Unequal Lane Usage in ARCADY using Junctions 9

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Synopsis

Modelling the performance of roundabouts, without signal-control, has traditionally been conducted using the ARCADY software in the UK, developed by the Transport Research Laboratory (TRL). The ARCADY module is now incorporated within the Junctions 9 software along with the PICADY (priority junctions) and OSCADY (signal-controlled junctions) modules.

Care must always be taken to account for unequal lane usage on entries to the roundabout, as the empirical formulae used to derive capacities / queues do not take any consideration to the number of lanes or turning directions. This was highlighted by Barbara Chard in the "ARCADY Health Warning" paper in 1997, which also provided a method to adjust the intercept to account for unequal lane usage.

Since 1997, although the empirical formulae remain essentially the same, additional features and tools are now available in Junctions 9, such as full capacity adjustments and Lane Simulation.

This paper revisits Barbara Chard's method in accounting for unequal lane usage, and whether any of the new tools in Junction 9 can be incorporated to refine the results. It also compares this method with results from the Lane Simulation tool in Junctions 9 and identifies areas where caution is required using Lane Simulation.

Unequal Lane Usage – Barbara Chard Method

The capacity calculations used in ARCADY assume that traffic can use all of the entry width when there is a queue. However, this fact does not always hold when there is a significant imbalance of traffic across the lanes at the give-way line.

In cases were imbalance exists, an adjustment to the capacity must be considered.

A method of determining Intercept corrections for unequal lane usage was discussed by Barbara Chard in the paper "ARCADY Health Warning: Account for lane usage or risk damaging the Public Purse". This recommended the following steps:

1. Calculate the Intercept for the whole approach.
2. Determine which lane(s) will be the most heavily used.
3. Calculate the Intercept using the geometry of the busiest lane(s) only.
4. Multiply the answer from (3) by the total traffic flow on the entry, then divide this by the traffic flow using the busiest lane(s).
5. If the result from (4) is lower than (1), then (4) is the Intercept you want ARCADY to use.
6. Given that ARCADY will contain the geometry of the full entry, and therefore calculate (1) as the Intercept, a negative Intercept adjustment is required so that (4) is used instead.
7. If the result from (4) is higher than (1), then no adjustment is required.

The capacity relationship with circulating flow is shown in Figure 1, and the impact of applying an Intercept correction.

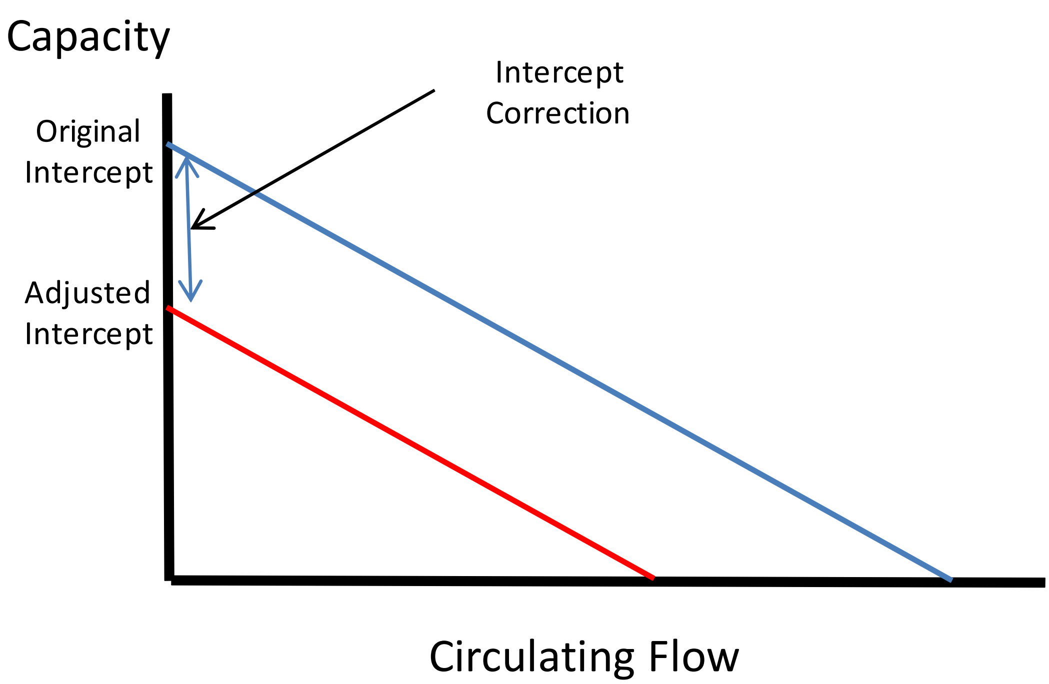


Figure 1: Impact of Intercept correction on Capacity Relationship with Circulating Flow

Limitation of the Intercept Adjustment

The paper by Barbara Chard was written at a time in which adjustments could be made to the Intercept in the software, but not the Slope. Therefore, the absolute reduction to capacity would be equal to the Intercept correction, regardless of circulating flow. However, this results in larger proportional reductions to capacity as circulating flows increase, which may result in overly pessimistic results.

Take a simple hypothetical example:

Imagine an approach consisting of two full lanes to the give-way line (i.e. no flaring). Following the measurement of geometric parameters, the Intercept for the approach is calculated as 2000 pcu/hr and the Slope as 0.6.

However, let us assume that during one peak period 100% of the total traffic flow on the approach uses one lane only. Logic indicates that as the Intercept for both lanes combined is 2000 pcu/hr, then the Intercept of each lane (and therefore the busiest lane) is 1000 pcu/hr. Therefore, an Intercept correction of -1000 pcu/hr would be required to ensure ARCADY used an Intercept of 1000 pcu/hr rather than 2000 pcu/hr during this flow period. The impact of applying this Intercept correction is shown in **Figure 2**.

