1. INTRODUCTION

Gap acceptance parameters form a crucial part of many intersection simulation and traffic operations models. VISSIM, SATURN, SIDRA, PARAMICS and many other software provide default values but allow the modeller to change these to more relevant values. When a traffic network is congested, drivers may choose to behave more aggressively and accept smaller gaps than is modelled by standard parameters. Existing conditions may therefore be hard to reproduce unless more aggressive parameters are adopted.

In this paper we present a methodology for developing locally appropriate gap acceptance parameters based on video observations. Using CCTV video recordings of driver behaviour around a congested roundabout in Birmingham, the gap acceptance behaviour of vehicles has been analysed, resulting in suitable input values for representation in VISSIM.

Once the gap acceptance data was collected and analysed, curves representing the frequency of rejection and acceptance of gaps were developed. Three methods of analysis were investigated. These include:

• Raff’s critical gap;
• An “equal” overlapping area gap and;
• 50th Percentile of rejected gap curve.

The study concludes that the 50th percentile reject curve method provides the most reliable gap acceptance values. Further analysis of driver behaviour by disaggregating the observations by vehicle type reveals that gaps accepted by heavy vehicles differ from light vehicles. Accepted and rejected gaps are dependent on the traffic composition of conflicting and opposing streams, with higher time gaps required when the conflicting stream contains heavy vehicles. In congested situations heavy vehicles exhibit rather surprisingly aggressive behaviour on the minor arm by accepting smaller gaps.

Sensitivity testing of the simulation model reveals that the gap acceptance behaviour is a function of traffic composition which affects the capacity and performance of the roundabouts and has an impact on the design of
roundabouts. The calculated gap acceptance parameters were applied in a microsimulation model and compared with observed travel times. These showed a better level of fit compared to the use than the default values.

2. PROBLEM DEFINITION

Roundabouts are one of the important elements of urban road design in UK. Reproducing correct driver behaviour around the roundabouts is vital for the correct evaluation of its performance. Traditionally ARCADY (Assessment of Roundabout Capacity and Delay) has been used in the UK for design and assessment of roundabout schemes. However, if there are several closely spaced congested intersections, interactions between the junctions may lead to blocking back between them which cannot be modelled using conventional tools. In addition, bus or pedestrian priority systems which are often promoted by local authorities cannot be explicitly modelled using the conventional toolkit.

In the case study of Six Ways roundabout, it was proposed that the existing roundabout needs to be redesigned to cater to a higher public transport demand and priority. The Six Ways roundabout is located in Erdington, north-east Birmingham on the A5127, which experience large volumes of traffic flows during the peak periods. It is the major route between the north-east of Birmingham, Birmingham City Centre and the motorway network (Figure 1).

Figure 1: Case study intersection
The Six Ways roundabout also accommodates major bus routes such as Outer Circle route 11, 109 on Reservoir Road to Wood End Road, which cross the main north-south movement, while radial routes between Erdington, Sutton Coldfield and Birmingham City Centre include routes 66, 104, 105, 110, 112, 663, 902, 904, 905 and 915. The overall frequency of these routes is 114 buses per hour during the peak periods. During the peak hours there were 2,727 vehicles in the AM peak and 3,551 vehicles in the PM peak surveyed travelling through the junction.

To solve the congested nature of the junction, Birmingham City Council produced improvement options for the Six Ways roundabout together with the Wood End Road/Oakfield Road/Trafalgar Road junction to improve travel times for buses through the Six Ways roundabout junction.

The base model development, calibration and validation were carried out as part of the junction assessment exercise using the micro-simulation package VISSIM. The VISSIM microsimulation package was chosen as it could model the interactions between closely spaced intersections and replicate the bus and pedestrian priority systems explicitly. Initially, even though most of the modelled links showed correct levels of traffic volumes the modelled travel times did not match the observed times. This was primarily due to default coding of driver behaviour and gap acceptance parameters of the software. The modelled animations did not closely resemble the site observations and showed obvious flaws in the modelled driver behaviour.

It was therefore proposed that traffic data had to be collected on the driver behaviour parameters. This included collecting gap acceptance values to calibrate the model and understand intersection performance.

3. COLLECTION OF GAP ACCEPTANCE DATA

To gather the traffic data for the above project, CCTV cameras were used to record existing conditions on the roundabout during peak hours. Cameras were positioned so that the traffic entering the roundabout from one of its arms, and the circulating traffic that opposed it could be seen simultaneously. The positions of the video cameras and a typical view point from the camera are shown in Figure 2. The video footage was then analysed back in the traffic lab. In addition to counting the turning movements from the intersections the CCTV footage was utilised to understand the driver and gap acceptance behaviour.

Figure 2: Camera locations and a typical viewpoint.
Enumerators were instructed to watch the videos and record the time when vehicles approached different locations in the network. These are shown below in Figure 3.

