence on $q_{33}$ is not completely explained, although it seems reasonable to conclude that an interaction may take place unless there is an effective left-turning facility with adequate widening at the corner.

This conclusion is consistent with the German design recommendations $^1$ for priority junctions in which fifty percent of the left-turning major road traffic is added to the straight-through traffic $(3-2)$ to determine the effective inhibition to the minor stream if there is no left-turning lane; otherwise the left-turning stream is ignored. If anything, the present data suggest a stronger inhibition when the left-turning facility is inadequate.

Two steps may be distinguished when assessing the coefficients $a_1$, $a_3$, $a_4$. Firstly, if a coefficient does not differ significantly from zero we conclude that there is no evidence, within the range of data considered, to suggest any interaction between $q_{33}$ and the appropriate major road flow. Secondly, coefficients that differ significantly from zero provide a measure of the effect of a major road stream on the emerging minor road stream. Generally there are only slight differences from site to site between the non-zero coefficients for a given major road flow, and data would be required from a considerably greater range of sites before such differences could be associated with site factors.

The constant term, $q_0$, is similar for sites 1 – 4 (with an overall weighted mean of 590 vehicles/hour)
but is considerably lower at 331 vehicles/hour for site 5. The reason for this is not clear, although the presence of two other roads joining the A423 very close to the junction considered may have had a restrictive effect.

4.2 Effects of traffic composition

It is important in relation to traffic composition effects to recognise the essential asymmetry in the traffic flows of a major/minor junction. The level of major road flows consistent with satisfactory operation of the junction (ie still allowing an acceptable inflow from the minor arm) do not usually approach the capacity limitations of the major road itself\(^4\). Thus composition effects in both major and minor flows are only relevant inasmuch as they affect the minor road capacity. Two possible effects can be isolated: the minor road flows could be affected by the composition of the major road streams, or by that of the minor road traffic itself.

4.2.1 Composition of major road traffic

It has been established that the right-turning minor road capacity depends on the total vehicular flows in the relevant major road streams. Any effect due to composition should appear as an association between the fraction of heavy vehicles in a major road stream and the flow counts for the minor road movement.

Tests were therefore made for association between the minute-by-minute composition of the major road streams and the minor road flow, firstly without regard to the vehicular totals in the major streams, and secondly by sub-dividing the major streams into a number of distinct ranges of vehicular flow and looking for association in each range separately. The second method has the advantage that it is, in principle, capable of detecting effects which might be present at high major flows but disappear at lower flows. It also avoids the difficulty of the first method that, as a consequence of certain demand patterns, major flows might be correlated with the proportion of heavy vehicles. For example, at peak hours, commuter traffic consisting mainly of light vehicles would at the same time increase the total vehicular flows and decrease the fraction of heavy vehicles; without sub-dividing the major flows this might give rise to a spurious positive correlation between the minute-by-minute heavy vehicle fractions and the minor road outflows, even in the absence of a composition effect.

However, although there was an appreciable proportion (10–15%) of heavy vehicles at all but site 4, none of the tests revealed any significant association. There is thus no evidence to suggest that the composition of the major road streams has any detectable effect on the emerging minor road streams.

4.2.2 Composition of minor road streams

The segregation of vehicles into the classes ‘light’ and ‘heavy’ in the saturated minor road streams should give a negative association in the flow counts. Increases in the flow of one class should be accompanied by corresponding decreases in the flow of the other, because, between them, members of the two classes effectively use all the available road space. However, the streams entering the junction from the minor arm depend on the major road flows, and the association is degraded by the effects of minute-by-minute fluctuations in these flows. For example, if the total minor road light and heavy flows are linearly related,

\[
q_{13} (1) = Q + dq_{13} (h)
\]

where \(d\) is some (negative) coefficient to be determined, \(Q\) will be a constant only for a given set of major road flows and will change if they are changed: ie \(Q = f (q_{32}, q_{23}, q_{21}, q_{31})\). In principle, \(d\) may depend on \(Q\) and should be determined for each set of major flows, but this is not possible within the limits of the data and the approach is simplified by taking an overall figure obtained by fitting to the data the linear equation:
\[ q_{13}(1) = Q_0 + d_h q_{13}(h) + d_1 q_{32} + d_2 q_{31} + d_3 q_{21} \]  \hspace{1cm} \ldots \ldots \ldots (2)

A detectable association between \(q_{13}(1)\) and \(q_{13}(h)\) is indicated by a non-zero value for the coefficient \(d_h\).