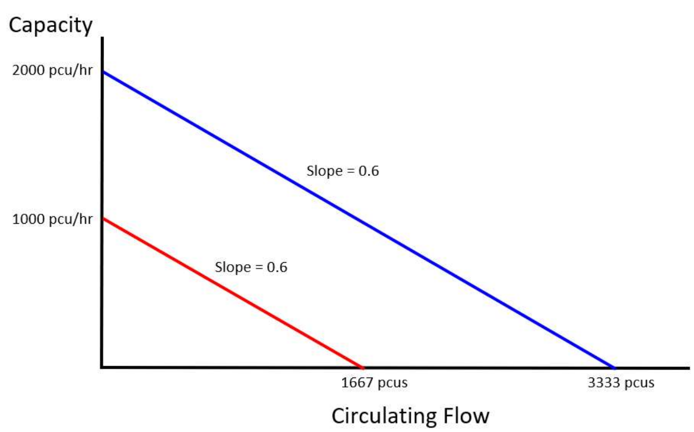


Figure 2: Intercept Correction when Only One Lane of Two Full Lane Approach Utilised

Following the application of the Intercept correction, Figure 2 shows that when circulating flow is zero, the capacity would be 1000 pcu/hr rather than 2000 pcu/hr. This would be expected given that traffic can only proceed into the roundabout from one lane rather than two, resulting in the actual capacity being 50% of the total approach.

However, as the circulating flow increases, the available capacity (red line) continually decreases below 50% of the total approach capacity (blue line). For example, if the circulating flow was 1000 pcu/hr, the capacity for both lanes of the approach would be 2000 – 0.6 x 1000 = 1400 pcu/hr. However, with the Intercept correction, the capacity would be 1000 – 0.6 x 1000 = 400 pcu/hr. Therefore, the capacity of the single lane would be 28.6% of the total capacity of both lanes. The graph also shows that capacity falls to zero when the circulating flow is 1667 pcus following the Intercept correction, whereas if both lanes were well utilised, the combined capacity of both lanes at this point would be 1000 pcu/hr.

The Solution to the Intercept Correction Problem

The latest version of ARCADY (within Junctions 9) now allows direct capacity adjustments rather than Intercept adjustments. Therefore, once a suitable Intercept is calculated using the Barbara Chard method, a calculation should be conducted to determine its percentage against the Intercept for the whole approach. For the case in Figure 2, a percentage of 50% would be calculated (i.e. 1000/2000 x 100%). Junctions 9 then enables this capacity reduction to be applied to the Analysis Set. The impact on the capacity relationship is shown in **Figure 3**.

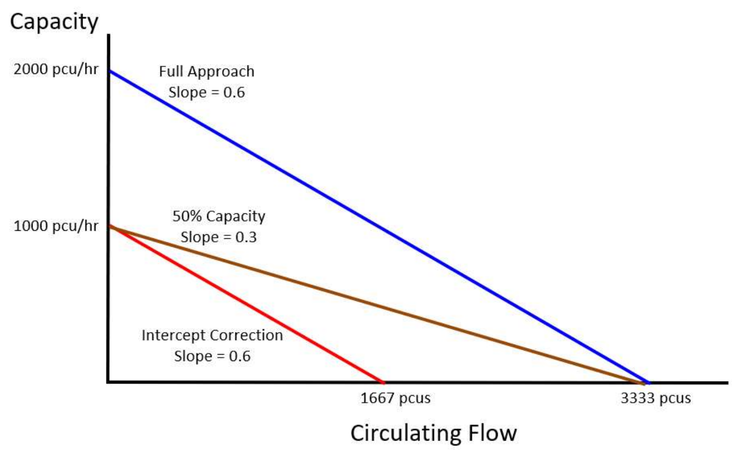


Figure 3: Application of Capacity Adjustment (Brown/Middle Line)

This adjustment to capacity ensures that the capacity reduction will always be proportionally the same (in this case 50%), regardless of circulating flow. This is also equivalent to dividing both the Intercept and Slope by the same proportion.

As described by Barbara Chard, it is still important to bear in mind the following points:

- A capacity adjustment determined using this method should only be applied if the calculated Intercept for the busy lane(s) is lower than the Intercept for the full approach (i.e. the capacity adjustment should not be over 100%).
- The capacity adjustment is dependent on traffic flow proportions and should therefore be calculated independently for each traffic Demand Set. Variable capacity adjustments can be set up in Junctions 9 by creating an Analysis Set for each Demand Set, with the capacity adjustment linked to the Analysis Set.

Demonstration of the Application of a Capacity Adjustment at a Junction

As an example, take the junction in **Figure 4**.

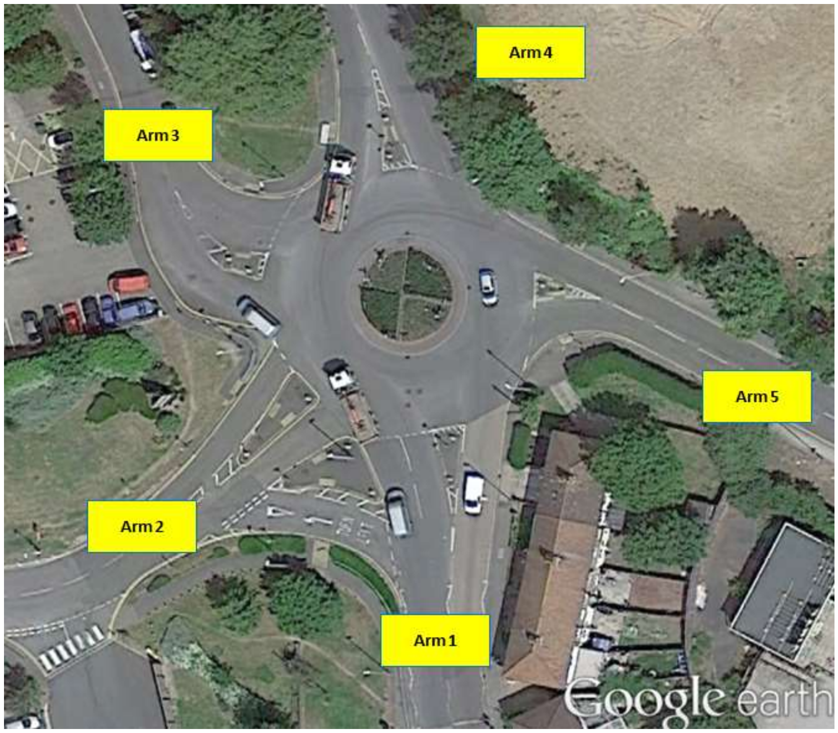


Figure 4: Capacity Adjustment on Arm 4

Arm 4 consists of two lanes. If it was assumed that left turning and ahead traffic used the nearside lane (to Arms 5 and 1) and all other traffic used the offside lane (to Arms 2 and 3), then the usage of each lane would be as follows during the AM Peak:

Nearside	=	166 (to Arm 5) + 727 (to Arm 1)	=	893
Offside	=	15 (to Arm 2) + 25 (to Arm 3)	=	40
Total Arm Flow	=	893 +40	=	933

The geometric measurements and Intercept for Arm 4 are shown below, as well as the corresponding measurements for the nearside lane only (as this was shown to be the busiest lane above).