1. When a vehicle on the approach lane stopped at the give way line. (A1, A2);
2. When a vehicle from the approach lane moved to enter the circulating stream. (Move from A1 or A2);
3. When a circulating (conflicting) vehicle crosses the point where it conflicts with the approach vehicle. (P1, P2, P3, P4).

**Figure 3: Points at which traffic data was recorded**

Several steps were taken to ensure the accuracy of the data. In the first instance, a clear plastic sheet was placed over the TV screen marked with the actual trajectories of the arriving and conflicting vehicles, the points shown in Figure 3 being clearly overlaid on the video footage. This ensured that the arrival/departure times for each vehicle were recorded from the same position (See Figure 3).

In order to establish a high degree of accuracy, it was not possible to rely on the time displayed on the video footage. Instead the, enumerators used notebook computers, the clocks of which were set to the same time. A custom made MS Excel program was then used to collect arrival/departure time information. The technicians were asked to press specific keys when the vehicles reached designated locations. This method generated a unique timestamp (to the nearest 100th of a second) marking the positions of the vehicles on the above points.
Not only did this process ensure greater accuracy of the data than an on site survey, but also the supervising staff were better positioned to oversee and improve the data collection.

4. ANALYSIS OF GAP ACCEPTANCE DATA

The gaps between two vehicles can be quantified in two different ways, the time gap and the space gap.

Time Gap or Time headway is the time elapsed between the arrivals of the fronts of the two successive vehicles at the same point on the road (see Figure 4).

Space Gap or Space headway is distance between the rear of a vehicle and the front of the following vehicle at a point in time. (Figure 5).

All traffic entering a roundabout has to make a decision whether there is sufficient time and space for it to enter the intersection safely. The vehicles on the approaching stream assess the gaps on the conflicting stream. They decide
based on their perception, if the time and space gap is too small to cross or large enough to safely manoeuvre their vehicle. In the former case they would reject the gap and maintain their current position and in the latter case they would accept the gap and merge into the circulating stream.

By definition, a vehicle entering the roundabout would have only one accepted gap but zero or more rejected gaps. In this case study the database generated by technician’s observations (keystrokes) was analysed to generate a list of accepted and rejected gaps by various vehicle types (heavy and light). As the time stamps for the above measurements were recorded to the accuracy of 100th of a second, a high level of data accuracy was ensured. However, there is a degree of human error involved due to perception and translation in this process, which could not be eliminated. The final structure of the data was the time gaps available and the gaps which were accepted or rejected by vehicle type.

5. INTERPRETATION OF GAP ACCEPTANCE CURVES

The objective of this gap acceptance study was to find out the critical gap which a vehicle accepts at the roundabout. This critical gap value is used by the VISSIM microsimulation model to reflect the driver behaviour at a give way intersection.

Three different methods were used to investigate the gap acceptance data:

1. Raff’s Critical Gap method;
2. Equal Overlapping Area Method (proposed here);
3. Reject Gap Percentile Curve (proposed here);

5.1 Raff’s Critical Gap method

The first method used for analysis of the gap acceptance data was the Raff’s Critical Gap analysis method. The Raff’s Critical Gap is the time gap where a vehicle is considered equally likely to reject that gap as accept it. In practice, this is the point where the curves for Rejected Gaps and Accepted Gaps cross (See Figure 6, Raff's Critical Gap).
5.2. Equal Overlapping Area Method

The next method used for the analysis of the gap acceptance data was the equal overlapping area method, proposed here. The “equal overlapping area gap” is also based on the relationship between the rejection and acceptance curves. In this method the overlapping regions of the curves are examined. The critical gap is defined as the point where the area under the “rejects” curve equals the area under the “accepts” curve. In practice, all gaps below the critical gap are rejected. Some gaps are wrongly accepted and some are wrongly rejected (see Figure 7). The equal overlapping area critical gap is the one where the number of wrongly rejected gaps equals the number of wrongly accepted ones. In comparison, the standard Raff’s critical gap lends itself to either wrongly accept more than it rejects or vice versa, unless the Reject and Accept curves happen to be symmetrical.
5.3. **Problems with Raff and Equal Area Method**

The problem with the first two methods is the relative infrequency of accepted gap data. This is especially due to the infrequency of data exhibiting large gap acceptance values. In our case study with a highly congested roundabout only a few long gaps were found. The acceptance curve tends to look linear, almost horizontal (Figure 8), when they are expected in theory to appear as an “exponential like” curve (Raff, 1950). In many cases there often exist multiple crossing points in the data which make the critical gap acceptance difficult and unreliable (Figure 9). From Figure 8 and 9 one can see that there was no viable way to determine the critical gap acceptance values using the above two methods.