The remaining coefficients, \(d_1, \ldots, d_4\), are similar to \(a_1, \ldots, a_4\) in equation (1). Table (4) shows \(d_h\) values obtained in this way. Only sites 1, 2 and 3 had an appreciable proportion of heavy vehicles in the minor streams, and for sites 4 and 5, \(d_h\) cannot be determined.

### Table 4

<table>
<thead>
<tr>
<th>Site</th>
<th>Regression coefficient for minor road heavy vehicles ((d_h))</th>
<th>Correlation coefficient for overall light and heavy counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1.27 (0.11)</td>
<td>-0.53</td>
</tr>
<tr>
<td>2</td>
<td>-0.64 (0.15)</td>
<td>-0.32</td>
</tr>
<tr>
<td>3</td>
<td>-0.71 (0.17)</td>
<td>-0.21</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In addition to the analysis described above, the association between the overall light and heavy counts for all the major and minor components for each minute was examined. Table (4) shows the corresponding correlation coefficients. Sites 1, 2 and 3 show a statistically significant negative association in these overall counts, whereas sites 4 and 5 do not. It seems reasonable to conclude that any overall effect due to traffic composition has its origin in the saturated minor road streams. This is consistent with the conclusion of 4.3.1 that the composition of the major road traffic is unimportant.

The effects of traffic composition on the capacity of junctions are often represented by pcu (passenger 'car unit') factors. In the present analysis pcu factors would differ from unity only for the minor road heavy vehicles and would take the values (\(d_h\)). However, the values are strongly site-dependent. The usefulness of a pcu factor in improving predictions of junction capacity can be gauged by the reduction in the variance of the quantity being estimated- in this case \(q_{13}(1)\). In fact, the predictive capability of equation (2) is only marginally improved by the use of each site-specific pcu value rather than unity (about 2.7% in the variance of \(q_{13}(1)\)). Certainly, no overall benefit is available from any single value for all sites.

It is interesting that an analysis of the flow data collected after the sites had been converted to mini-roundabout operation gives pcu factors which are very similar site for site to the present ones, despite changes in the priority status of the major road streams. This suggests that site-specific factors, rather than factors relating to the form of control, may play a dominant role.

### 4.2.3 Conclusions

There is nowhere a clear and consistent effect due to variations in traffic composition. Where pcu values can be ascribed, they offer only slight improvements in capacity prediction and appear not to depend specifically on the major/minor priority system itself.

Of course, the present data cover only a limited range of heavy vehicle fractions and it is possible that
outside this range the situation may change: for example, it would be surprising if considerably higher than average heavy fractions were not accompanied by consistent and detectable effects on the minor road capacity. However, for the observed range of compositions — which are fairly representative of the 'average' range for road junctions — there is no evidence to suggest that any flow depends appreciably on traffic composition or that the use of a pcu value other than unity for heavy vehicles is warranted. The simple vehicular totals used in Section 4.1 are therefore the most appropriate combinations of the flows in the 'light' and 'heavy' classes.

5. INFERENCES

5.1 Right-turning minor road vehicles

The flow of right-turning minor road vehicles can best be described by equation (1) which uses simple vehicular totals. Table (5) gives rounded overall estimates for the coefficients and summarises how they relate to the junction features.