	Full Approach	**Nearside Lane**
v	3.6	3.6
e	7.8	3.9
l’	15.8	1.0
r	11	11
D	34	34
Φ	18	18
Intercept	**1781**	**1139**

The intercept of 1781 pcu/hr would apply with reasonably balanced flows across both lanes. If the offside lane was never used, then a more appropriate intercept would be 1139 pcu/hr. Given that some traffic does use the offside lane, the Intercept will lie between 1139 pcu/hr and 1781 pcu/hr. This can be estimated as follows:

Adjusted Intercept = Busy Lane Intercept x Total Arm Flow / Busy Lane Flow

= 1139 x 933 / 893

= 1190 pcu/hr

Note, if the calculation above resulted in an answer at or above 1781 pcu/hr, this would indicate no adjustment is required. Increases to Intercepts / Capacity should not be made for unequal lane usage.

The Capacity Adjustment may be calculated as follows:

Capacity Adjustment = 1190 / 1781 x 100 = **66.82%**

Therefore, regardless of circulating flow, ARCADY would always assume a reduction of 66.82% when calculating the output parameters. In comparison, had the Intercept correction been applied only, the calculated capacities are shown for a range of circulating flows in **Table 1**.

Table 1: Capacity Comparison between Capacity Adjustment versus Intercept Adjustment

Circulating	Capacities		
	Full Approach	Capacity Reduction	Intercept Reduction
0	1781	1190	1190
500	1446	966	855
1000	1111	742	520
1500	776	519	185
2000	441	295	0
2500	106	71	0

Once the circulating flow increases beyond zero, the capacity used by ARCADY is always lower if an Intercept correction is applied in comparison to a capacity correction. This may only have a small impact when circulating flows are relatively low or the approach is well within capacity. However, as circulating flows become higher the impact on the results will become more significant, particularly on critical approaches.

Lane Simulation Tool and Comparison to the Capacity Adjustment Method

Junctions 9 includes a Lane Simulation Tool where individual lanes can be set up, the distances at which the number of lanes increases as traffic approaches the give-way line (i.e. flare lengths) and lane turning directions.

The standard ARCADY geometry is still applied to each approach. The Lane Simulation Tool can then share the calculated capacity of the standard model across the specified lanes at the give-way line. There are several stated benefits to Lane Simulation, one of these being that it can model the impact of unequal lane usage.

"Short" Flare

To investigate the results of the Lane Simulation Tool, two models were set up of the same three arm roundabout, each consisting of two lanes at the give-way line and one lane upstream of any flare. Traffic flows were kept constant from Arms B and C. However, a range of flows were tested from Arm A, from 100% (i.e. complete lane starvation of the offside) of the total flow using the nearside to 50% (i.e. balanced usage). Arm A had an approach road half width of 3.5m, entry width of 7.5m and effective flare length of 9m. The first model applied the capacity adjustment calculations, which were an extension to the Barbara Chard method (referred to as Health Warning Update). The second model used the Lane Simulation Tool. Both were modelled using Junctions version 9.5.

Lane Simulation does not provide an RFC for the approach. Therefore, the comparison of calculated delay for Arm A is shown in **Figure 5**.

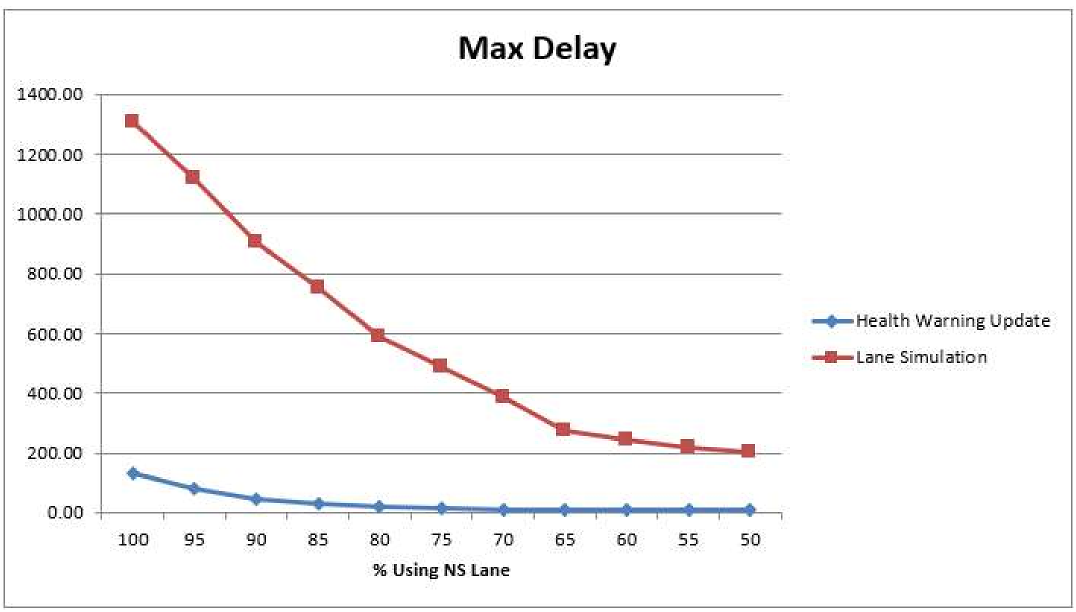


Figure 5: Capacity Adjustment versus Lane Simulation – Arm A Delay

The graph shows that Lane Simulation calculated considerably more delay than the Capacity Adjusted method. However, it is important to note that no capacity adjustment was applied when the traffic flows were balanced. In fact, no capacity adjustment was applied in this example until 75% or more traffic utilised the nearside lane. Therefore, where the nearside flow was less than 75% of the total flow (right side of graph), the Capacity Adjusted is effectively the standard ARCADY model with no corrections.

So, when traffic flows were balanced across both lanes, the standard ARCADY model calculated a delay of 11.79 seconds. However, Lane Simulation calculated a delay of 204.57 seconds, 1635% higher than the standard model. This raised concerns to the results produced by Lane Simulation and indicated that these concerns would also be applicable to where unequal lane usage did exist. For example, where 100% of traffic used the nearside lane, the capacity adjusted model predicted a delay of 130.85 seconds, whereas Lane Simulation calculated a delay of 1307.36 seconds, 899% higher than the capacity adjusted model.