![Figure 8: Typical graph of reject and accept curves for all vehicle types](image)

![Figure 9: Typical graph of reject and accept curves for heavy vehicles](image)
5.3 **Reject Gap Percentile Curve**

In this method we analyse at the gap representing the 50th percentile of rejection data. In congested conditions there is an abundance of rejected gap data. A vehicle can only have one accepted gap but many rejected gaps. Plotting the rejected gaps produces a ‘negative exponential type’ curve. The 50\textsuperscript{th} percentile value was selected as it reflected half of the rejected gaps which were definitely rejected. Any gaps generated to the left of 50\textsuperscript{th} percentile distribution had a very low probability of acceptance (Figure 10).

**Figure 10: 50th percentile reject gap acceptance curve**

The gaps accepted by different vehicles were found to be different for different lanes on the same approach and they also varied by different arms of the junction (see Table 1). In reality the gaps accepted or rejected by a vehicle are dependent on number of different conditions such as the geometric layout of the intersection, visibility and environmental factors. In our study however, we have studied the impact of varying geometric locations, vehicle types and traffic composition only.

All traffic data was split and analysed into three different categories:

1. Light vehicles (motorcycles, cars and light good vehicles);
2. Heavy vehicles (medium and heavy goods vehicles and buses);
3. All vehicle types combined

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The results from the analysis of 50th percentile reject gap curve were plotted in tabular format. The values in the individual cells showed for each of the individual lanes on the approach, the vehicle to vehicle gap acceptance values. Hence, for the three vehicle categories, nine different interactions were analysed (see Table 1).

<table>
<thead>
<tr>
<th>Approach Arm</th>
<th>Approach Vehicle Type</th>
<th>Circulating Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>HEAVY</td>
</tr>
<tr>
<td>Gravelly Hill North Lane 1</td>
<td>All</td>
<td>2.48</td>
</tr>
<tr>
<td></td>
<td>HEAVY</td>
<td>1.83</td>
</tr>
<tr>
<td></td>
<td>LIGHT</td>
<td>2.58</td>
</tr>
<tr>
<td>Gravelly Hill North Lane 2</td>
<td>All</td>
<td>2.34</td>
</tr>
<tr>
<td></td>
<td>HEAVY</td>
<td>1.79</td>
</tr>
<tr>
<td></td>
<td>LIGHT</td>
<td>2.42</td>
</tr>
<tr>
<td>Wood End Road Lane 1</td>
<td>All</td>
<td>2.72</td>
</tr>
<tr>
<td></td>
<td>HEAVY</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td>LIGHT</td>
<td>2.72</td>
</tr>
<tr>
<td>Wood End Road Lane 2</td>
<td>All</td>
<td>2.13</td>
</tr>
<tr>
<td></td>
<td>HEAVY</td>
<td>1.93</td>
</tr>
<tr>
<td></td>
<td>LIGHT</td>
<td>2.14</td>
</tr>
<tr>
<td>Summer Road Lane 1</td>
<td>All</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>HEAVY</td>
<td>2.02</td>
</tr>
<tr>
<td></td>
<td>LIGHT</td>
<td>2.05</td>
</tr>
<tr>
<td>Summer Road Lane 2</td>
<td>All</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>HEAVY</td>
<td>2.28</td>
</tr>
<tr>
<td></td>
<td>LIGHT</td>
<td>2.43</td>
</tr>
</tbody>
</table>

From Table 1 it can be inferred, contrary to expectation, that in most cases the heavy vehicles accept smaller gaps than the light vehicles. In addition, the light vehicles on the minor arm will accept a lower gap if there is a light vehicle on the conflicting stream. In previous studies (Ahuja, 1999) it has been observed that light vehicle accept smaller gaps if they are conflicting with heavy vehicles on the conflicting stream. Our case study shows different results compared to this earlier study, as it is based on a different country with different driver behaviour and possibly better performance specifications of heavy goods vehicles.

The observed minimum acceptable time gap for light vehicles ranges from 1.50 seconds to 2.93 seconds for different arms compared to the default recommended value of 2.6 seconds. For the heavy vehicles the minimum acceptable gaps ranged from 1.02 seconds to 2.95 compared with 3.0 seconds of default value.

These lower than expected gap acceptance values are observed due to heavy traffic congestion observed on case study intersection. The congested traffic conditions also exhibit a state of ‘mutual conflict resolution’ between the minor...
and conflicting approaches where the vehicles on the main approach may give way to allow the minor stream vehicles to enter the intersection. Hence the accepted gap is not just a function of time but of free space available. This needs to be reflected in the gap parameter values of microsimulation models.

One can also argue that the heavy vehicles in the conflicting stream force the light vehicles to reduce their speed and observe safer gap acceptance values.

