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Calibrating strategic models for congested networks

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Abstract

Calibrating strategic models has traditionally been a standard task, requiring a network, a seed matrix and the surveyed traffic flow data for the links and turns in the network. In the early days of strategic modelling, the modelled network typically operated under free flow conditions. When the survey data did not fit the trend, it was quite common to exclude outliers in the calibration process. However, in many parts of road networks in major cities, it is generally accepted that the traffic moves in the congested flow conditions. Therefore, more care needs to be undertaken when modelling congested networks.

It will be shown in the fundamental Flow - Speed - Density diagrams that a surveyed traffic flow:

- cuts the Speed-Flow curves at two points (free-flow and forced-flow), and
- cuts the Flow-Density curve at two locations at a point of a low density and at a point of high density.

Almost all strategic modelling software packages assume that the traffic survey data with low volumes are in the free-flow (low density) region used in the calibration process. This implies that some more traffic can be added to the roadway before maximum flow is reached.

However, looking at even outside peak hours, or at any road major road in Sydney, we can see that the cars are not travelling close to the posted speed limit – but rather at a much lower speed. This means that the traffic flows are in the forced flow region. Therefore, any more traffic added to the system would result in more congestion.

This paper discusses the process of transforming traffic flow values from survey data in the forced flow region to demand flow and the corresponding speed values in the oversaturated part of the Flow - Speed - Density diagrams using simplified Volume – Density lines. This process is illustrated with an actual example.

1 Introduction

In the 1980's, 1990's and 2000's traffic generally flowed in free flow conditions. In those days calibrating strategic models was a straight forward task: use the demand adjustment module, configure the base network and provide a seed matrix. The traffic survey data had to be associated with the particular links used in those surveys, and if available, the turning movement counts. Setting the number of iterations was important: the higher the number, the more accurate the model was.

The modelling studies in those days covered areas that had mostly free-flow region but typically on the main arterial the traffic was either close to or just in the forced flow region. The focus of the modelling centred around the capacity improvements along the arterial road, and/or shifting traffic onto an alternatively parallel path.

In the last ten years or so, traffic flows on many roads move in the forced flow region. Evening news often carry stories showing the red snakes of tail lights weaving along the roads. The journalists in the traffic helicopters explain that there are long delays as the traffic is moving slowly.

Now, the traffic models need to be calibrated with much more care. The modelling objectives of improving capacity and/or rerouting traffic still exists, but there are additional multimodal analysis objectives such as providing for public transport, cyclists and pedestrians (Akçelik 2024, TRB 2016).

2 Appreciating traffic flow data

From a traffic modeller's point of view, the traffic flow count statistic has always been of critical importance.

When the traffic surveyed flow counts lands on the modeller's desk, the modeller's task is to link every surveyed flow to their particular link. Every survey data point needs to be identified with the A-node and B-node of that link. Now, much greater care needs to be taken with that traffic flow count.

Figure 1 shows Austroads, AGTM02-20 (2020), Figure 2.4: Speed-volume-density relationships, page 11. The author has added a typical surveyed traffic count and has highlighted the additional statistic required to pin-point the exact location on the curves.

The author uses a three-dimensional curve to demonstrate these three graphs as one three-dimensional curve. Three dimensional curves always require two parameters to locate the third. The flow matrix by itself is not sufficient to determine its precise location.

