A3 Travel time estimation procedures

A3.1 Use of travel time estimation procedures

Use of travel time estimation proceduresIntroduction

Travel times shall be estimated according to the procedures in this appendix. Definitions for classifying traffic data and default traffic data values are provided in appendix A2. Where a specific procedure is not given, the travel time shall be determined according to a recognised procedure compatible with the manuals and procedures referred to in this appendix.

The methods are capable of application by hand, spreadsheet and within transportation models. The methodology gives a reasonable approximation for travel time without having to analyse dynamic queuing situations. More precise methods are not precluded.

Use of measured data

Wherever practical, measured data shall be used in preference to the default values given in the tables.

Basis of methodology

The procedures for road sections are based on and are consistent with the Highway capacity manual (HCM)[1].

The procedures for intersections are drawn from Akcelik and Rouphail[2], ARRB internal report 367-1[3], ARRB research report 123[4], Kimber and Hollis[5] and Austroads *Guide to traffic engineering practice, part 6 - roundabouts*.

Transportation models

When a transportation model is used for project analysis, the model shall have been satisfactorily validated on both traffic volumes and travel times. Checklists for validating transportation models are provided in worksheet 8 of the full procedures.

It is necessary that the travel times used by the model to derive the flows must be consistent with the travel times estimated by using this appendix during evaluation. To adhere to this it is suggested that the functions implied by the procedures in this appendix be used as a starting point, and modified as necessary to get a satisfactory validation.

In this appendix

This appendix contains the following topics:

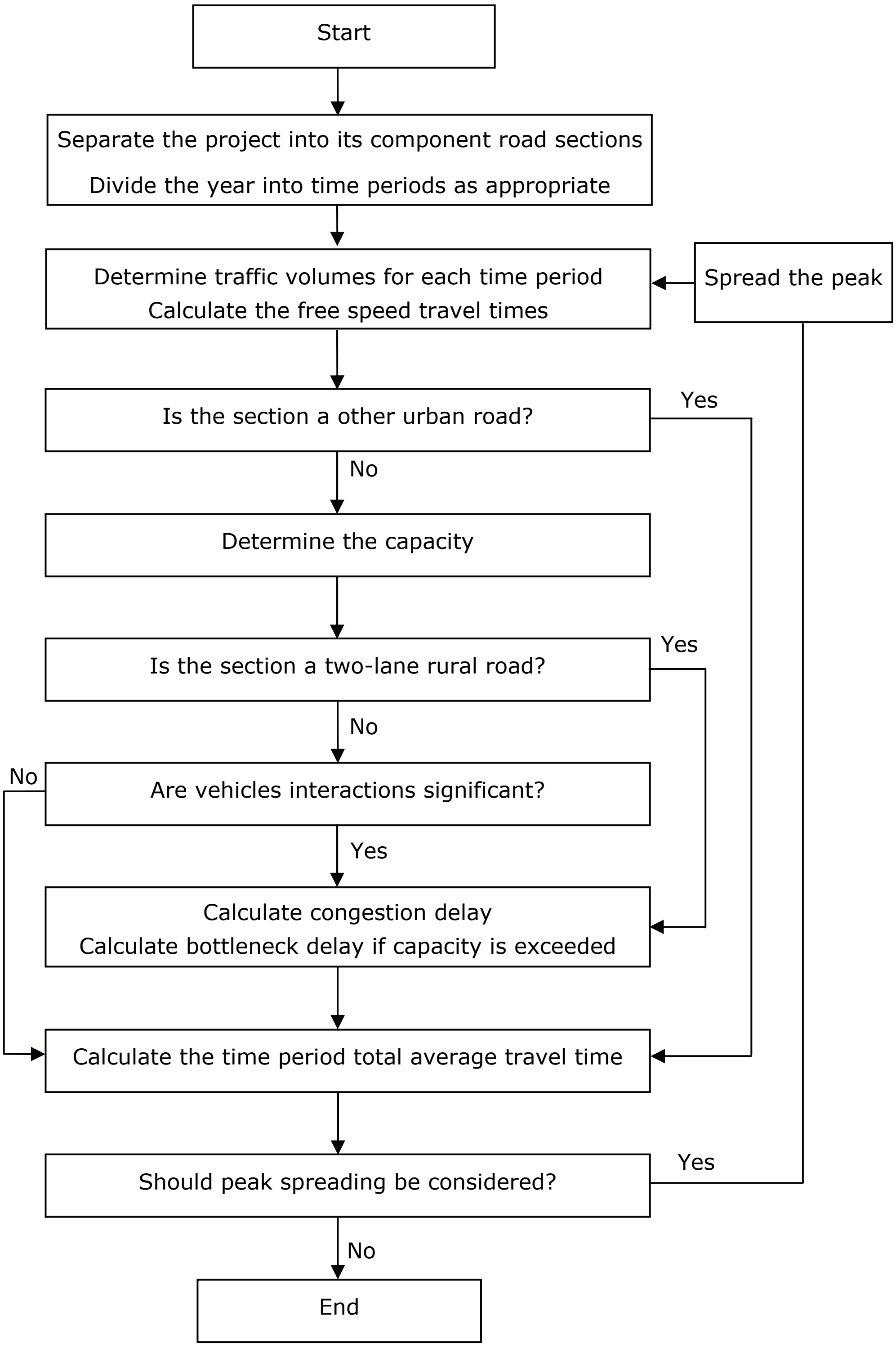
A3.1 Use of travel time estimation procedures, continued

In this appendix, continued

A3.2 The stages for estimating travel time

Flow chart for estimating travel time

The flow chart below shows the basic stages for estimating road section travel time (the stages are slightly different for intersections).



A3.3 Determining traffic volumes

Introduction

This procedure details the base and future year traffic volumes that need to be determined for estimating travel time.

In some cases, growth constraint methods may be needed to estimate the do minimum and project option matrices where high future levels of congestion are anticipated, usually because the network(s) have insufficient capacity to meet unrestrained travel demands. In some cases, variable matrix methods may be needed to estimate the do minimum and project option matrices (refer to appendix A11).

Definition

The *base traffic volumes* are the traffic volumes as at either:

- a recent census year adjusted to time zero, or
- a year at which the transportation model has been calibrated to time zero.

Procedure

Follow the steps below to determine traffic volumes:

Step	Action
1	Determine the base traffic volumes for each section using the procedure outlined in appendix A2.6, or by means of a transportation model.
2	Estimate the traffic volumes for each section for at least two future years using a suitable prediction method. Note: The method adopted for estimating future traffic volumes must satisfy the requirement that demand is in approximate equilibrium with supply.

A3.3 Determining traffic volumes, continued

Procedure, continued

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td rowspan="5">3</td><td colspan="2">Judge whether future year capacity problems occur.
Note: This step requires an estimate of the capacity that is not determined until appendix A3.8. A first iteration of this whole procedure may be used before judging whether this step is relevant.</td></tr>
<tr><td>If there is…</td><td>Then…</td></tr>
<tr><td>Sufficient capacity for future year traffic volumes in the do minimum and project option</td><td>Generally apply standard fixed trip matrices and evaluation procedures.</td></tr>
<tr><td>Adequate levels of service for future year traffic volumes in the project option, but not in the do minimum (typically a do minimum level of service of E or F)</td><td>• Generally improve the capacity of the do minimum network and/or apply growth constraint techniques to the do minimum matrix (see appendix A11.1);
• When evaluating project benefits, use the procedures in worksheet 3.</td></tr>
<tr><td>High congestion (typically level of service E or F) in both the do minimum and project options</td><td>• Generally apply variable matrix methods (see appendix A11.9);
• When evaluating project benefits, use the procedures in worksheet 3;
• For verification purposes, carry out a fixed matrix analysis using growth constraint techniques (appendix A11.2).</td></tr>
</table>

A3.4 Calculating free speed travel time

When to use

Use this procedure for all road section types.

Procedure

Follow the steps below to calculate the free speed travel time:

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td>1</td><td colspan="2">Take measurements of free speed in the field at flow rates below 600 veh/h per lane.
Alternatively, measurements of free speed from a similar road section in the locality, with similar characteristics, can be used.
Note: To proceed with a preliminary value of free speed before measurements have been collected or if the road section is part of a proposed facility, then follow step 2.</td></tr>
<tr><td rowspan="6">2</td><td colspan="2">If measured speeds are not available, then determine the free speed using the appropriate procedure as follows:</td></tr>
<tr><td>If the road section is…</td><td>Then use the procedure in…</td></tr>
<tr><td>a motorway section</td><td>105 km/h
where design speed > 110 kmh</td></tr>
<tr><td>a multlilane road</td><td>Appendix A3.5</td></tr>
<tr><td>a two-lane rural road</td><td>Appendix A3.6</td></tr>
<tr><td>an other urban road</td><td>Appendix A3.7</td></tr>
<tr><td>3</td><td colspan="2">Using the free speed determined in either step 1 or 2, calculate the travel time in minutes per kilometre.
Example:
Free speed = 100 km/h
Free speed travel time = 60/100
= 0.600 mins/km</td></tr>
<tr><td>4</td><td colspan="2">Determine the capacity from appendix A3.8.
Other urban road capacity is not required for calculating travel time but used in determining additional vehicle operating cost of congestion.</td></tr>
</table>

A3.5 Determining the free speed of multilane roads

When to use

This procedure is called from appendix A3.4.