6.0 SIMULATION MODEL OF THE CASE STUDY AREA

A VISSIM microsimulation model of the case study was built using both the default gap acceptance values and the observed gap acceptance values (Table 1) with the ‘mutual conflict resolution’ behaviour described above.

Figure 11 shows that the use of the VISSIM default values overestimates the journey times and the use of newly analysed data closely matched the observed travel times on the critical approach.

Sensitivity tests were conducted to analyse the impact circulating traffic volume and varying traffic composition on the performance of the roundabout. To isolate the network analysis, the network was cordoned into an isolated single roundabout as shown in Figure 12. In addition the conflicting traffic volume was altered only for the Wood End Road approach stream only. The traffic composition was altered for all other approaches to the roundabout.
Figure 12: Cordoned network used for sensitivity testing

The results were compiled and analysed for the following levels of conflicting traffic volumes:

<table>
<thead>
<tr>
<th>Level</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 25% of existing traffic volume</td>
<td>25%</td>
</tr>
<tr>
<td>2. 125% of existing traffic volume</td>
<td>125%</td>
</tr>
<tr>
<td>3. 50% of existing traffic volume</td>
<td>50%</td>
</tr>
<tr>
<td>4. 150% of existing traffic volume</td>
<td>150%</td>
</tr>
<tr>
<td>5. 75% of existing traffic volume</td>
<td>75%</td>
</tr>
<tr>
<td>6. 175% of existing traffic volume</td>
<td>175%</td>
</tr>
<tr>
<td>7. 100% of existing traffic volume</td>
<td>100%</td>
</tr>
<tr>
<td>8. 200% of existing traffic volume</td>
<td>200%</td>
</tr>
</tbody>
</table>

The effect of varying traffic compositions was analysed for following levels.

1. 0% light and 100% heavy vehicles (0% LV);
2. 25% light and 75% heavy vehicles (25% LV);
3. 50% light and 50% heavy vehicles (50% LV);
4. 75% light and 25% heavy vehicles (75% LV);
5. 92.7% light and 7.3% heavy vehicles (observed Value) (92.7% LV);
6. 100% light and 0% heavy vehicles (100% LV);

The above sensitivities were tested for the model containing calculated gap acceptance values. In addition, the performance of the model built using default gap acceptance values with observed traffic composition was also tested (Default Values) The results of the sensitivity tests are shown in Figures 13 to 16.
Figure 13: Comparative distribution of average network speeds

Average Speed on Network

Figure 14: Comparative distribution of average delay per vehicle

Averaged Delay per Vehicle on Network (s)
Figure 15: Comparative distribution of number of stops per vehicle

Figure 16: Comparative distribution of average stopped delay

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The following inferences can be made from the above graphs (Figures 13 to 16). As the conflicting traffic volume increases, the network speed reduces and average delays, stops and the stopped delay increases. In the models coded with the observed gap acceptance data, increasing the conflicting traffic volume beyond 125% of the observed volume, the increase in the conflicting traffic volumes does not reduce the intersection performance exponentially. This is due to the fact that these models have been built with correctly observed gap acceptance behaviour. These models exhibit mutual conflict resolution (‘Yellow box type behaviour’) where the vehicles on the major arm do not block the minor stream under congested conditions. In the model built with default coding, increasing the conflicting traffic volume exponentially reduced the network performance. Therefore, if the simulations models are coded using default Give Way parameters they result in an overestimation of delays which may lead to the over design of roundabouts.

Increasing the share of heavy vehicles in the network also affects the network performance in a negative way. This is in line with expectations and the analysis presented in Table 1 which showed the vehicles gap acceptance criteria is larger if there are more heavy vehicles in the conflicting traffic stream. This finding has a bearing on roundabout design, as roundabouts with a high share of heavy vehicles may need to be designed taking into account their negative impact on intersection performance.

7. CONCLUSIONS

The study concludes that under congested conditions the proposed methodology of analysing the 50th percentile gap of the reject curve gives a robust estimation of the gap acceptance driver behaviour of the intersection. The other existing methods may be unsuitable to understand the gap acceptance.

Sensitivity testing of the simulation model reveals that the gap acceptance behaviour is function of traffic composition and affects the capacity and performance of the roundabouts and has an impact on the design of roundabouts. The calculated gap acceptance parameters were validated in a microsimulation model and compared with observed travel times, showing a better level of fit with observed behaviour than the default values.

The additional benefits of VISSIM microsimulation is its ability to model flexible and detailed gap acceptance behaviour of drivers coupled with its ability to allow the user to visualise traffic behaviour and adapt its resemblance to reality.
References

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http://www.trlsoftware.co.uk


ACKNOWLEDGEMENTS

The authors would like to thank Kirpal Jutley from Birmingham City Council for their support for the project and Paul Hoad from Mott MacDonald for their help in the project.