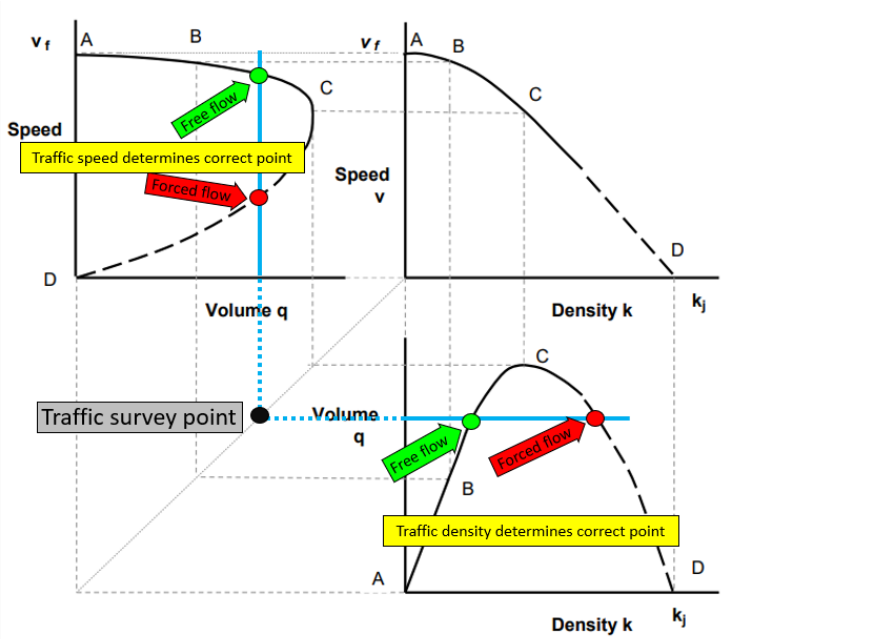
When a surveyed data point is plotted on the Speed - Volume diagram, the data point falls either

- on the free-flow part of the curve (marked with the green dot) where there is spare capacity for additional traffic before capacity is reached, or
- in the forced flow part of the curve (marked with the red dot) indicating that the traffic is in the forced flow region and no spare capacity.

Similarly, if the data point is plotted on the Volume – Density diagram, the point falls either in the low-density range where there is spare capacity, or high-density range with no room for traffic growth.

Thus, it is seen that either the speed or density statistic is required to locate the correct region of travel conditions. A method to estimate the demand flow rates as a function of the surveyed (or estimated) density values for the forced flow region is described in Section 5.

Figure 1 Austroads Speed-Volume-Density relationship

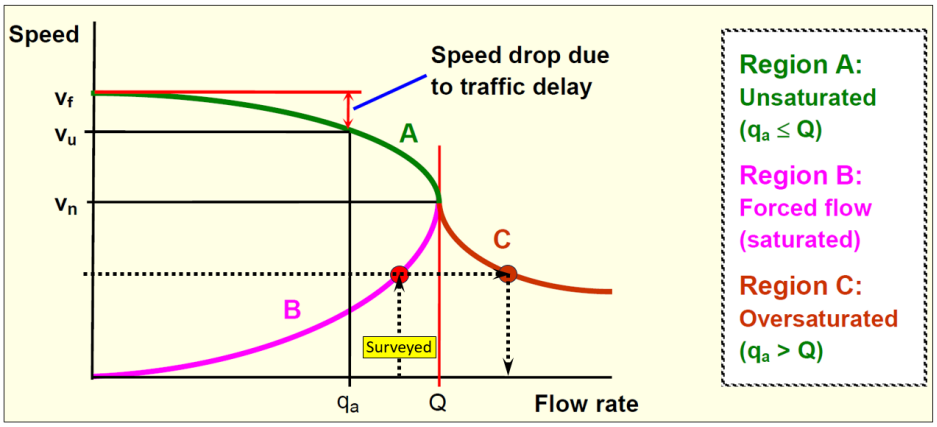


Source: (Austroads 2020, Section 2.4)

3 Traffic flow and travel demand

In the speed-flow models shown in Figure 1, the flow rate is as surveyed by road-side observation or by an on-road detector. It is important to distinguish between this flow rate and the "demand flow rate" used in strategic travel demand models (Akçelik 1991, 1996, 2002, 2006). In Figure 2, the surveyed “traffic flow” is in Region B and “demand flow rate” is in Region C. This difference becomes important in congested networks since the maximum surveyed flow rate is the capacity whereas the demand flow rate can be larger than capacity.

Figure 2 Relationship between "traffic flow" in Region B and "travel demand" in Region C



Source: (Akçelik 1996, 2006)

This is an important aspect of the calibration of strategic travel demand models. In a forced flow, a surveyed data point gives the “traffic flow” but for calibration purposes the “travel demand” is required.

On the other hand, when strategic model results are going to be used in economic analyses, this distinction between travel demand and traffic flow becomes critical. Strategic model generates travel demands - which can be, and often are, higher than capacity, especially in future scenarios. Those travel demand flow numbers should not be used in economic analyses, rather, those numbers should be converted back to traffic flow, otherwise the benefits to the road user could be exaggerated.