The free speed of proposed or existing facilities for which there is no measured data is estimated by adjusting the basic free speed under ideal conditions.

Adjustments to the basic free speed are made for:

- dividing medians
- lane width
- lateral clearance
- density of access points

Lateral clearance

The lateral clearance is the sum of any median shoulder and sealed left hand shoulder widths beyond the edge of the through lanes that are continuously available.

Procedure

Follow the steps below to determine the free speed of a multilane road section.

Step	Action	
1	If measured speeds are not available, then determine the **basic free speed** for the multilane road section as follows:	
	If the section has a posted speed limit of…	Then use a basic free speed of…
	100 km/h	105 km/h
	80 km/h	90 km/h
	70 km/h	80 km/h
	50 km/h	60 km/h
2	Adjust the basic free speed to account for **dividing medians** as follows:	
	Dividing median	Adjustment to basic free speed
	Has a dividing median	No reduction
	No dividing median	Reduce by 3 km/h
3	Adjust the basic free speed to account for **lane widths** as follows:	
	If lane widths are…	Adjustment to basic free speed
	3.5 metres or greater	No reduction
	Less than 3.5 metres	Reduce by 3 km/h

A3.5 Determining the free speed of multilane roads, continued

Procedure, continued

Step	Action	
4	Adjust the basic free speed to account for **lateral clearance** as follows:	
	If the section has lateral clearance of…	Adjustment to basic free speed
	3m or greater	No reduction
	Less than 3m but at least 2m	Reduce by 2 km/h
	Less than 2m but at least 1m	Reduce by 4 km/h
	Less than 1m	Reduce by 9 km/h
5	Adjust the basic free speed to account for **density of access points** along the section as follows:	
	If the section has a density of access points per km of…	Adjustment to basic free speed
	Less than 40	0.4 km/h per access point
	40 or more	16km/h

Example calculation

Below is an example calculation for the free speed of a multilane road section where measured speeds are not available.

Example:

Posted speed limit = 70 km/h

Median divided = yes

Lane width = 3.5 metres

Lateral clearance = 1.0 metres

Access points density = 10 per km

Basic free speed = 80 km/h

Dividing median speed reduction = 0 km/h

Lane width speed reduction = 0 km/h

Lateral clearance speed reduction = 4 km/h

Access point speed reduction = 10 × 0.4 = 4 km/h

Free speed = 80 – 0 – 0 – 4 – 4 = 72 km/h

A3.6 Determining the free speed of two-lane rural roads

When to use

This procedure is called from appendix A3.4 and should be used if no measured speeds are available.

Option for more detailed methodology

The procedure adopted in this section provides a realistic but approximate method for assessing travel times. Alternatively the HCM provides a more detailed methodology for the evaluation of local improvements, such as design speed increases and climbing and passing lanes, and the computer programme TRARR may be used for detailed analyses.

Design speed

The definition of design speed used in this section is that used by the HCM and the Austroads *Guide to traffic engineering practice part 2 roadway capacity.*

Procedure

The free speed of a two-lane rural road is determined by the speed environment that can be approximated by the average design speed of the road section under consideration and the associated approaches.

Follow the steps below to determine the free speed of a two-lane rural road section.

Step	Action
1	Obtain the following basic data for the road section: • length of road section • centreline length of each curve including transitions • length of each straight (tangent) • design speed of the straights (tangents) • design speed of the curves.
2	Calculate the travel time for each curve and straight, as per steps 3 and 4. Note: it is acceptable to assume an abrupt change in speed where straights and curves meet.
3	Calculate the travel time on curves (including transitions). Example: Curve 1 length = 0.200 km Curve 1 design speed = 80 km/h Curve 1 travel time = 0.2/80 × 60 = 0.150 minutes Curve 2 length = 0.150 km Curve 2 design speed = 70 km/h Curve 2 travel time = 0.15/70 × 60 = 0.129 minutes Curve 3 length = 0.100 km Curve 3 design speed = 70 km/h Curve 3 travel time = 0.10/70 × 60 = 0.086 minutes Total curve travel times= 0.150 + 0.129 + 0.086 = 0.365 minutes

A3.6 Determining the free speed of two-lane rural roads, continued

Procedure, continued

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>4</td><td>Calculate the travel time on the straights (tangents)
Note: unless constrained by other design criteria the design speed for straights (tangents) should be assumed to be 100 km/h in severe terrain and a maximum of 120 km/h in gentler country (Austroads Rural Road Design)
Example:
Tangent length = 0.550 km
Tangent design speed = 120 km/h
Tangent travel time = 0.550/120 × 60
= 0.275 minutes</td></tr>
<tr><td>5</td><td>Calculate the total travel time on the road section.
Example:
Travel time on curves = 0.365 minutes
Travel time on straights = 0.275 minutes
Total travel time = 0.365 + 0.275
= 0.640 minutes</td></tr>
<tr><td>6</td><td>Calculate the average design speed for the road section.
Example:
Road section length = 1.000 km
Total travel time = 0.640 minutes
Average design speed = 1.000/0.640 × 60
= 93.75 km/h</td></tr>
<tr><td>7</td><td>Determine the free speed as follows:
<table>
<tr><th>If the average design speed is …</th><th>Then the free speed is…</th></tr>
<tr><td>above 100 km/h</td><td>105 km/h</td></tr>
<tr><td>below 100 km/h</td><td>105 km/h minus 13 km/h for every 18 km/h reduction in design speed below 100 km/h</td></tr>
</table></td></tr>
</table>

Example:

Average design speed = 93.75 km/h

Free speed = 105 – ([(100 – 93.75) / 18] × 13)

= 100.5 km/h

A3.7 Determining the free speed of other urban roads

When to use

This procedure is called from appendix A3.4 and should be used if no measured speeds are available.

Procedure

Follow the steps below to determine the free speed of an 'other urban road'.

Step	Action
1	Determine the classification of the other urban road section as follows:

If the design category of the road section is …	And the functional category is…	Then the road classification is…
suburban	principal	Class I
suburban	minor	Class II
intermediate	principal	Class II
intermediate	minor	Class II or III
urban	principal	Class II or III
urban	minor	Class III

Design category

Criterion	**Suburban**	**Intermediate**	**Urban**
Driveway/access density	Low density	Moderate density	High density
Arterial type	Multilane divided, undivided or two-lane with shoulders	Multilane divided or undivided, one-way, two-lane	Undivided one-way, two-way, two or more lanes
Parking	No	Some	Significant
Separate right-turn lanes	Yes	Usually	Some
Signals/km	0.6–3.0	2–6	4–8
Pedestrian activity	Little	Some	Usually
Roadside development density	Low to medium	Medium to moderate	High

A3.7 Determining the free speed of other urban roads, continued

Procedure, continued

Functional category

Criterion	**Principal**	**Minor**
Mobility function	Very important	Important
Access function	Very minor	Substantial
Points connected	Motorways, important activity centres, major traffic generators	Principal arterials
Predominant trips served	Relatively long trips between major points and through-trips entering, leaving, and passing through the city	Trips of moderate length within relatively small geographical areas

2 Determine the **free speed** for the road section as follows:

If the road classification is…	Then the range of likely free speeds are between…	And a typical free speed would be…
Class I	60 and 65 km/h	63 km/h
Class II	50 and 60 km/h	55 km/h
Class III	45 and 55 km/h	50 km/h

A3.8 Determining the capacity of road sections

Introduction

In the absence of measured capacities, the capacity of a road section shall be determined by the methods specified in this appendix for each facility type according to the conditions that prevail during the time interval. For example, when estimating capacity: the proportion of commercial vehicles, the average intensity of conflicting flows, and the performance of traffic control devices during the time interval shall be taken into account.

For other road types not covered by these procedures refer to the HCM.

In fulfilling the requirement that demand is in approximate equilibrium with supply, the procedure adopted for estimating future traffic volumes must ensure that in particular, the estimated traffic volume over any time period is less than the total available capacity for the time period of all road sections and intersections located within and near the project under analysis

Blocking back onto upstream sections

Where traffic volumes exceed capacity, the resulting queues may block back onto upstream links. In such circumstances care must be taken that the delays arising on the under-capacity section are not double counted on any upstream section.