Figure 6 shows the comparison of the predicted queue lengths for the same modelled runs.

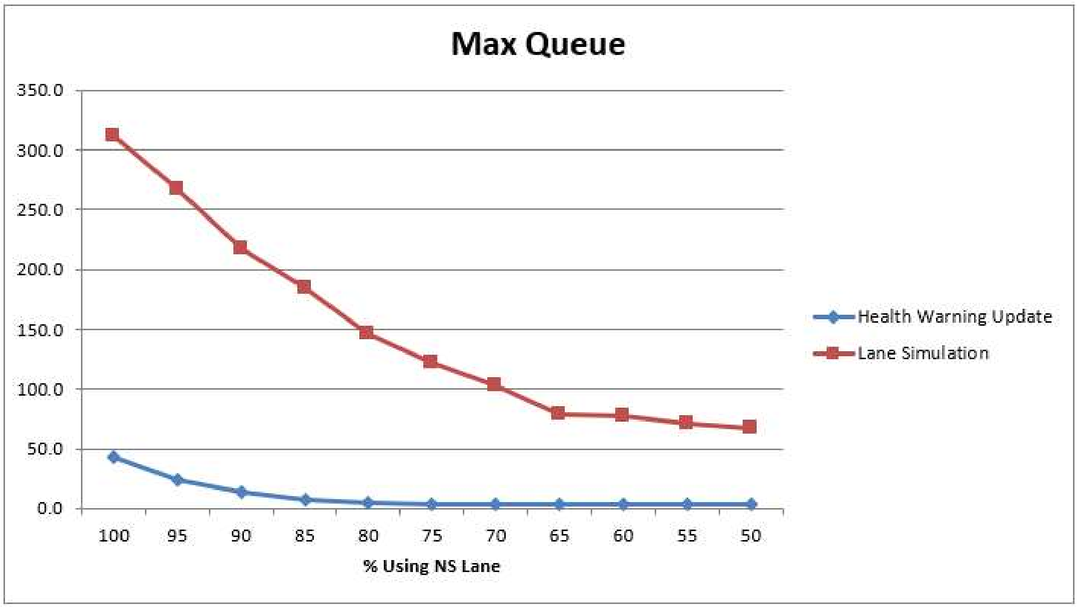


Figure 6: Capacity Adjustment versus Lane Simulation -Arm A Queue

When traffic flows were balanced across both lanes, the standard ARCADY model calculated a queue of 3.5 pcus. However, Lane Simulation calculated a queue of 67.2 pcus, 1820% higher than the standard model. Where 100% of traffic used the nearside lane, the capacity adjusted model predicted a queue of 42.6 pcus, whereas Lane Simulation calculated a queue of 311.5 pcus, 631% higher than the capacity adjusted model.

A likely explanation for the significantly worse results produced using the Lane Simulation tool is that the negative effect of any flaring on the approach is effectively double counted. Firstly, when calculating the combined capacity across all lanes, Lane Simulation will use the values calculated using the standard geometry, which incorporates the effective flare length. Secondly, when setting up the lane levels and lane lengths in Lane Simulation, this will also model the impact of the flare as simulated traffic cannot enter one lane when traffic completely fills the adjacent lane.

"Longer" Flare

Due to the relatively short effective flare length of 9m used in the evaluations above, the models were re-run with an increased flare length of 33m. It was expected that a closer match between the models could be achieved given that the impact of the flare on capacity should be less critical. The comparison of delays on Arm A is shown in **Figure 7**.

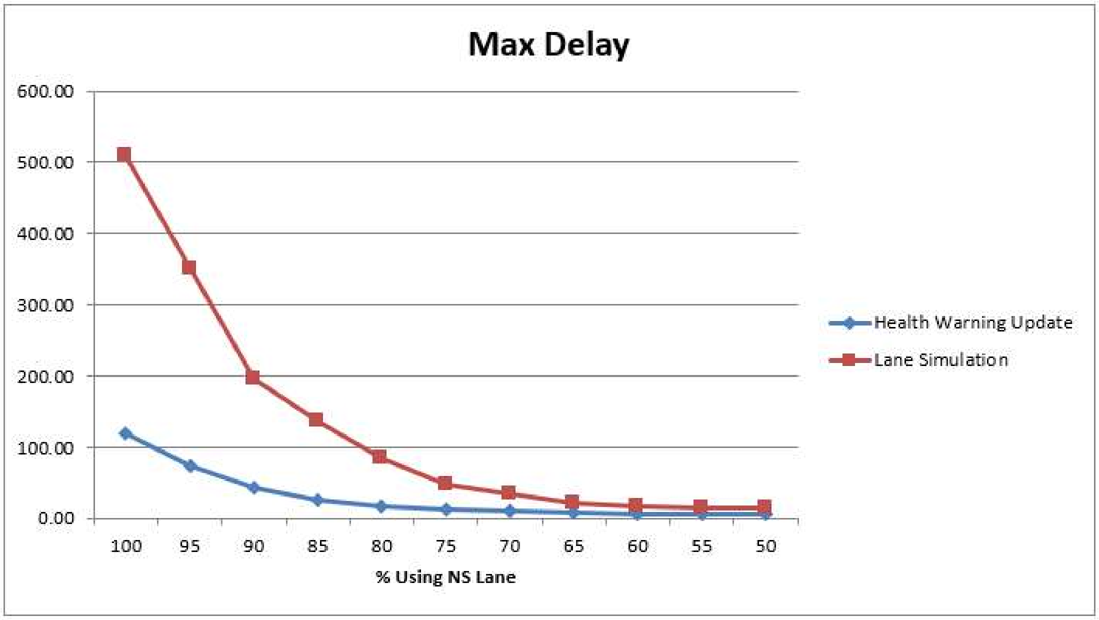


Figure 7: Capacity Adjustment versus Lane Simulation – Arm A Delay, Longer Flare

The graph shows a closer relationship between both sets of results with the increased flare length, although using Lane Simulation continued to provide longer delays, particularly where lane usage was more imbalanced. When traffic flows were balanced across both lanes, the standard ARCADY model calculated a delay of 5.64 seconds. However, Lane Simulation calculated a delay of 13.96 seconds, 148% higher than the standard model. Where 100% of traffic used the nearside lane, the capacity adjusted model predicted a delay of 120.38 seconds, whereas Lane Simulation calculated a delay of 509.06 seconds, 323% higher than the capacity adjusted model.