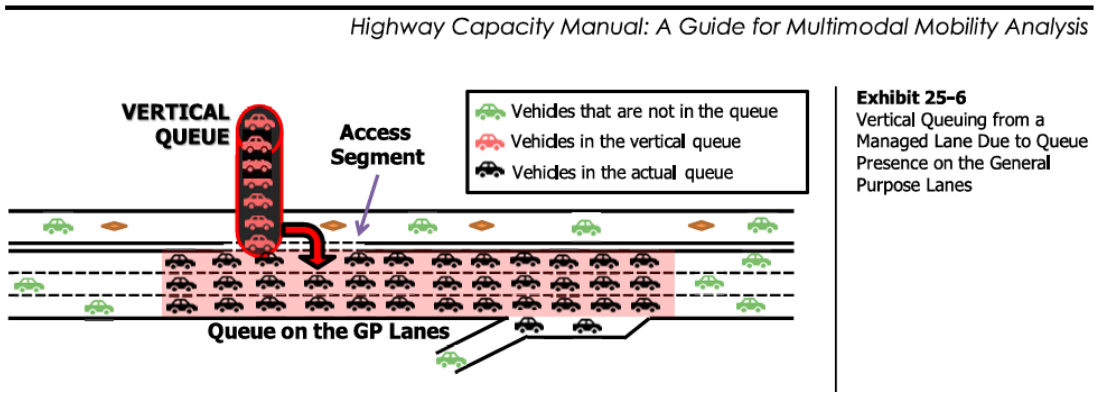
4 Examining traffic flow data

In the last ten years or so, traffic flows have become more complex and much greater care needs to be used in the choice of models used and in calibration of them. The calibration process requires precise input data points, for the model calibrations.

Deriving that precise input data has always been a challenge. What may have been treated as “outliers” and therefore simply ignored in the early modelling days, especially during peak hours, are often in the forced flow region. Now roads are often congested, increasing the complexity of the traffic movement analyses.

Fortunately, mesoscopic modelling software has become available which is designed to examine congested network in far more detail. The earlier road network gridlock issue has been overcome with the vertical queue concept as illustrated in Figure 3.

Figure 3 Concept of a vertical queue



Source: Highway Capacity Manual, Oversaturated Segment Evaluation, Page 25-27

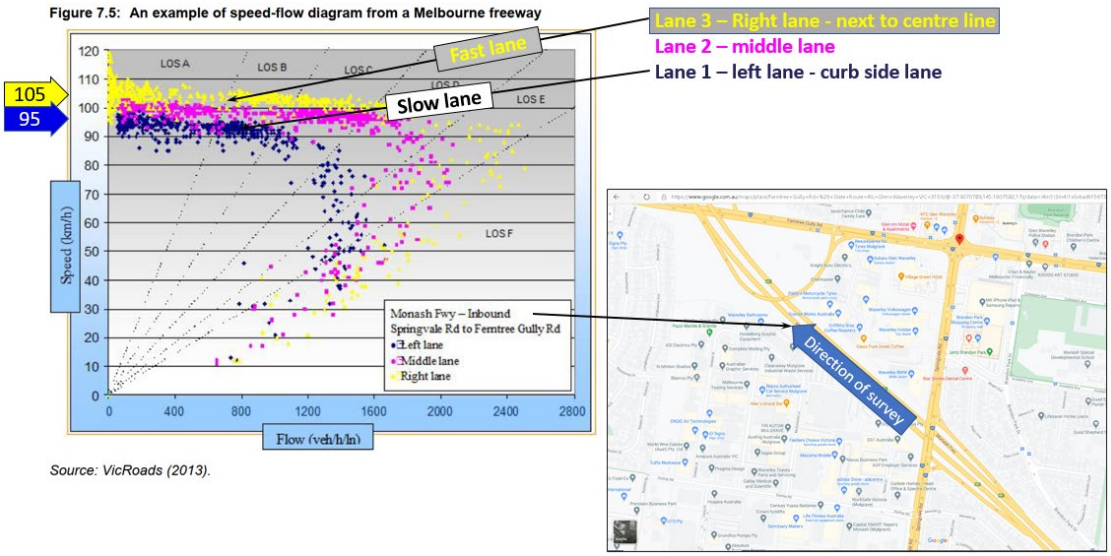
Mesoscopic models start with travel demands which are often generated in strategic software package. In that case, the emphasis of the strategic modelling will shift towards generating the correct travel demands that are required in those mesoscopic models. This is a very significant task. For example, for the base year in the Rockhampton study, there were six calibration runs, one for each of the three hours in the AM peak and PM peaks. In the Wagga model there are twelve calibration runs, one run for each of the six 15-minute time slices in the AM and the six time slices in the PM peak. Generally speaking, those calibration processes require a higher level of robustness of the auto network when compared with the usual one-off type calibration process, because the model must reproduce the large range of traffic flows that occur during these periods.