Selecting the appropriate procedure

Follow the steps below to select the appropriate procedure for determining the capacity of each road section.

<table>
<tr><th>Step</th><th colspan="3">Action</th></tr>
<tr><td rowspan="10">1</td><td colspan="3">Select the appropriate procedure for determining the capacity of each road section as follows:</td></tr>
<tr><td>If the road section is….</td><td colspan="2">Then go to…</td></tr>
<tr><td>a motorway section</td><td colspan="2">appendix A3.9</td></tr>
<tr><td>a multilane road</td><td colspan="2">appendix A3.10</td></tr>
<tr><td>a two-lane rural road</td><td colspan="2">appendix A3.11</td></tr>
<tr><td rowspan="5">an other urban road</td><td colspan="2">appendix A3.22
It is not necessary to determine capacity for travel time. However the capacities below are required when determining the additional congestion vehicle operating cost.</td></tr>
<tr><td>Road class</td><td>Capacity</td></tr>
<tr><td>Class I</td><td>1200 veh/lane/hour</td></tr>
<tr><td>Class II</td><td>900 veh/lane/hour</td></tr>
<tr><td>Class III</td><td>600 veh/lane/hour</td></tr>
<tr><td>2</td><td colspan="3">Once the capacity has been determined go to appendix A3.12.</td></tr>
</table>

A3.9 Determining the capacity of motorways

When to use

This procedure is called from appendix A3.8.

Procedure

Following the steps below to determine the capacity of a motorway section where each direction of travel is a separate motorway section component (See appendix A2.3). Capacities are expressed as passenger car equivalents (pcu).

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td rowspan="5">1</td><td colspan="2">Determine the **basic capacity** for the motorway section as follows:</td></tr>
<tr><td>If the road section has...</td><td>Then use a basic capacity of…</td></tr>
<tr><td>2 through lanes</td><td>4,500 pcu/h</td></tr>
<tr><td>3 through lanes</td><td>6,900 pcu/h</td></tr>
<tr><td>4 through lanes</td><td>9,600 pcu/h</td></tr>
<tr><td rowspan="5">2</td><td colspan="2">Determine the passenger car equivalent to be used for trucks for the motorway section as follows:</td></tr>
<tr><td>If the terrain type is…</td><td>Then use a passenger car equivalent for trucks (E_t) of…</td></tr>
<tr><td>level</td><td>1.7 pcu</td></tr>
<tr><td>rolling</td><td>4.0 pcu</td></tr>
<tr><td>mountainous</td><td>8.0 pcu</td></tr>
<tr><td>3</td><td colspan="2">Calculate the adjustment factor for trucks using the passenger car equivalent for trucks (E_t) determined in step 2.
Adjustment factor (f_t) = $1/ (1 + P_t \times (E_t - 1))$
where P_t = the proportion of trucks in the traffic stream during the peak period.
Example:
Terrain type = rolling
Proportion of trucks (P_t) = 0.12
Pcu for trucks (E_t) = 4.0 pcu
Adjustment factor (f_t) = $1/(1 + 0.12 \times (4.0 - 1))$
= 0.735</td></tr>
</table>

A3.9 Determining the capacity of motorways, continued

Procedure, continued

Step	Action
4	Calculate the motorway section capacity by multiplying the basic capacity, determined in step 1, by the adjustment factor for trucks (f_t) determined in step 3. Motorway section capacity = Basic capacity x f_t Example: Through lanes = 3 lanes Basic capacity = 6,900 pcu/h Adjustment factor (f_t) = 0.735 Motorway section capacity = 6,900 × 0.735 = 5072 veh/h

Using field measurements

If actual field measurements at the site give a different capacity from that which is determined above, then the field measurements should be used. However, if field measurements are used, then the analyst must prove that the measurements are representative of the average capacity in a variety of conditions.

Accounting for auxiliary lanes

Auxiliary lanes within road sections may contribute to the road's capacity in which case the detailed procedures of the HCM shall be used. Otherwise the auxiliary lanes shall be considered not to contribute to the capacity.

A3.10 Determining the capacity of multilane roads

When to use This procedure is called from appendix A3.8.

Procedure Follow the steps below to determine the capacity of a multilane road.

Step	Action
1	Obtain 'the sum of the basic free speed reductions' for the multilane road section, as determined in appendix A3.8. Example: Free speed reductions for: dividing median = 0 km/h lane width = 0 km/h lateral clearance = 4 km/h access points = 4 km/h Sum of the basic free speed reductions = 8 km/h Note: If the free speed for the multilane road section was measured rather than estimated, then use step 1 of the procedure in appendix A3.8 to determine the multilane road basic free speed, and subtract the measured free speed to obtain the equivalent of 'the sum of the basic free speed reductions'.
2	Determine the capacity of the multilane road section as follows:

If the sum of the basic free speed reduction is…	Then use a capacity of…
zero	2,200 veh/h per lane
between 0 and 30 km/h	2,200 veh/h per lane minus 10 veh/h per lane for every km/h of basic free speed reductions
above 30 km/h	1,900 veh/h per lane

Example:

Sum of the basic free

speed reductions = 8 km/h

Road section capacity = 2,200 – 8 × 10

= 2,120 veh/h per lane

A3.11 Determining the capacity of two-lane rural roads

When to use

This procedure is called from appendix A3.8.

The capacity of the road section shall be calculated by adjusting the ideal capacity of 2,800 veh/h (total in both directions of travel) to account for the following factors:

- directional distribution of traffic during the time period
- the presence of narrow lanes and restricted shoulders
- the proportion of heavy vehicles in the flow.

Procedure

Follow the steps below to determine the capacity of a two-lane rural road section.

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td rowspan="8">1</td><td colspan="2">Determine the adjustment factor for traffic **directional distribution** during the time period as follows:</td></tr>
<tr><td>If the directional distribution is…</td><td>Then use an adjustment factor of:</td></tr>
<tr><td>100/0</td><td>0.71</td></tr>
<tr><td>90/10</td><td>0.77</td></tr>
<tr><td>80/20</td><td>0.83</td></tr>
<tr><td>70/30</td><td>0.89</td></tr>
<tr><td>60/40</td><td>0.94</td></tr>
<tr><td>50/50</td><td>1.00</td></tr>
<tr><td>2</td><td colspan="2">Determine the total roadway width. The total roadway width equals the lane width(s) plus sealed shoulder width. Round to the nearest metre.</td></tr>
<tr><td rowspan="8">3</td><td colspan="2">With the total roadway width determined in step 2 determine the adjustment factor for **trafficable width** as follows:</td></tr>
<tr><td>If the total roadway width is…</td><td>Then use an adjustment factor of:</td></tr>
<tr><td>8 metres or greater</td><td>1.00</td></tr>
<tr><td>7 metres</td><td>0.91</td></tr>
<tr><td>6 metres</td><td>0.82</td></tr>
<tr><td>5 metres</td><td>0.73</td></tr>
<tr><td>4 metres</td><td>0.65</td></tr>
<tr><td>less than 4 metres</td><td>0.60</td></tr>
</table>

A3.11 Determining the capacity of two-lane rural roads, continued

Procedure, continued

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>4</td><td>Determine the passenger car equivalent for trucks for the road section as follows:
<table>
<tr><th>If the terrain type is…</th><th>Then use a passenger car equivalent for trucks (E_t) of:</th></tr>
<tr><td>level</td><td>2.2 pcu</td></tr>
<tr><td>rolling</td><td>5.0 pcu</td></tr>
<tr><td>mountainous</td><td>10.0 pcu</td></tr>
</table></td></tr>
<tr><td>5</td><td>Calculate the adjustment factor for trucks using the passenger car equivalent for trucks (E_t) determined in step 4.
Adjustment factor (f_t) = 1/(1 + Pt x (E_t- 1))
Where P_t is the proportion of trucks in the traffic stream during the time period
Example:
Terrain type = rolling
Proportion of trucks (P_t) = 0.10
pcu for trucks (E_t) = 5.0 pcu
Adjustment factor (f_t) = 1/[1 + 0.10 × (5.0 – 1))]
= 0.714</td></tr>
<tr><td>6</td><td>Calculate the road section capacity by multiplying the ideal two-way capacity of 2,800 veh/h by the adjustment factors determined in steps 1, 3 and 5.
Road section capacity = Ideal capacity x adjustment factor for directional distribution x adjustment factor for trafficable width x f_t
Example:
Directional distribution = 70/30
Trafficable width = 7.0 metres
Adjustment factors:
directional distribution = 0.89
trafficable width = 0.91
trucks = 0.714
Road section capacity = 2800 × 0.89 × 0.91 × 0.714
= 1620 veh/h</td></tr>
<tr><td>7</td><td>Calculate the peak direction capacity using the road section capacity determined in step 6.
Peak direction capacity = road section capacity x proportion of traffic in the peak direction
Example:
Proportion of traffic in peak direction = 0.7
Peak direction capacity = 1620 × 0.7
= 1134 veh/h</td></tr>
</table>

A3.12 Determining whether vehicle interactions are significant

Introduction

When the effects of vehicle interactions are significant on road sections it is necessary to calculate the additional travel time caused by those interactions. Vehicle interactions do not apply to other urban roads.