Figure 8 provided the queue comparison between both models.

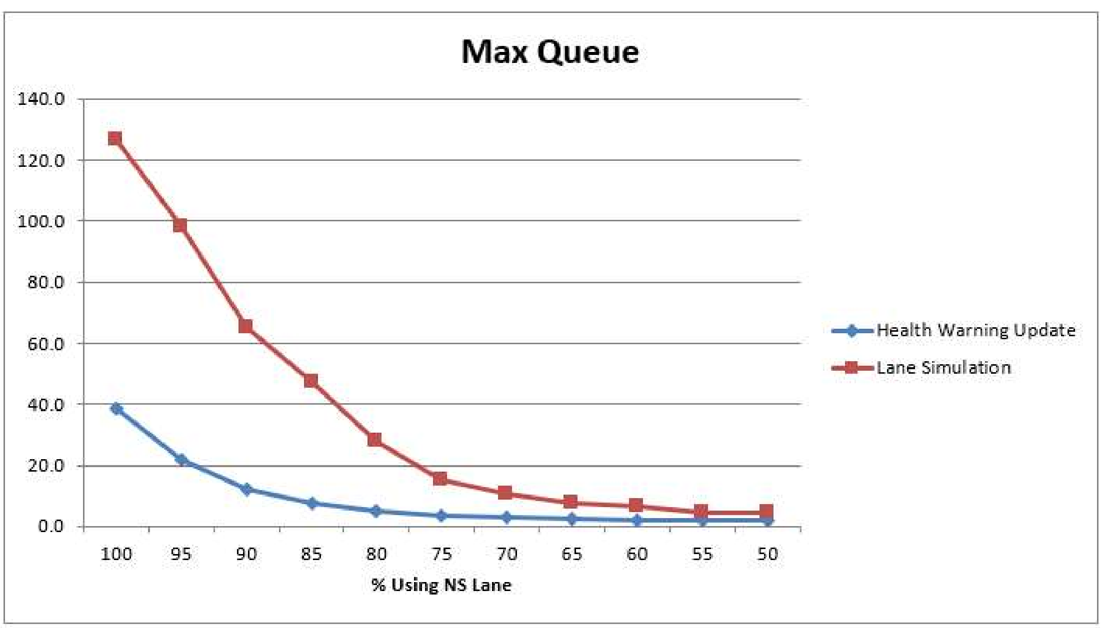


Figure 8: Capacity Adjustment versus Lane Simulation -Arm A Queue, Longer Flare

When traffic flows were balanced across both lanes, the standard ARCADY model calculated a queue of 1.7 pcus. Lane Simulation calculated a queue of 4.7 pcus, 176% higher than the standard model. Where 100% of traffic used the nearside lane, the capacity adjusted model predicted a queue of 38.8 pcus, whereas Lane Simulation calculated a queue of 126.5 pcus, 226% higher than the capacity adjusted model.

Although there was a closer match, there was still a significant difference in results with unbalanced traffic flows. This is because the Intercept of the single lane will be higher than half the Intercept of the full approach, because the full approach Intercept would be reduced due to the impact of any flare. This is taken into account using the Capacity Adjusted method, as the single lane Intercept is first calculated. The single lane Intercept is effectively the lowest Intercept that should be used, and would be used only when 100% of traffic use the busy lane. Otherwise a higher value would be used, lying between the single lane Intercept and the full approach Intercept. However, when using Lane Simulation, if 100% of traffic uses the busy lane only, it simply assumes half of the full approach Intercept. This would be too low, as the impact of any flare would have no impact on the single lane, as it would for the full approach with more balanced traffic flows. When using Lane Simulation, alternatively the capacity for each lane can be entered directly, rather than assuming a simple 50/50 split of capacity across both lanes. Although this could be applied to provide a more realistic result, it would have to be calculated independently for each flow group as variations in lane usage will impact on the capacity of each individual lane.

Modified Lane Simulation Tool and Comparison to the Capacity Adjustment Method

It was shown in the last section that results from the Lane Simulation Tool did not correspond to those from the standard ARCADY model, even when unequal lane usage did not occur. This was because the impact of the flare was effectively double counted in Lane Simulation, with the biggest differences in results occurring for shorter flare lengths. However, the differences in results were still significant for relatively long flares, especially when unequal lane usage was a factor.

Therefore, to remove double counting the impact of the flare, an alternative strategy was tested using Lane Simulation. This was to update the lane geometry to represent a full two-lane approach (i.e. increase the approach road half width to equal the entry width and reduce the effective flare length to zero). The capacity across the two lanes at the give-way line would then initially be calculated from the geometry of a 2 full lane approach, with the impact of the flare length accounted for during simulation using the lane lengths set within the Junction Diagram.

The comparison of delays on Arm A is shown in **Figure 9**, assuming the more critical short flare length. **Figure 10** compares the queue lengths.

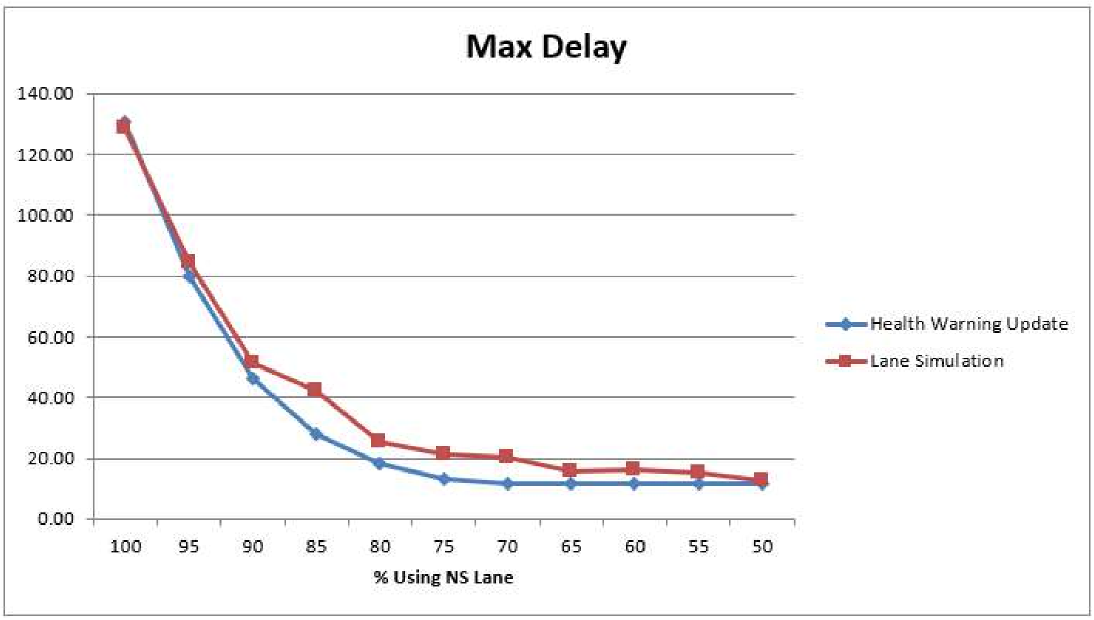


Figure 9: Capacity Adjustment versus Modified Lane Simulation – Arm A Delay, Shorter Flare