The expectation is the travel demand generated in strategic models are accurate. Therefore, a deeper understanding of the traffic count data is required, and greater care must be applied that data input.

In the examination of traffic flow data, there are two components to consider: the scatter of data and historical data.

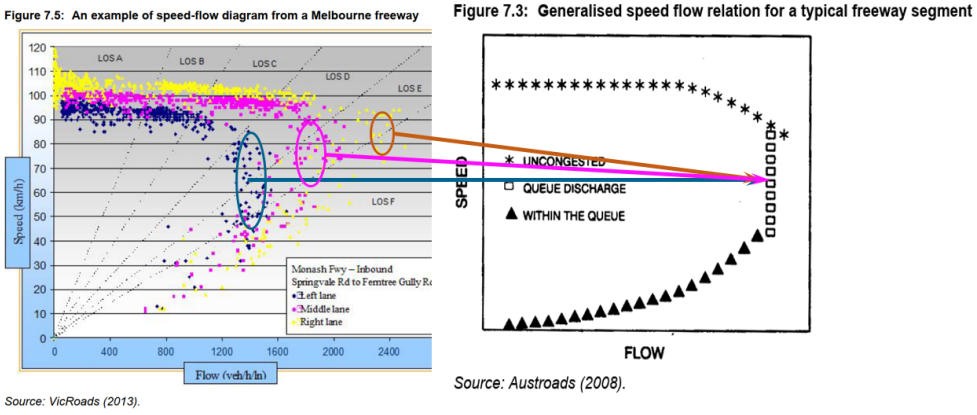
Figure 4 taken from Austroads 2020, Section 7.5.3, shows that the three lanes have very different speed-flow characteristics. The fast lane which is indicated by the yellow dots has a free-flow speed of around 105 km/hr. The slow lane with the blue dots has a free-flow speed of 95 km/hr. The speed of the middle lane is 100 km/hr.

Figure 4 Source: Austroads 2020, Section 7.5.3



A closer examination shows that each lane has different operating characteristics. This is highlighted in Figure 5 taken from Austroads 2020, Section 7.5.3. Each lane has its own queue discharge range, that is, different maximum flows and speed ranges. Mesoscopic modelling provides the tools to examine these characteristics more fully. The modelling results could reflect those data points closely - provided the travel demands are correct.