<table>
<thead>
<tr>
<th>Major road stream</th>
<th>Coefficient</th>
<th>Pooled estimate (rounded)</th>
<th>Conditions for dependence</th>
<th>Approximate range of representation (vehicles/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2–3)</td>
<td>$a_1$</td>
<td>-0.2</td>
<td>Two-way carriageway</td>
<td>$60 &lt; q_{23} &lt; 1260$</td>
</tr>
<tr>
<td>(3–2)</td>
<td>$a_2$</td>
<td>-0.3</td>
<td>All sites</td>
<td>$60 &lt; q_{32} &lt; 1080$</td>
</tr>
<tr>
<td>(3–1)</td>
<td>$a_3$</td>
<td>-0.3</td>
<td>No adequate major road left-turning facility</td>
<td>$60 &lt; q_{31} &lt; 720$</td>
</tr>
<tr>
<td>(2–1)</td>
<td>$a_4$</td>
<td>-0.5</td>
<td>General (but see para 4.1 (ii))</td>
<td>$60 &lt; q_{21} &lt; 300$</td>
</tr>
</tbody>
</table>

These rounded coefficients, together with a representative value for the constant term $q_0$ can be used to provide an overall capacity description for junctions of the type included in this report. A reasonable overall value for $q_0$ is obtained from the average omitting site 5 (590 vehicles/hour). The mean saturation flows $<q_{13}^s>$ predicted by this simplified description are compared with the means of the observations in Table (6). Apart from site 5, the agreement is to within $\sim 10\%$.

<table>
<thead>
<tr>
<th>Site</th>
<th>Observed mean</th>
<th>Calculated mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>510</td>
<td>469</td>
</tr>
<tr>
<td>2</td>
<td>299</td>
<td>306</td>
</tr>
<tr>
<td>3</td>
<td>350</td>
<td>396</td>
</tr>
<tr>
<td>4</td>
<td>277</td>
<td>303</td>
</tr>
<tr>
<td>5</td>
<td>155</td>
<td>284</td>
</tr>
</tbody>
</table>

5.2 Left-turning minor road vehicles

The left-turning minor road demand was not sufficient to allow measurement of saturation flows.
However, it is possible to infer limiting values for such flows from a consideration of the traffic patterns. The movement $q_{12}$ conflicts directly for road space with the straight-through major road flow $q_{32}$ only. Since in some circumstances the right-turning minor road vehicles interact with the left-turning major road stream $q_{31}$, it seems advisable to assume that left-turning minor road vehicles will do so as well.

The saturation flows for the left-turning movement would therefore be:

$$q^* = q_0 + a_2 |q_{12}| + a_3 |q_{31}| \ldots \ldots \ldots (3)$$

On the assumption that the inhibiting effects of the major road streams are the same for left- as for right-turning vehicles, $a_2 = -0.3$ and $a_3 = -0.3$ or 0 as appropriate.

To what extent is such a representation realistic? Firstly, the assumption that $q_0$, $a_2$, and $a_3$ are the same for left-turning as for right-turning minor road vehicles may not be correct. Strictly speaking, we should expect the inhibition to be less. If, for example, Owens' gap-acceptance results are compared for junctions carrying only left- and only right-turning minor road traffic, the calculated saturation flows are about 10% to 20% more for the left-turning manoeuvre.

Secondly, it is important to be aware of the conditions to which such a representation relates. In the present case mutual interference between right- and left-turning minor road vehicles was minimal, because the left-turning demand was low. Had it been high enough to produce saturation flows some interference might have resulted. Thus equation (3), like (1), can only describe the flow of an independent stream.

With these provisos the approach is probably reasonable. It will, if anything, be somewhat conservative.

### 5.3 Single lane minor road approach

Given the saturation flow predictions $q^*_1$, $q^*_3$ for independent streams it is easy to calculate the expected capacity of a single lane minor approach where right- and left-turning vehicles are obliged to share the same queue. If the left-turning arrivals are distributed randomly and constitute a proportion $f$ of the total, the mean waiting time at the give-way line is $((f/q^*_1) + (1-f)/q^*_3)$. This is equal to $(1/q_c)$ where $q_c$ is the 'combined' capacity.

Thus

$$q_c = \frac{q^*_1 \cdot q^*_3}{(1-f) q^*_1 + f q^*_3} \ldots \ldots \ldots (4)$$

### 6. DESIGN CAPACITY

#### 6.1 Capacity predictions

The present results can be used to provide a simple framework for capacity predictions. Equations (1), (3) and (4) are used either separately or in combination to calculate the saturated minor road flows for a given layout from a knowledge of the major road demand flows. No assumed gap-acceptance values are required.