When traffic flows were balanced across both lanes, the standard ARCADY model calculated a delay of 11.79 seconds. Lane Simulation calculated a delay of 12.68 seconds, 8% higher than the standard model. Where 100% of traffic used the nearside lane, the capacity adjusted model predicted a delay of 130.85 seconds, whereas Lane Simulation calculated a delay of 128.45 seconds, 2% lower than the capacity adjusted model. Therefore, there was a good correlation between the results from both models.

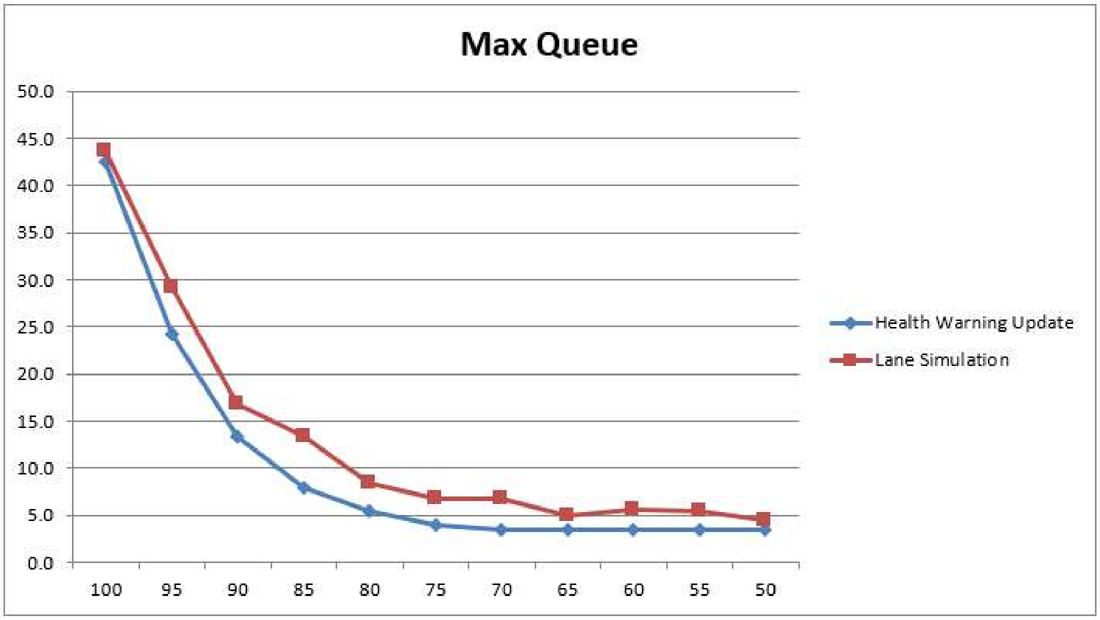


Figure 10: Capacity Adjustment versus Modified Lane Simulation – Arm A Queue, Shorter Flare

When traffic flows were balanced across both lanes, the standard ARCADY model calculated a queue of 3.5 pcus. Lane Simulation calculated a queue of 4.5 pcus, 29% higher than the standard model. Where 100% of traffic used the nearside lane, the capacity adjusted model predicted a queue of 42.6 pcus, whereas Lane Simulation calculated a queue of 43.7 pcus, 3% higher than the capacity adjusted model. Therefore, there was a good correlation between the results from both models. Although the percentage difference was higher with more evenly balanced traffic flows, this was only because the absolute queue predictions were low.

Finally, **Figures 11 and 12** provide the same results as Figures 9 and 10 respectively, but include the standard use of the Lane Simulation Tool (i.e. assuming the standard ARCADY geometry as originally tested, thus double counting the impact of the flare). This was included so that all results could be compared using the same scale in the vertical axis.

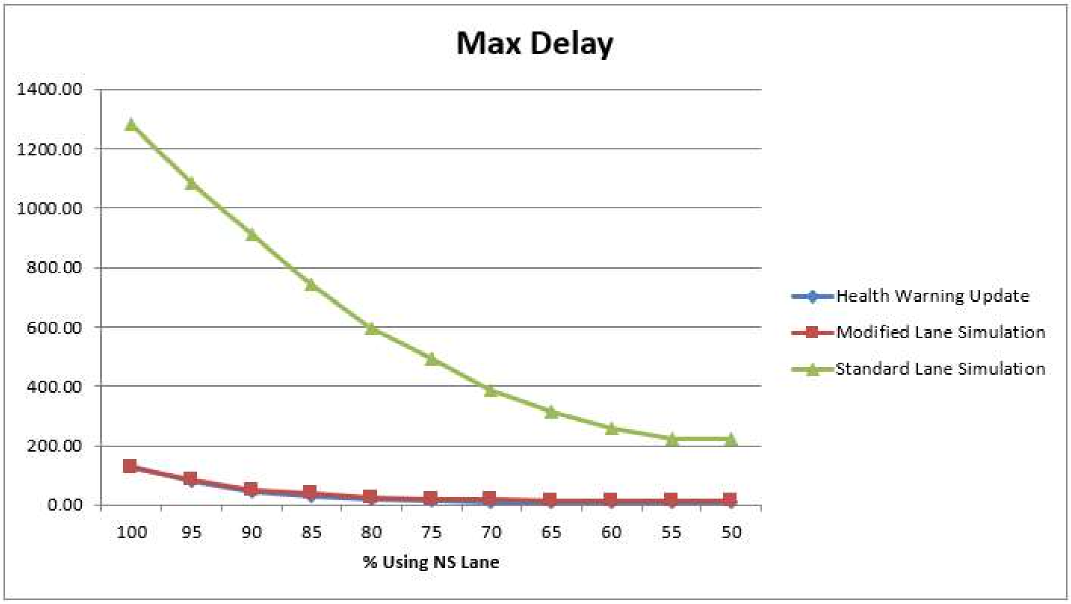


Figure 11: Capacity Adjustment versus Modified Lane Simulation versus Standard Lane Simulation – Arm A Delay, Shorter Flare