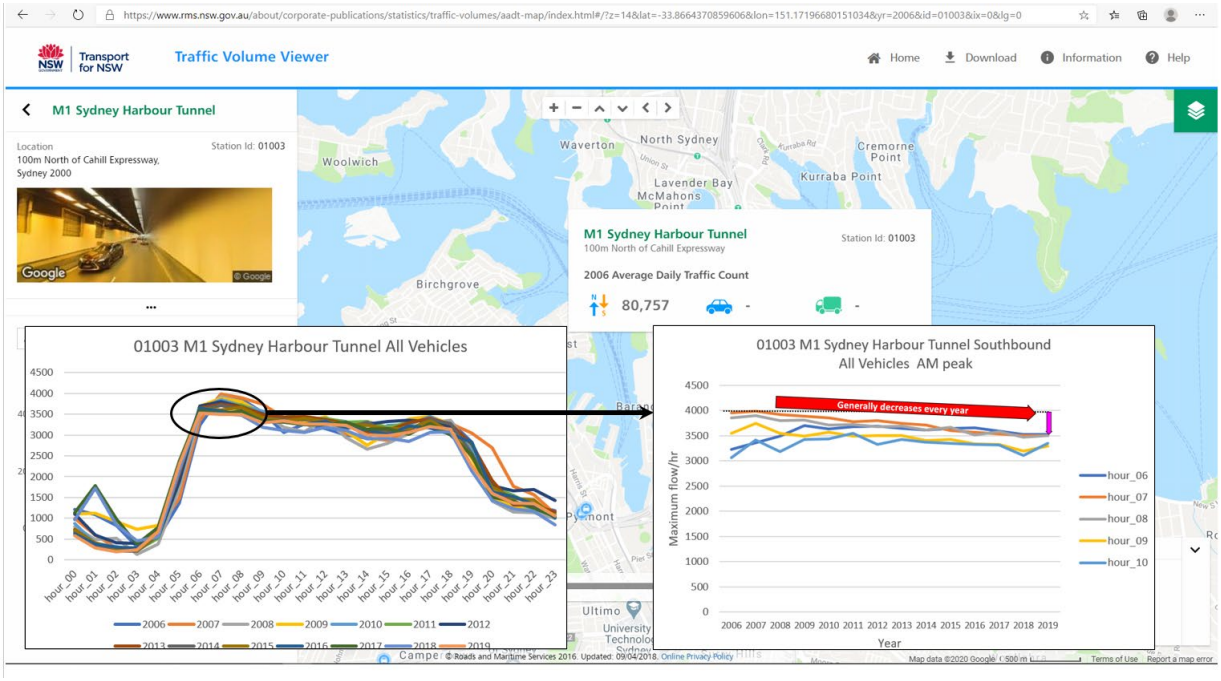
Figure 5 Traffic lanes can have different operating characteristics



Strategic models model use traffic count data on links. For the Austroads example, the data points from the three lanes would be combined and the resulting plot would look similar to the middle lane with its corresponding scatter of pink data points.

The other consideration is the historic data. Figure 6 shows the historic southbound traffic volume in the Sydney Harbour Tunnel, together with the AM Peak hour flows. For this site, the maximum peak hour flows generally decrease each year after the year 2007. In addition, the traditional 07:00-08:00 AM peak hour in 2007 has become a much longer 06:00 to 10:00 peak, with each of those hours having similar maximum flows.

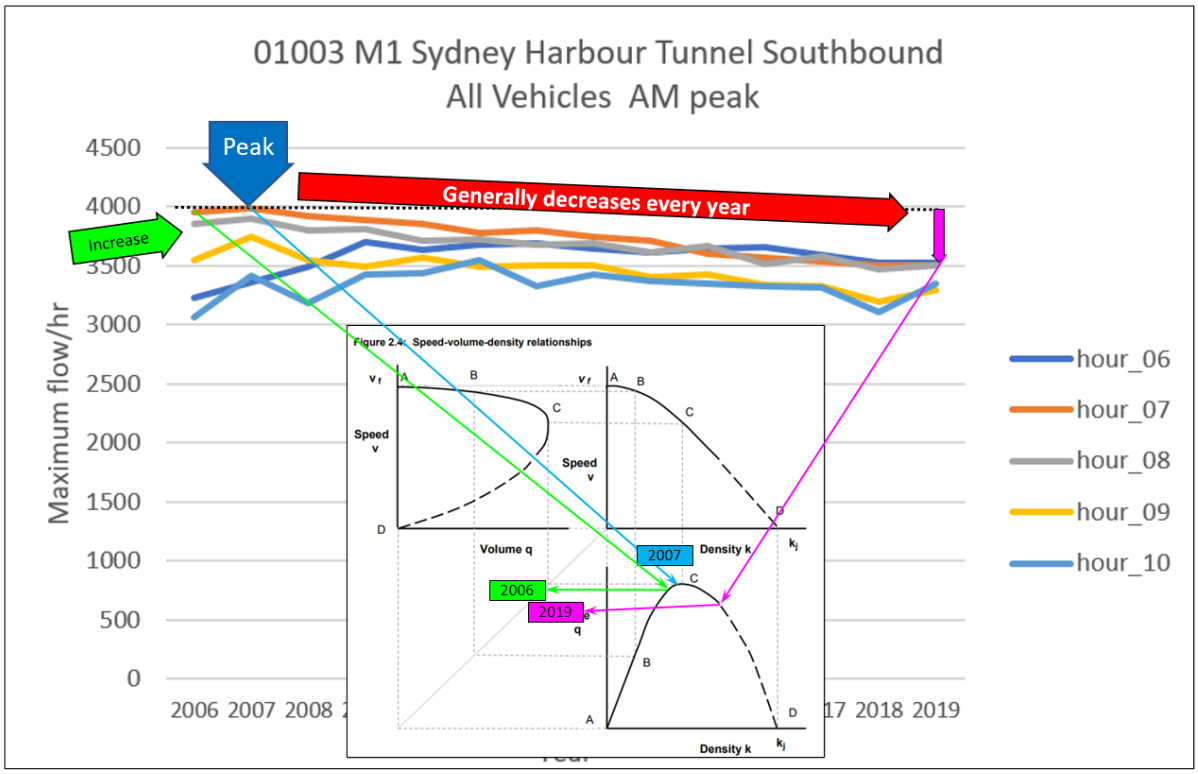
Figure 6 Historic southbound traffic volume in the Sydney Harbour Tunnel, together with the AM peak hourly flows