Procedure

Follow the steps below to determine whether the effects of vehicle interactions are significant:

<table>
<tr><th>Step</th><th colspan="3">Action</th></tr>
<tr><td>1</td><td colspan="3">Use the capacity for the road section determined in appendix A3.8.</td></tr>
<tr><td>2</td><td colspan="3">Take a time period with its corresponding traffic volume (demand) as determined in appendix A3.3.</td></tr>
<tr><td>3</td><td colspan="3">Calculate the volume to capacity ratio.
Example:
Time period = 0700 to 0900
Time period traffic vol = 6202 vehicles
Traffic flow = 6202/2
= 3101 veh/h
Capacity = 4300 veh/h
Volume to capacity ratio = 3101 / 4300
= 0.72</td></tr>
<tr><td rowspan="8">4</td><td colspan="3">Determine whether the effects of vehicle interactions are significant as follows:</td></tr>
<tr><th>If the road section is a…</th><th>And the volume to capacity ratio is…</th><th>Then vehicle interactions…</th></tr>
<tr><td>motorway section</td><td>greater than 0.7</td><td>shall be considered (go to appendix A3.13)</td></tr>
<tr><td>motorway section</td><td>0.7 or less</td><td>are not considered (go to appendix A3.21)</td></tr>
<tr><td>multilane road</td><td>greater than 0.7</td><td>shall be considered (go to appendix A3.13)</td></tr>
<tr><td>multilane road</td><td>0.7 or less</td><td>are not considered (go to appendix A3.21)</td></tr>
<tr><td>two-lane rural road</td><td>greater than 0.7</td><td>shall be considered (go to appendix A3.13)</td></tr>
<tr><td>two-lane rural road</td><td>0.7 or less</td><td>are not considered (go to appendix A3.21)</td></tr>
<tr><td>5</td><td colspan="3">Repeat steps 2 to 4 for any other time periods in which traffic volumes are likely to result in significant vehicle interactions.</td></tr>
</table>

A3.13 Types of delay

Introduction

This section describes the difference between vehicle interaction delay and bottleneck delay, explaining why the two types of delay require different procedures to calculate their levels.

Definition of vehicle interaction delay

Vehicle interaction delay is the delay that occurs as demand approaches capacity, and each vehicle's progress is impeded by the proximity of other vehicles.

Ideally, no delay would occur when demand was below capacity, but variations in driver behaviour and differences in speed between individual vehicles mean that delay does occur. Because the actual delay depends on the many variable factors, vehicle interaction delay is also known as *random delay*.

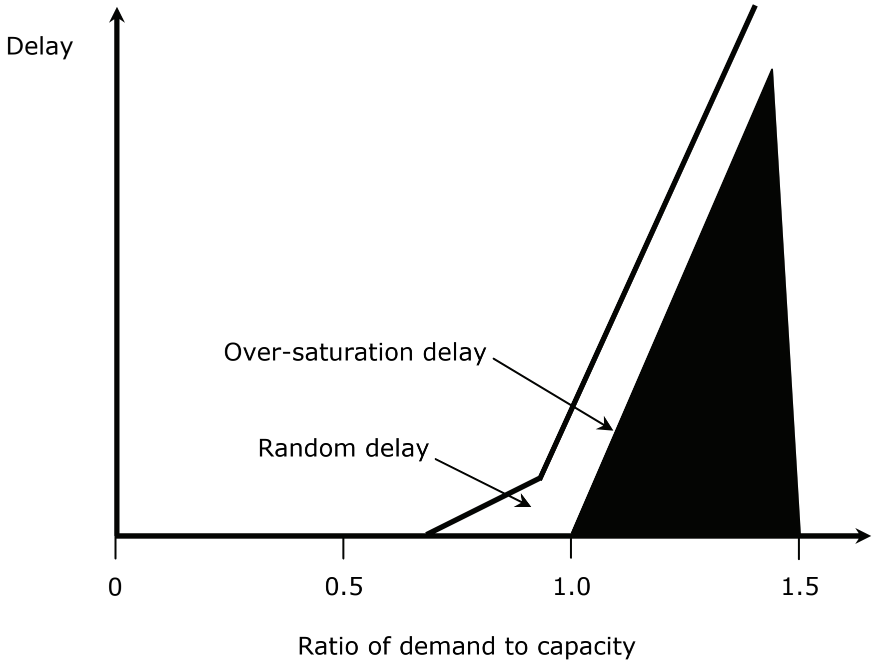
Definition of bottleneck delay

Bottleneck delay is the delay which is experienced when the demand at some location exceeds the capacity of the road at the location. Such delays occur at a point on the road section where the capacity is below that of the upstream capacity, and equal to or less than the downstream capacity.

Because bottleneck delay occurs when demand exceeds capacity (ie, when the volume to capacity ratio exceeds 1.0), it is also known as *over-saturation delay*.

Diagram

The diagram below shows approximately when vehicle interaction (or random) delay and bottleneck (or over-saturation) delay occur.



A3.14 Average peak interval traffic intensity

Background

As traffic volumes on a road increase vehicle interactions increase, and as a result the average travel time per vehicle increases. The additional travel time that results from vehicle interactions is a function of the volume to capacity flow ratio (VC ratio), where VC ratio is the ratio of demand volume to road capacity averaged over a period of time. When predicting the average travel time to traverse a section of road, the extent to which averaging smoothes the flow profile will affect the accuracy of the estimate of the additional travel time due to vehicle interactions. Peak interval analysis is one method of correcting for potential loss of accuracy.

Average time period traffic intensity

The average time period traffic intensity is the average traffic flow for the time period under analysis. It is generally reported as vehicles per hour, or vehicles per x minutes.

Peak interval

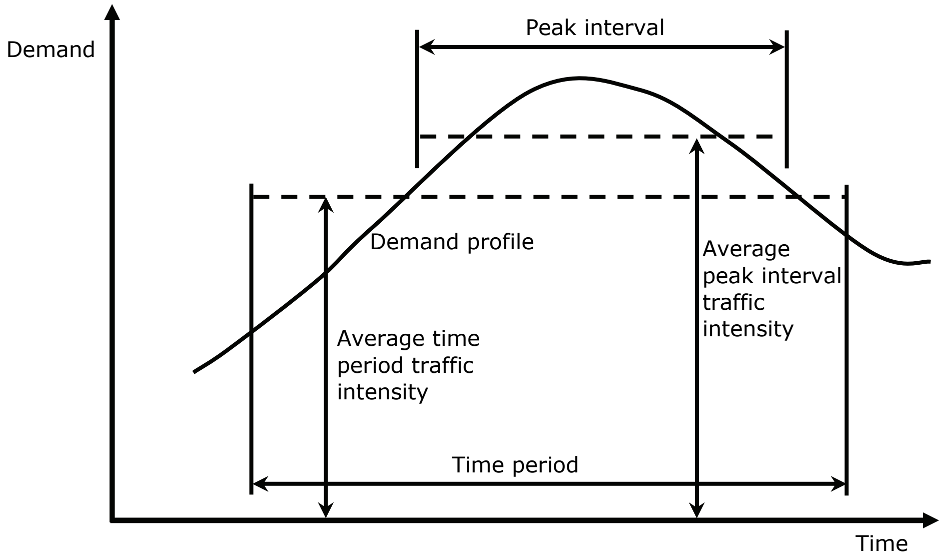
The peak interval (in minutes) is that portion of the time period over which the demand is greater than the average time period traffic intensity.

Average peak interval traffic intensity

The average peak interval traffic intensity is the average traffic flow for the peak interval. The average peak interval traffic intensity is used in the analysis to determine delays. Generally average peak interval traffic intensity is reported in vehicles per hour.

Peak interval diagram

The diagram below shows the relationship between the time period and the peak interval, and the relationship between the average traffic intensities for the time period and the peak interval.



A3.15 Determining the peak interval

When to use

Use this procedure if the conclusion from the procedure in appendix A3.12 'determining whether vehicle interactions are significant' was that vehicle interactions shall be considered.

Procedure

Follow the steps below to determine the peak interval.