The criterion for adequacy of lane separation in cases where the minor road approach has one lane
diverging to two near the give-way line cannot be decided from the present study. It will in general depend on the minor road demand flows for the left- and right-turning movements and the capacities determined by the major road demand pattern. In such cases it is, at the moment, a matter of judgement which description is the more appropriate: the independent lane approach using equations (1) and (3) or the combined approach using equations (1), (3) and (4). When the left- and right-turning fractions of the minor road demand are very imbalanced, it is unlikely that localised lane separation will allow full use of the available capacity for the smaller fraction. For example, as the left-turning proportion, \( f \), decreases towards zero, so the capacity approaches the single lane value \( q_c \) and the probability of left-turners becoming trapped in a queue of right-turners decreases. However, the situation is in a sense self-compensating, since for low \( f \) there are relatively few left-turners to incur the corresponding delay penalty. In contrast, right-turners benefit in this case from localised lane separation, since they are not delayed by left-turners waiting at the give-way line. The problem would be most easily investigated by numerical simulation techniques.

6.2 Practical capacity

The capacity values \( q_{12}^g, q_{13}^g, \) and \( q_c \) refer to conditions of saturated demand and the delays experienced by minor road vehicles in these circumstances can be considerable. Thus for practical design purposes it is necessary to allow some margin between the design flow and the calculated capacity. Vehicle delays increase rapidly near capacity and an acceptable approach is to define the practical capacity as some fraction (e.g., 85\%) of the absolute capacity. An analysis of vehicle delays at the junctions studied indicates that at 85\% of capacity the expected delay per minor road vehicle is of the order of 50 seconds. There is no evidence that this figure depends strongly on the individual junction features.

6.3 Comparison with the German design procedure

At present the most comprehensive design procedure for priority junctions is that recommended in Germany 1. This takes detailed account of the interaction of the major and minor road streams in a way similar to that of the present analysis, although it is based on gap-acceptance concepts and relies on an extensive listing of gap parameters. It is of particular interest since it treats both 3-way junctions and 4-way priority crossroads. Appendix I outlines a possible extension of the present capacity framework to the 4-way case based on the relative statistical weights given to the extra conflicting streams in the German recommendations.

6.4 Limitations

The present data represent a very limited range of sites. All were semi-rural and although two had 70 mph speed limits, the approach speeds on the major road were a lot less, probably close to 40 mph. If wider use is to be made of the proposed capacity relationships, it will be necessary to extend the range and determine the coefficients for sites in other categories, particularly urban junctions and high-speed rural junctions. In addition, certain specific aspects of junction geometry will require more detailed investigation. Besides the question of lane separation in the minor road approach discussed in 6.1, for dual-carriageways the minor road capacity is likely to be affected by the reservoir space in the central reserve and the relative sizes of the nearside and offside major road flows, and possibly by the presence of acceleration lanes on the major road.

7. CONCLUSIONS

Traffic flow interactions have been studied at five three-way major/minor priority junctions. Capacity
relationships have been obtained for the right-turning minor road streams in terms of the major road demand flows. The effects of traffic composition were found to be slight and were specific to the site rather than to the form of control; the accuracy of capacity prediction was not appreciably improved by the use of pcu factors.

A framework for the calculation of practical capacities has been proposed. Basically this framework consists of specifying maximum flows from the minor road \( q_0 \) which are then reduced by amounts proportional to the interacting flows on the major road. The left- and right-turning minor road stream capacities can be treated singly or in combination. An extension to the four-way case has been suggested on the basis of similarities with the German design recommendations. A great deal of further data collection and analysis is needed if the principles of capacity prediction for major/minor junctions expressed in this report are to be applied as a general means for estimating the capacity of junctions of this type.

8. ACKNOWLEDGEMENTS

The work described in this Report was carried out in the Traffic Systems Division (Division Head: Mr G Maycock) of the Traffic Engineering Department of TRRL.

9. REFERENCES


APPENDIX I

Extension to the four-way case

The methods of prediction suggested by the present study bear some resemblance to those of the German procedure for three/four-way priority junctions. It may therefore be appropriate to carry over certain aspects of the German procedure in order to extend the present method to the 'straight-through' four-way case.