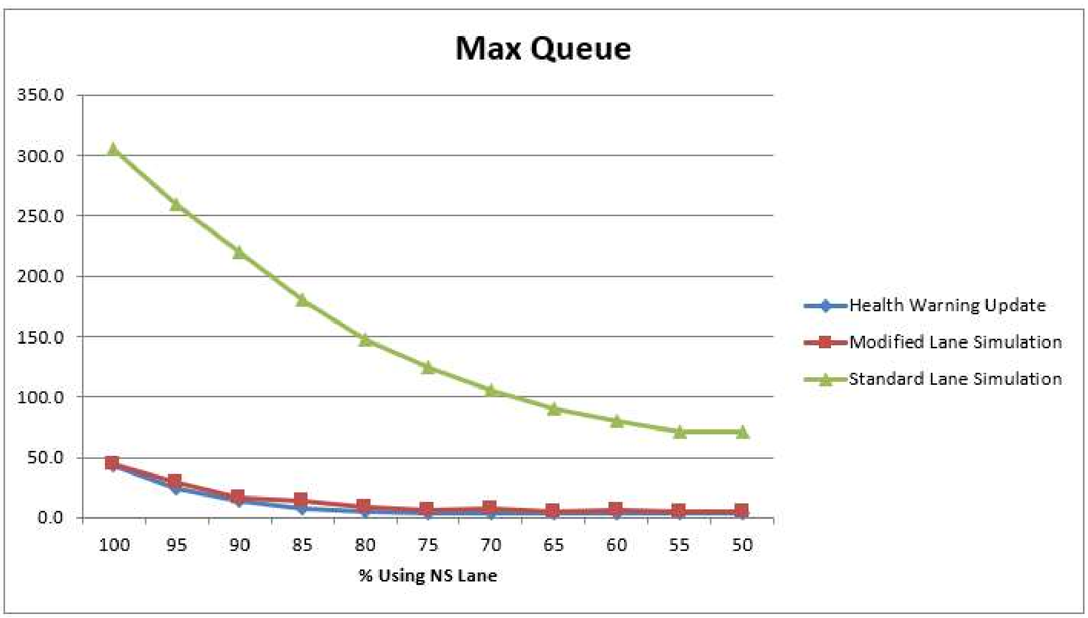


Figure 12: Capacity Adjustment versus Modified Lane Simulation versus Standard Lane Simulation – Arm A Queue, Shorter Flare

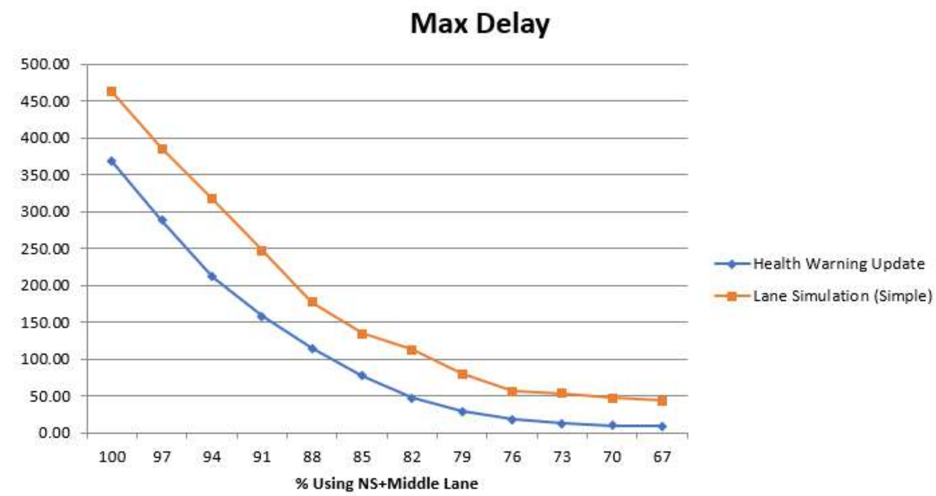
Figures 11 and 12 highlight the close relationship between the standard ARCADY model and the Lane Simulation model once the geometry is modelled to assume two full lanes. Furthermore, once unequal lane usage becomes more significant, the capacity adjustment method (Health Warning Update) also provides similar results to the modified Lane Simulation model.

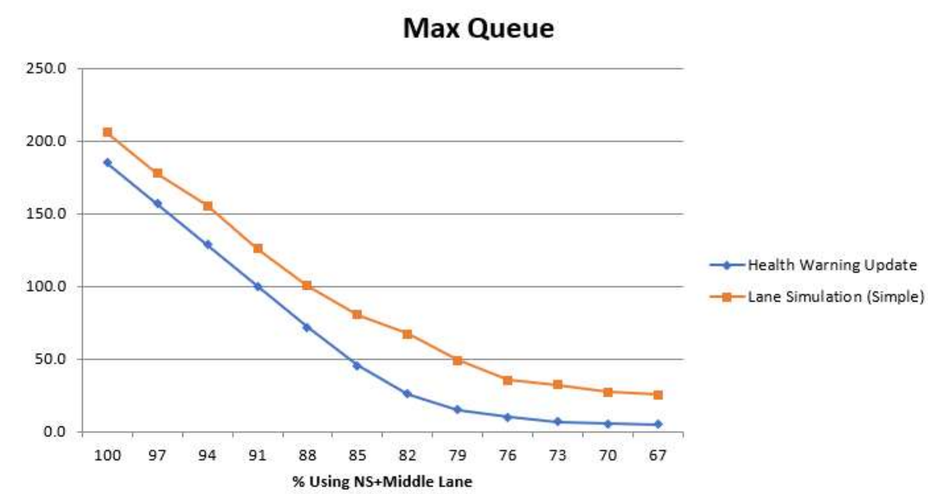
Other Examples comparing Lane Simulation with Capacity Adjustment Method

This section provides more examples, making use of models that were produced as part of Consultancy projects. Each model has been updated to allow for a variation of lane usages on a specified arm and the results compared between the capacity adjusted model and (modified) lane simulation.