Step	Action
1	Select a time period to be analysed (usually the weekday morning or evening commuter peak). See appendix A2.4. Note: The time period must be long enough to ensure sufficient capacity, even though for some time that capacity is exceeded.
2	Identify the time interval that traffic data for the time period has been collected (usually 5, 10 or 15 minute intervals).
3	Set out the traffic data for the time period. Example:

Time	Observed traffic volume
7:00 – 7:15	800
7:15 – 7:30	1,040
7:30 – 7:45	1,200
7:45 – 8:00	1,280
8:00 – 8:15	1,240
8:15 – 8:30	1,140
8:30 – 8:45	1,020
8:45 – 9:00	840

Step	Action
4	Calculate the average time period traffic intensity (F_{tp}) (see definition in appendix A3.14) Example: Time period traffic volume = 8,560 vehicles Length of time period = 2 hours Traffic data time interval = 15 minutes Average time period traffic intensity (F_{tp}) = 8,560 / (2 × 60 / 15) = 1,070 per 15 minutes

A3.15 Determining the peak interval, continued

Procedure, continued

Step	Action
5	Identify when the observed traffic volume rose above the average time period traffic intensity (F_{tp}) Example: From step 3, the interval 7:30-7:45 was the first interval with an observed traffic volume greater than the average time period traffic intensity (F_{tp}) Start time of interval (t_i) = 7:30 Volume in interval (v_i) = 1,200 vehicles Volume in prior interval (v_{i-1}) = 1,040 vehicles
6	Calculate the peak interval start, which is the notional time at which the flow rate rose above the average time period traffic intensity (F_{tp}). Peak interval start = $t_i + (F_{tp} - v_{i-1})/v_i - v_{i-1}) \times$ interval from step 2 Example: Peak interval start = 7:30 + (1,070 - 1,040)/(1,200 - 1,040) × 15 = 7:32.8
7	Identify when the observed traffic volume fell below the average time period traffic intensity (F_{tp}). Example: From step 3, the interval 8:30 – 8:45 was the first interval after the peak with an observed traffic volume lower than the average time period traffic intensity (F_{tp}). Start time of interval (t_i) = 8:30 Volume in interval (v_i) = 1,020 vehicles Volume in prior interval (v_{i-1}) = 1,140 vehicles
8	Calculate the peak interval end, which is the notional time at which the flow rate fell below the average time period traffic intensity (F_{tp}). Peak interval end = $t_i + (v_{i-1} - F_{tp})/(v_{i-1} - v_i)$ x interval Example: Peak interval end = 8:30 + (1140 - 1070)/(1140 - 1020) × 15 = 8:38.8
9	Calculate the length of the peak interval. Example: Peak interval start = 7:32.8 Peak interval end = 8:38.8 Length of peak interval = 8:38.8 – 7:32.8 = 66.0 minutes

A3.16 Calculating the average peak interval traffic intensity

When to use Use this procedure after having determined the peak interval in appendix A3.15.

Procedure Follow the steps below to calculate the average peak interval traffic intensity.

Step	Action
1	Calculate the peak interval traffic volume. Example: Peak interval start = 7:32.8 Peak interval end = 8:38.8 Volume 7:30 – 7:45 = 1200 vehicles Volume 7:45 – 8:00 = 1280 vehicles Volume 8.00 – 8.15 = 1240 vehicles Volume 8:15 – 8:30 = 1140 vehicles Volume 8:30 – 8:45 = 1020 vehicles Peak interval traffic vol = (7:45 – 7:32.8)/15 × 1200 + 1280 + 1240 + 1140 + (8:38.8 – 8:30)/15 × 1020 = 5234 vehicles
2	Calculate the average peak interval traffic intensity (F_{pi}). Example: Length of peak interval = 66.0 minutes Average peak interval traffic intensity (F_{pi}) = 5234 × 60/66.0 = 4758 veh/h

A3.17 Calculating the volume to capacity ratio

When to use

The volume to capacity ratio is also known as the saturation ratio.

Procedure

Follow the steps below to determine the volume to capacity ratio (VC ratio).

<table>
<tr><th>Step</th><th colspan="2">Action</th></tr>
<tr><td rowspan="6">1</td><td colspan="2">Determine the appropriate capacity for calculating the volume to capacity ratio as follows:</td></tr>
<tr><td>If the road section is a…</td><td>Then use the…</td></tr>
<tr><td>motorway section</td><td>capacity determined in appendix A3.9</td></tr>
<tr><td>multilane highway</td><td>capacity determined in appendix A3.10</td></tr>
<tr><td>two-lane rural road</td><td>peak direction capacity determined in appendix A3.11</td></tr>
<tr><td>other urban road</td><td>capacity specified in appendix A3.8</td></tr>
<tr><td>2</td><td colspan="2">Obtain the average peak interval traffic intensity (F_{pi}) as determined in appendix A3.16, and use this volume in step 3.
Note: If the volume to capacity ratio is being calculated for a time period for which it is not appropriate to calculate F_{pi}, then use an appropriate peak volume.</td></tr>
<tr><td>3</td><td colspan="2">Calculate the volume to capacity ratio using the appropriate capacity and traffic volume determined in steps 1 and 2.
Example:
Volume to capacity ratio = volume/capacity
= 4758/5072
= 0.938</td></tr>
</table>

A3.18 Calculating the additional travel time

Introduction

The average additional travel time above that experienced when travelling at the free speed shall be determined as a function of the volume to capacity ratio during the peak interval of a given time period.

The additional travel time calculated for the peak interval is also used as the value for time period additional travel time.

Procedure

Follow the steps below to calculate the additional travel time.

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1</td><td>Determine the appropriate procedure for the road section as follows
<table>
<tr><th>If the road section is a…</th><th>Then go to…</th></tr>
<tr><td>motorway section</td><td>step 2, and then step 4</td></tr>
<tr><td>multilane highway</td><td>step 2, and then step 4</td></tr>
<tr><td>two-lane rural road</td><td>step 3, and then step 4</td></tr>
</table></td></tr>
<tr><td>2</td><td>Calculate the peak interval additional travel time factor, using the volume to capacity ratio determined in appendix A3.17, as follows (for motorways and multilane roads only):
<table>
<tr><th>If the peak interval volume to capacity ratio is…</th><th>Then the peak interval additional travel time factor (F_{dr}) equals…</th></tr>
<tr><td>less than or equal to 0.7</td><td>0</td></tr>
<tr><td>between 0.7 and 1.0</td><td>0.27 × (VC ratio – 0.70)</td></tr>
<tr><td>equal to or greater than 1.0</td><td>0.081</td></tr>
</table>
Go to step 4.</td></tr>
<tr><td>3</td><td>Determine the peak interval additional travel time factor from the tables below, using the volume to capacity ratio determined in appendix A3.17 for two-lane rural roads only.
Additional travel time factor for level terrain
<table>
<tr><th rowspan="2">VC ratio</th><th colspan="6">Percent no-passing</th></tr>
<tr><th>0</th><th>20</th><th>40</th><th>60</th><th>80</th><th>100</th></tr>
<tr><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td></tr>
<tr><td>0.10</td><td>0.04</td><td>0.04</td><td>0.05</td><td>0.05</td><td>0.06</td><td>0.06</td></tr>
<tr><td>0.20</td><td>0.08</td><td>0.08</td><td>0.09</td><td>0.10</td><td>0.10</td><td>0.11</td></tr>
<tr><td>0.30</td><td>0.11</td><td>0.12</td><td>0.12</td><td>0.13</td><td>0.14</td><td>0.14</td></tr>
<tr><td>0.40</td><td>0.14</td><td>0.14</td><td>0.15</td><td>0.16</td><td>0.16</td><td>0.17</td></tr>
<tr><td>0.50</td><td>0.16</td><td>0.16</td><td>0.17</td><td>0.18</td><td>0.18</td><td>0.19</td></tr>
<tr><td>0.60</td><td>0.18</td><td>0.19</td><td>0.19</td><td>0.20</td><td>0.20</td><td>0.21</td></tr>
<tr><td>0.70</td><td>0.21</td><td>0.21</td><td>0.21</td><td>0.22</td><td>0.22</td><td>0.23</td></tr>
<tr><td>0.80</td><td>0.24</td><td>0.24</td><td>0.24</td><td>0.25</td><td>0.25</td><td>0.25</td></tr>
<tr><td>0.90</td><td>0.27</td><td>0.27</td><td>0.28</td><td>0.28</td><td>0.28</td><td>0.28</td></tr>
<tr><td>1.00</td><td>0.32</td><td>0.32</td><td>0.32</td><td>0.32</td><td>0.32</td><td>0.32</td></tr>
</table></td></tr>
</table>