Figure (9) shows the notation adopted here for a four-way major/minor junction. Each minor road approach now has three stream capacities, for example $q^5_{12}$, $q^5_{14}$, and $q^5_{13}$, corresponding to the left/straight-on/right manoeuvres.

i. **Left-turning minor road vehicles $q^5_{12}$**

The left-turning minor road capacities are the same in principle as in the three-way case (equation 3)).

ii. **Straight-on minor road vehicles $q^5_{14}$**

The straight-on movement is equivalent to the right-turning minor road stream in a three-way junction, except for the additional conflicting streams $q_{34}$ and $q_{24}$ ($q_{42}$ is considered to give way to the straight-through movement). The German approach accords these the same weight as that from the movement $q_{32}$. Thus a hybrid approach would give:

$$q^5_{14} = q_0 + a_1q_{23} + a_2(q_{32} + q_{34} + q_{24}) + a_3q_{31} + a_4q_{21}$$

where the coefficients are as given in 5.1.

iii. **Right-turning minor road vehicles $q^5_{13}$**

The extra conflicting streams are in this case $q_{34}$, $q_{41}$, and $q_{43}$. $q_{42}$ is omitted because its priority in relation to $q_{13}$ is ill-defined, and it cannot be determined independently of opposing side road flows as can $q_{41}$ and $q_{43}$ (from i and ii); hopefully its effect is small. Again $q_{41}$ and $q_{43}$ are accorded equal weight to $q_{32}$, and

$$q^5_{13} = q_0 + a_1q_{23} + a_2(q_{32} + q_{34} + q_{41} + q_{43}) + a_3q_{31} + a_4q_{21}$$

The effects of lane separation are as before: if each movement is provided with a separate lane, the stream capacities $q^5_{12}$, $q^5_{14}$, $q^5_{13}$, etc are independent; if a common lane is used, the capacity for this lane is formed (as in 5.3) by the rule

$$\frac{1}{q_c} = \frac{f_1}{q^5_{12}} + \frac{f_2}{q^5_{14}} + \frac{f_3}{q^5_{13}},$$

where $f_1$, $f_2$, and $f_3$ are the fractions of the total minor road demand (for the relevant entry) following the movements $(1-2)$, $(1-4)$, and $(1-3)$ respectively. A similar rule applies to any pair of adjacent movements sharing a common lane.
Fig. 1 FLOWS AND NOTATION: THREE-WAY
Fig. 4 SITE 3—MARDEN ASH
Fig. 6 SITE 5—BANBURY
\[ q = \frac{Q(1 - \beta_2 Q)}{e^{(\alpha - \beta_1)Q} (1 - e^{-\beta_2 Q})} \]

where \( \alpha \) = minimum time gap in major road traffic for a minor road vehicle to enter
\( \beta_1 \) = minimum major road headway \( \beta_2 \) = move-up time for minor road vehicles

Fig. 7 FORM OF THE CAPACITY RELATIONSHIP PREDICTED BY GAP ACCEPTANCE THEORY

\[ q_{13} = 560 - 0.32q_{32} \]

Fig. 8 COMPARISON OF THE REGRESSION RESULT FOR SITE 2 (SEE TABLE 3) WITH THE MEAN OBSERVED MINOR ROAD FLOW FOR EACH LEVEL OF FLOW IN THE CONTROLLING STREAM (3–2)
N.B. A non-cyclic notation is used in order to maintain homogeneity with the 3-way notation of Figure (1)

Fig. 9 NOTATION: 4–WAY
ABSTRACT

The capacity of some major/minor priority junctions: R M KIMBER: Department of the Environment, TRRL Laboratory Report 735: Crowthorne, 1976 (Transport and Road Research Laboratory). The Report describes traffic flow observations made at five three-way major/minor priority junctions under conditions of heavy minor road demand. The results have been analysed by linear regression methods to determine the extent of the interactions between the major and minor road streams. Variations in the composition of major road traffic had no detectable effect on the total flow through the junction; effects due to variations in minor road composition were slight only. The relationships between the major and saturated minor road traffic flows are represented by linear equations which allow the minor road approach capacities to be calculated. The results provide a framework for predicting the practical capacities of three-way junctions. An extension to the four-way case is suggested.

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