Junction 1: A134 Balkerne Hill / A1124 / Southway / B1022 - Colchester

Arm:	Balkerne Hill (North)	Rbt Type:	Standard
Arm Type:	2 into 3 lane flare	Busy Lane(s):	Nearside/Middle
Flow Range:	Nearside + Middle – 100% to 67%	Capacity Adjustments:	>70%



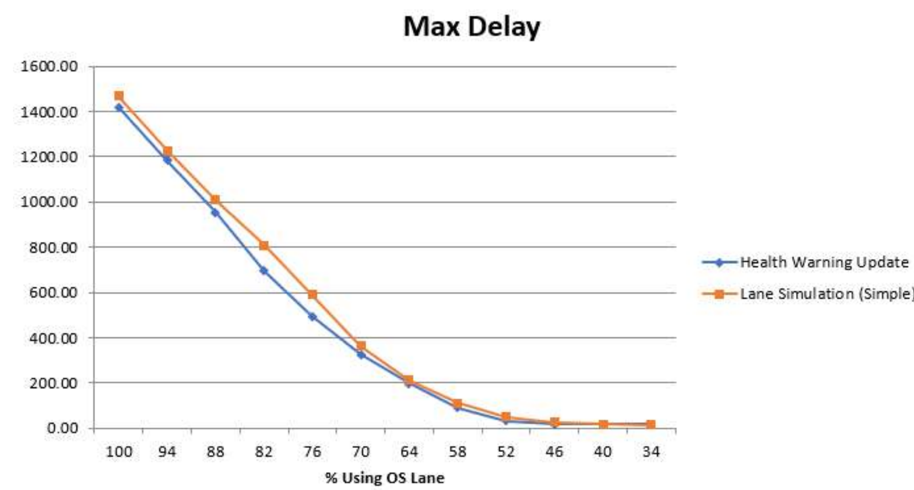


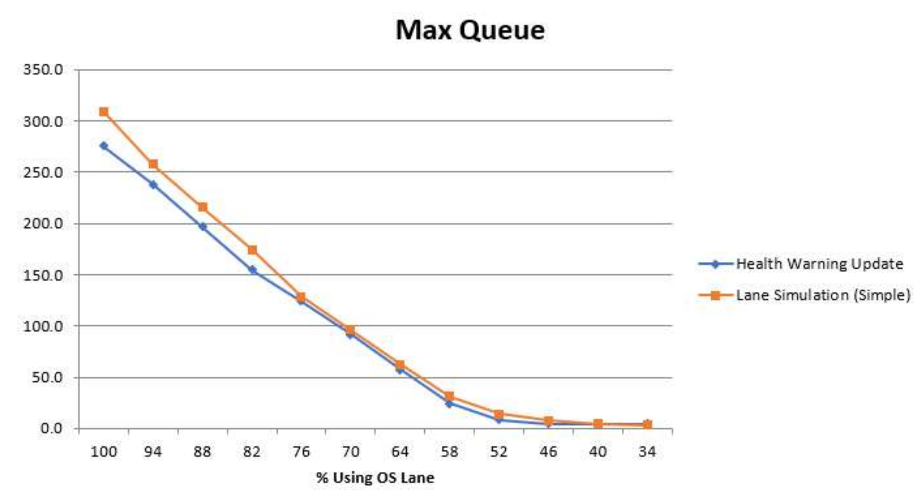
The lane simulation tool predicted higher delays and queues than the standard model with capacity adjustments, even when traffic flows were reasonably balanced across all lanes (i.e. 67% in nearside and middle lanes) and no capacity adjustments were applied to the standard model.

However, the absolute difference between queues and delay between each model were relatively consistent across all the full range of lane usage tests. There was a good correlation in how delays and queues increases as flows became more imbalanced.

Junction 2: Bearsted Rd Rbt - Maidstone

Arm:	Bearsted Rd (East)	Rbt Type:	Standard
Arm Type:	1 into 3 lane flare	Busy Lane(s):	Offside
Flow Range:	Offside – 100% to 34%	Capacity Adjustments:	>46%





There was a good correlation for delays and queues between both methods.

Conclusions

The traditional method for accounting for unequal lane usage at roundabouts was provided by Barbara Chard in the 1997 paper "ARCADY Health Warning". Although this ensured that the impact of unequal lane usage was not under-estimated in the ARCADY results, it was shown that results could be overly robust with higher circulating flows. This was due to the inability to make any adjustments to the Slope.

With the additional features that Junctions 9 (ARCADY 9) contains, the Barbara Chard method can be adapted so that higher circulating flows do not provide overly robust results. Rather than making an adjustment to the Intercept only, a full capacity adjustment can be made that is independent of circulating flows. The full capacity adjustment can be calculated once the flow group dependent Intercept is calculated using Barbara Chard's methodology.

Junctions 9 also provides the Lane Simulation Tool which can be used to test the impact of unequal lane usage. However, caution must be applied when using this. It was shown that, even when traffic flows across all lanes were relatively balanced, lane simulation provided significantly worse results in comparison to the standard ARCADY model. The reason for this was the fact that the impact of the flare was double-counted, in that it was accounted for in both the standard lane geometry and the lane length specified in each lane level used in Lane Simulation. Although the differences between Lane Simulation and the standard model were greatest with shorter flares, the difference continued to be significant for longer flares.

To avoid the double-counting of the flare in Lane Simulation, it was shown that changing the approach road half width (v) to equal the entry width (e) and changing the effective flare length (l') to zero, provided results that were more comparable to the standard ARCADY model.

A range of lane usage values were tested for several roundabouts, ranging from complete lane starvation to even balancing across all lanes. These were tested using both the Capacity Adjustment method (derived from Barbara Chard's methodology but with Capacity rather than Intercept adjustment), and the Lane Simulation Tool (where v changed to match e and l'=zero). The results showed a very good correlation between both methods.

Therefore, when accounting for unequal lane usage, using Capacity Adjustments derived using a similar process to that produced by Barbara Chard continues to provide a logical and robust assessment, without becoming overly robust at higher circulating flows. If Lane Simulation is to be used, lane geometry needs to be changed so that the impact of the flare is not double-counted. It is also recommended that when using Lane Simulation Tool, a Demand Set with balanced traffic flows across all the lanes is set up and the results compared to the standard ARCADY model. This will provide confidence that the Lane Simulation Tool is not providing radically different results to the standard ARCADY model when unequal lane usage cannot be considered the explanation.