A3.18 Calculating the additional travel time, continued

Procedure, continued

Step	Action						
3, cont.	**Additional travel time factor for rolling terrain**						
	VC ratio	**Percent no-passing**					
		0	**20**	**40**	**60**	**80**	**100**
	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	0.10	0.06	0.06	0.07	0.08	0.09	0.09
	0.20	0.11	0.12	0.13	0.13	0.14	0.15
	0.30	0.14	0.15	0.16	0.17	0.18	0.18
	0.40	0.16	0.17	0.19	0.20	0.20	0.20
	0.50	0.18	0.19	0.21	0.22	0.23	0.23
	0.60	0.20	0.22	0.24	0.25	0.26	0.26
	0.70	0.23	0.26	0.28	0.30	0.31	0.31
	0.80	0.29	0.32	0.35	0.37	0.38	0.39
	0.90	0.38	0.42	0.45	0.47	0.49	0.50
	1.00	0.50	0.55	0.59	0.62	0.64	0.65
	Additional travel time factor for mountainous terrain						
	VC ratio	**Percent no-passing**					
		0	**20**	**40**	**60**	**80**	**100**
	0.00	0.00	0.00	0.01	0.02	0.03	0.03
	0.10	0.06	0.09	0.11	0.12	0.13	0.14
	0.20	0.13	0.16	0.19	0.20	0.22	0.23
	0.30	0.19	0.22	0.25	0.27	0.29	0.30
	0.40	0.24	0.28	0.31	0.33	0.35	0.37
	0.50	0.29	0.33	0.36	0.39	0.42	0.44
	0.60	0.35	0.40	0.43	0.47	0.50	0.53
	0.70	0.43	0.48	0.52	0.56	0.59	0.63
	0.80	0.54	0.59	0.64	0.68	0.72	0.75
	0.90	0.68	0.73	0.78	0.83	0.87	0.92
	1.00	0.86	0.92	0.98	1.03	1.07	1.12

A3.18 Calculating the additional travel time, continued

Procedure, continued

Step	Action
3, cont.	Alternatively calculate F_{dr} directly using the expression:

$$F_{dr} = \min(a + b.P_{NP} + d.P_{Np}^2\ g.P_{NP}^3 + c.VC\ ratio + e.VC\ ratio^2 + h.VC\ ratio^3 + f.P_{NP}.VC\ ratio + i.P_{NP}.VC\ ratio^2 + j.P_{NP}^2.VC\ ratio\ ,0)$$

where:

VC ratio = the volume to capacity flow ratio

P_{NP} = the percent no passing

And the coefficients a to j are given below

Coefficient	Level terrain	Rolling terrain	Mountainous terrain
a	-1.906×10^{-2}	-2.658×10^{-2}	-3.039×10^{-2}
b	1.420×10^{-4}	1.640×10^{-4}	1.480×10^{-3}
c	0.617	1.008	1.059
d	3.260×10^{-6}	3.610×10^{-6}	1.378×10^{-5}
e	-0.771	-1.918	-1.515
f	6.43×10^{-4}	6.220×10^{-4}	1.570×10^{-3}
g	-2.42×10^{-8}	-9.470×10^{-9}	5.260×10^{-8}
h	0.496	1.440	1.346
i	-8.70×10^{-4}	-1.748×10^{-3}	2.897×10^{-4}
j	-6.49×10^{-7}	-1.320×10^{-5}	-1.379×10^{-6}

A3.18 Calculating the additional travel time, continued

Procedure, continued

Step	Action
4	Calculate the peak interval additional travel time by multiplying the free speed travel time in appendix A3.4 by the factor from step 2 or 3. Peak interval additional travel time = free speed travel time x peak interval additional travel time factor (F_{dr}) Example 1: (motorway or multilane highway): Free speed travel time = 0.571 mins/km Volume to capacity ratio = 0.938 F_{dr} (from step 2) = 0.27 × (0.938 – 0.70) = 0.0643 Peak interval additional travel time = 0.571 × 0.0643 = 0.037 mins/km Time period additional travel time = Peak interval additional travel time = 0.037 mins/km Example 2: (two-lane rural road): Free speed travel time = 0.636 mins/km Terrain type = rolling Percent no-passing = 60% Volume to capacity ratio = 1.10 F_{dr} (from tables in step 3) = 0.62 Peak interval additional travel time = 0.636 × 0.62 = 0.394 mins/km Time period additional travel time = Peak interval additional travel time = 0.394 mins/km

A3.19 Calculating bottleneck delay

When to use

Use this procedure for all time periods during which demand exceeds capacity (volume to capacity ratio greater than one) at some time.

Blocking back onto upstream sections

Where traffic volumes exceed capacity, the resulting queues may block back onto upstream links. In such circumstances care must be taken to ensure that the delays that arise on the under-capacity section are not double counted on any upstream section.

Procedure

Follow the steps below to calculate bottleneck delay.

Step	Action
1	Select a time period to be analysed (usually the weekday morning or evening commuter peak).
2	Determine the capacity of the road section. See appendix A3.8.
3	Identify the time interval step that traffic data for the time period has been collected (usually 5, 10 or 15 minute periods).
4	Set out the traffic data for the time period. Example:

Time interval	Observed traffic volume
7:00 – 7:15	264
7:15 – 7:30	475
7:30 – 7:45	591
7:45 – 8:00	600
8:00 – 8:15	591
8:15 – 8:30	475
8:30 – 8:45	264
8:45 – 9:00	250
9:00 – 9:15	234

Step	Action
5	At each time interval, calculate the cumulative demand with a running total of observed traffic volume since the time period start. Cumulative demand at time interval = sum of observed traffic volume since time period start Example from step 4: Cumulative demand for time interval 8:00 to 8:15 = 264 + 475 + 591 + 600 + 591 = 2521

A3.19 Calculating bottleneck delay, continued

Procedure, continued

Step	Action
6	At each time interval, calculate the vehicles discharged. If the traffic volume for the time interval is below the road section capacity then all the traffic is discharged. Only the number of vehicles equivalent to the road section capacity is discharged if the traffic volume exceeds capacity. Example from step 4: Time interval = 8:00 to 8:15 Capacity = 500 vehicles Traffic volume = 591 vehicles Vehicles discharged = minimum of traffic volume or capacity = minimum (591, 500) = 500
7	At each time interval, calculate the cumulative discharge with a running total of vehicles discharged since the time period start. Cumulative discharge at time interval = sum of vehicles discharged since time period start
8	At each time interval, calculate the queue at the end of the interval when traffic volume exceeds capacity. Example from step 4: Time interval = 7:30 - 7:45 Traffic volume = 591 vehicles Capacity = 500 vehicles Queue at end of interval = traffic volume – capacity, if traffic volume > capacity = 0, if traffic volume ≤ capacity = 591 – 500 = 91 vehicles
9	At each time interval, calculate the queue at the start of the interval. This is the queue at the end of the previous interval. Time interval = 7:30 - 7:45 Queue at start of interval = queue at end of previous interval = 91 vehicles

A3.19 Calculating bottleneck delay, continued

Procedure, continued

Step	Action
10	At each time interval, calculate the average delay in vehicle minutes. Average delay = interval time step x (queue at end of interval + queue at start of interval)/2
11	Sum the average delays over the entire time period to obtain the time period total delay.
12	Calculate the time period average delay per vehicle from the time period total delay divided by the cumulative discharge of vehicles at the time period end. Average delay per vehicle = total delay / cumulative discharge of vehicles at the time period end

Example

An example of the bottleneck delay calculation using the data from step 4 and a road capacity of 500 vehicles.

Start time	Demand (veh)	Cumulative demand (veh)	Vehicles discharged (veh)	Cumulative discharge (veh)	Queue at end of interval	Queue at start of interval	Average delay (veh-min)
Step	**4**	**5**	**6**	**7**	**8**	**9**	**10**
7:00	264	264	264	264	0	0	0.0
7:15	475	739	475	739	0	0	0.0
7:30	591	1330	500	1239	91	0	682.5
7:45	600	1930	500	1739	191	91	2115.0
8:00	591	2521	500	2239	282	191	3547.5
8:15	475	2996	500	2739	257	282	4042.5
8:30	264	3260	500	3239	21	257	2085.0
8:45	250	3510	271	3510	0	21	157.5
9:00	234	3744	234	3744	0	0	0.0

Step 11. Time period total delay

= 682.5 + 2115 + 3547.5 + 4042.5 + 2085 + 157.5

= 12630 veh-mins

Step 12. Time period average delay per vehicle

= 12630 / 3744

= 3.37 min/veh

A3.20 Determining whether to consider peak spreading

Introduction

Some peak spreading may occur at low levels of bottleneck delay, but in general, drivers will only begin to refine their trips when bottleneck delays are severe.

Procedure

Follow the steps below to determine whether peak spreading should be considered.

Step	**Action**
1	Calculate the average delay per delayed vehicle, using the time period average delay per vehicle determined in appendix A3.19. Average delay per delayed vehicle = Time period average delay per vehicle x (Time period traffic volume/ sum of traffic volumes of intervals with an end queue) Example (using the example in appendix A3.19): Average delay per delayed veh icle = 3.37 x (3744 / (591 + 600 + 591 + 475 + 264)) = 3.37 x (3744 / 2521) = 5.0 mins/veh
2	Determine whether peak spreading should be considered as follows:

If the average minutes delay per delayed vehicle is…	And there is…	Then peak spreading…
between 0 and 15		does not need to be considered
between 15 and 25	an alternative route	does not need to be considered
between 15 and 25	no alternative route	shall be considered, use appendix A11.2
25 or greater		shall be considered, use appendix A11.2

A3.21 Determining the additional travel time resulting from speed change cycles

Introduction

If vehicles are required to slow to negotiate some isolated feature and then accelerate back to cruise speed the travel time estimated above must be increased to account for the time lost during this speed change cycle. Where the initial cruise speed and the minimum speed are available, tables in appendix A5.7 provide the amount of additional travel time in seconds for speed change cycles.

In the absence of measured data, the additional travel time that occurs as a result of having to slow for substandard horizontal curves can be approximated using this procedure.

Procedure

Follow the steps below to determine the additional travel time resulting from speed change cycles associated with substandard curves.

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1</td><td>
Determine the curve negotiating speed for each vehicle type in the traffic mix.
The desired negotiation speed for an isolated curve (S_c) is related to the ideal approach speed (S_a) and the curve radius (R) by the following equation: $S_c = a_0 + a_1.S_a + a_2 / R$
Where: $S_a = f_1.F_S$
F_s is the average free speed determined from appendix A3.9 and the coefficients f_1,a_0, a_1, and a_2 are as follows:
<table>
<tr><th>Vehicle type</th><th>f_1</th><th>a_0</th><th>a_1</th><th>a_2</th></tr>
<tr><td>Car</td><td>1.00</td><td>45.21</td><td>0.5833</td><td>-3892</td></tr>
<tr><td>LCV</td><td>0.97</td><td>54.51</td><td>0.4531</td><td>-3337</td></tr>
<tr><td>MCV</td><td>0.89</td><td>51.77</td><td>0.4744</td><td>-3245</td></tr>
<tr><td>HCV I</td><td>0.91</td><td>59.16</td><td>0.4068</td><td>-3506</td></tr>
<tr><td>HCV II</td><td>0.91</td><td>69.57</td><td>0.3085</td><td>-3768</td></tr>
<tr><td>Bus</td><td>0.91</td><td>59.16</td><td>0.4068</td><td>-3506</td></tr>
</table>
Example:
A horizontal curve of radius 100m exists within a road section where the free speed is estimated at 94.33 km/h.
Ideal approach speed = 0.89×94.33
For MCV = 84 km/h
Desired negotiation speed for MCV
= $51.77 + 0.4744 \times 84 - 3245/100$
= 59 km/h
</td></tr>
</table>

A3.21 Determining the additional travel time resulting from speed change cycles, continued

Procedure, continued

Step	Action
2	Determine the initial operating speed of the road section. The operating speed is the sum of the free speed travel time and the time period additional travel time all divided by the section length. This accounts for the reduction in the ideal approach speed as a result of traffic interactions. Initial operating speed = length/(TT_{FS} + TT_{ATT}) Example: 1 km at free speed travel time = 0.636 mins/km 1 km additional travel time for vehicle interactions (appendix A3.18) = 0.636 × 0.2 = 0.127 mins/km Initial operating speed = 1.00 / (0.636+0.127) × 60 = 1.00/0.763 × 60 = 79 km/hr
3	The additional travel time associated with speed change cycles is then determined from the appropriate table in appendix A5.7. Note: Where the desired negotiating speed is greater than the operating speed no speed change will occur. Example: Using table A5.28 Initial cruise speed for all vehicles = 79 km/h Curve speed for MCV = 59 km/h MCV additional travel time per speed change = 2.0 seconds
4	Calculate the total speed change cycle travel time for a road section with the additional following information. Traffic volume for the time period Traffic composition (default values available in appendix A2.2) For each vehicle type: • proportion in traffic from traffic composition • number of vehicles = traffic volume x proportion in traffic • additional travel time = number of vehicles x additional travel time for speed change cycles Sum over all vehicle types to obtain the total additional travel time.

A3.22 Calculating the time period total average travel time

When to use

Use this procedure once free speed and delays caused by vehicle interactions and speed changes have been calculated.

Note: For 'other urban roads', this procedure is called from appendix A3.8.

Procedure

Follow the steps below to calculate the time period total average travel time per vehicle.

Step	Action
1	Use the following previously calculated values: • free speed travel time (appendix A3.4) • time period additional travel time (appendix A3.18) • time period average delay per vehicle (appendix A3.19) • additional travel time due to speed changes (appendix A3.21) 'Other urban roads' only have a free speed travel time. 'Other urban roads' do not exhibit reductions in travel times with increasing traffic volumes. Travel times generally remain constant at the free speed. All delays due to increasing traffic volumes can be attributed to intersections as calculated in appendices A3.23 to A3.25. For motorway sections and multilane roads: • time period additional travel time is only calculated if the volume to capacity ratio exceeds 0.7 (see appendix A3.12) • bottleneck delay is only calculated if demand exceeds capacity at some time during the time period.
2	Multiply the free speed travel time and the time period additional travel time by the road section length.
3	Sum the values in step 2 and the bottleneck delay to get the time period total average travel time per vehicle.

Example

Section length = 1.00 km

Free speed travel time = 0.636 mins/km

Time period additional travel time = 0.232 mins/km

Speed change additional travel time = 0.003 mins

Bottleneck delay per vehicle = 1.5 mins/veh

Time period total average travel time

$$= (TT_{FS} + TT_{ATT}) \times \text{length} + \text{bottleneck delay} + \text{speed change}$$

$$= (0.636 + 0.232) \times 1.00 + 1.5 + 0.003$$

$$= 2.371 \text{ mins/veh}$$

A3.23 Traffic signals

Traffic signals

Travel time delays associated with traffic signals are the result of a complex interaction between arrivals on opposing phases, the response of the signal controller to detector impulses and external control commands, and vehicle driver responses. The physical layout, location, and phasing strategy also affect operations.

Commonly available analysis procedures are based on simplifying assumptions that reduce an essentially dynamic and stochastic process to a deterministic approximation of real events. Reliable estimates of delay require the careful selection of values for the governing variables and a thorough understanding of traffic operations at each site.

While the procedures of the HCM provide a useful guide, the more commonly understood methods of the ARRB publication ARR 123 should be followed.

This appendix uses HCM to derive a major modification to the ARR 123 methods to account for the proximity of other signals including linking or coordination.

Capacity or saturation flow rate

The average delay to all vehicles, irrespective of the turns made, shall be the basis of the analysis. Thus the methodology is approach based, not movement based.

Ideally, saturation flow rates for each approach should be determined from direct observation at the site. Approach saturation flow rates for the relevant lane groups can be estimated as specified below.

The procedure consists of adjusting an ideal saturation flow rate of 2,000 passenger cars units per hour of green by the factors tabulated in the following tables.

Parking movements refers to the number of such movements, in and out, within a length of 50 metres on either side of the intersection.

A3.23 Traffic signals, continued

Table A3.1 Lane width factors

Lane width (metres)	Factor
3.5	1.00
3.4	0.99
3.3	0.98
3.2	0.97
3.1	0.96
3.0	0.95

Table A3.2 Approach grade factors

Gradient %	Factor
-4	1.02
-2	1.01
0	1.00
+2	0.99
+4	0.98

Table A3.3 Parking factors

Parking movements (number/hour)	Approach lanes		
	1	2	3
0	0.90	0.95	0.97
10	0.85	0.92	0.95
20	0.80	0.89	0.93
30	0.75	0.87	0.85
40	0.70	0.85	0.89

Table A3.4 Locality factors

Type of street	Factor
CBD Shopping	0.90
Suburban Shopping	0.95
Other	1.00

A3.23 Traffic signals, continued

Cycle times and phase splits

Appropriate cycle times and phase splits shall be determined according to the conditions that prevail during the peak interval. In particular, the influence of minimum phase times for parallel pedestrian facilities, actual all-red periods, and other influences on lost-time shall be included.

Peak interval average travel time

The peak interval average travel time shall be the average delay calculated by the methods of ARR 123 adjusted to account for controller type and the arrival pattern of platoons produced by nearby intersections by applying the relevant delay adjustment factor specified below.

The arrival type is best observed in the field, but can be assessed by examining time-space diagrams for the arterial or street on which the approach is located.

It should be noted that fully vehicle actuated controllers, remote from other signals, produce delays 15% below that estimated by the methods of ARR 123.

Care must be exercised in applying the adjustment factors. Arrival types 1 and 5 will seldom occur unless either unfavourable or efficient linking control is imposed.

Platoons released by upstream signals will disperse according to the prevailing speed environment and the distance between successive signal controlled intersections. The following table provides a broad guide to such effects.

A3.23 Traffic signals, continued

Table A3.5 Arrival type

Arrival type	Condition
1	Dense platoon arriving at the commencement of red.
2	Dense platoon arriving near the middle of the red phase, or Dispersed platoon arriving at the commencement of red.
3	Random arrivals or dispersed platoons arriving throughout both the green and red phases. This condition applies to isolated intersections or those with cycle times differing from nearby signal controlled intersections.
4	Dense platoon arriving near the middle of the green phase, or Dispersed platoon arriving throughout the green phase.
5	Dense platoon arriving at the commencement of the green phase.

Table A3.6 Delay adjustment factor

Type of signal	Volume to capacity ratio	Adjustment factor				
		Arrival type				
		1	2	3	4	5
Pre-timed	≤ 0.6	1.85	1.35	1.00	0.72	0.53
	0.8	1.50	1.22	1.00	0.82	0.67
	1.0	1.40	1.18	1.00	0.90	0.82
Actuated	≤ 0.6	1.54	1.08	0.85	0.62	0.40
	0.8	1.25	0.98	0.85	0.71	0.50
	1.0	1.16	0.94	0.85	0.78	0.61
Semi-actuated on main road approach	≤ 0.6	1.85	1.35	1.00	0.72	0.42
	0.8	1.50	1.22	1.00	0.82	0.53
	1.0	1.40	1.18	1.00	0.90	0.65
Semi-actuated on side road approach	≤ 0.6	1.48	1.18	1.00	0.86	0.70
	0.8	1.20	1.07	1.00	0.98	0.89
	1.0	1.12	1.04	1.00	1.00	1.00

Table A3.7 Platoon dispersal distances (m)

Platoon type	Speed environment (km/h)	
	50 – 64	65 – 105
Dense	< 100	< 300
Dispersed	150 – 500	350 – 1000
Random	> 1000	> 2000

A3.23 Traffic signals, continued

Intersection departure delay

The HCM specifies reductions in the free speed according to the distance between signal controlled intersections along the route. This amounts to a nearly constant delay of 6 seconds (0.10 minutes) at each intersection. The effect can be represented by adding this constant delay in addition to actual intersection delays.

Time period total average travel time

The time period total average travel time for the intersection is approximated by the peak interval time period delay obtained plus the intersection departure delay as described in the previous sections of this appendix.

Application of traffic models

Delays associated with traffic signals can be estimated by traffic models, provided:

(a) input parameters such as running speeds and saturation flow rates are determined in a manner consistent with this appendix

(b) the delay calculated by the model is consistent with the definitions of this appendix, ie, the average delay per vehicle over the relevant approach

(c) the delay outputs of the model are based on the general procedure and delay equations of ARR 123 and this appendix.

Worked example

Basic data	
Lane width	3.3 m
Number of lanes	2
Approach grade	+2%
Parking movements/h	20
Locality	CBD
Arrival type	Random
Signal type	Actuated

Lane width factor (from table A3.1) = 0.98

Approach grade factor (from table A3.2) = 0.99

Parking factor (from table A3.3) = 0.89

Locality factor (from table A3.4) = 0.90

Saturation flow rate = 2000 × 0.98 × 0.99 × 0.89 × 0.90
= 1554 pcu/h

Arrival type (from table A3.5) = 3

Delay adjustment factor (from table A3.6) = 0.85

In using a traffic model to analyse this example intersection, a saturation flow rate of 1554 pcu/h shall be used, and the resulting delays multiplied by 0.85.

A3.24 Priority intersections

Priority intersections

Priority intersections include all intersections where entry is not controlled by traffic signals. Roundabouts are a particular class, and are separately considered in appendix A3.25.

Travel time delays are only incurred by movements where the priority of entry is controlled by stop signs, give way signs, or by the general intersection driving rules. Three levels of priority are involved:

(a) movements that have priority

(b) movements that yield the right-of-way to the priority flows

(c) movements that must give way to both the above categories.

Only priority levels (b) and (c) will experience delay.

Minimum headway in conflicting flow

The distribution of headways in the opposing traffic streams in turn depends on other variables, and is influenced by the proximity of signal controlled intersections. When the priority intersection is remote from traffic signals and the conflicting flows well below the capacities of their approach roadways, the distribution of headways in the conflicting traffic flows can be assumed to be random with a minimum headway of either 2.0 seconds (single lane conflict) or 0.5 seconds in other cases.

Capacity

The capacity of a non-priority movement shall be determined as a function of the following variables:

- the distribution of headways, being the time between successive users of the conflict area
- the critical gap in the opposing traffic flow through which a non-priority movement vehicle will move
- the follow-up headway being the time interval between successive vehicles which use the same gap in the opposing traffic stream.

The capacity of the non-priority movement shall be then estimated from:

$$c = (3600 / T_f) \times \exp(-V \times T_o / 3600)$$

where c = capacity

$T_o = T_g - H_m$ (H_m = 0.5 or 2.0)

H_m = minimum headway in conflicting flow

T_g = critical gap

T_f = follow-up headway

V = conflicting volume during peak interval, vehs/hr.

T_o, T_g, H_m and T_f are expressed in seconds, and c and V are expressed in vehicles per hour.

A3.24 Priority intersections, continued

Critical gap and follow up headways

The critical gap (T_g) and follow-up headway (T_f) are related and depend on the speed of the conflicting traffic flow, the class of control, and the movement type. In the absence of actual values determined by observations at the site or similar sites elsewhere in New Zealand, the values in table A3.8 should be used.

Modifying critical gap

Where the turning movement is required to cross more than one lane, a further 0.5 seconds shall be added to the values of the table.

If the left turn from a minor road is provided with an acceleration lane, the critical gap of the table shall be reduced by 1.0 seconds.

Follow-up headway (T_f)

The follow-up headway is related to the critical gap, by the expression:
$T_f = 2.0 + 0.2\ T_g$

Table A3.8 Critical gap (T_g)

Movement and control	**Average speed (km/h)**	
	<60	**≥60**
Right turn from		
major road	4.5	5.0
Stop sign on minor road:		
left turn	5.0	6.0
through	5.5	7.0
right turn	6.0	7.5
Give way on minor road:		
Left turn	4.5	5.0
Through	5.0	6.0
Right turn	5.5	6.5

A3.24 Priority intersections, continued

Volume to capacity ratio	The movement volume to capacity ratio is the ratio of the average movement traffic demand for that movement during the peak interval divided by the capacity.
Peak interval average travel time	The peak interval average travel time is equivalent to the delay for each movement. This delay depends on the volume to capacity ratio as tabulated in the table next page.
Time period total average travel time	The total average travel for the intersection is approximated by the peak interval time period.
Application of traffic models	The provisions of appendix A3.23 shall also apply to traffic models used to calculate delays at priority intersections.

Table A3.9 Average peak interval delay

Volume to capacity ratio	Ave peak interval delay (mins/vehicle)
0.20	0.05
0.30	0.06
0.40	0.07
0.50	0.10
0.60	0.12
0.70	0.17
0.80	0.28
0.90	0.58
1.00	2.75
1.05	5.70
1.10	10.2
>1.10	12.0

A3.25 Roundabouts

Roundabouts

Roundabouts are a special case of a priority intersection. Delays at each approach can be estimated in a manner similar to that of appendix A3.24, ie, each approach can be considered as an independent elemental intersection with one-way conflicting flows circulating round the central island.

Capacity

The procedures and methods of Austroads *Guide to traffic engineering practice, Part 6 – roundabouts* shall be used to obtain the capacities of each approach lane.

Volume to capacity ratio

The volume to capacity ratio for each approach lane shall be estimated as the expected average flow during the peak interval using that lane divided by the capacity.

Peak interval average travel time

The peak interval travel time is equivalent to the peak interval average delay for each lane. The peak interval delay shall be estimated from table A3.9 up to a maximum volume to capacity ratio of 1.05, and the average peak period delay for the approach shall be estimated as the weighted average of the individual approach lanes.

The performance of a roundabout becomes indeterminate for high flows, much beyond the capacity of an approach, due to a tendency for the flows to 'lock' round the central island.

Time period total average travel time

The time period total average travel time is the average delay during the time period, and shall be estimated from the peak interval delay.

Application of traffic models

The provisions of appendix A3.23 shall also apply to traffic models used to calculate delays at roundabouts.

A3.26 References

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