The decrease in maximum flows is the result of the increased traffic density, which has shifted the queue discharge range.

This decrease in traffic volume and increase in density is illustrated in Figure 7. The hourly historic AM peak southbound traffic volume in the Sydney Harbour Tunnel as shown in Figure 6 is schematically superimposed on the Austroads' Speed-Volume-Density relationship from Figure 1.

Figure 7 The reduced traffic flows as a result of increasing traffic density



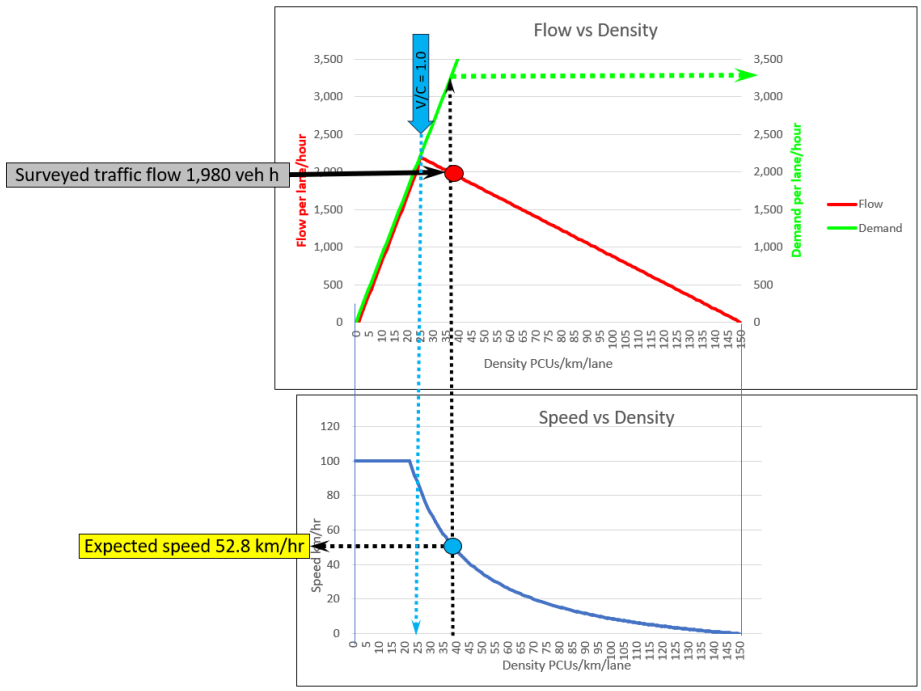
The author has witnessed similar trends in the outlying areas of Sydney which have experienced significant population growth but not a corresponding employment growth nor an expansion of public transport infrastructure. The traffic peaks occur in different years and by directional flow. Those peaks are later than 2007 implying that the optimum density peak may be spreading slowly outwards from the CBD.

In summary, when traffic count data lands on the modeller's desk, the modeller should be aware that it is highly likely that the counts could have come from the forced flow region and special care should be applied.

5 Processing traffic flow data

Figure 8 shows the conceptual process of transforming a traffic survey data point (traffic flow) in Region B to point in Region C (travel demand) using a simplified Volume – Density line. The expected speed can also be obtained from the fundamental diagrams.

Figure 8 Transforming a traffic count which is in the forced flow region to a travel demand count



The simplified Volume – Density line is constructed by connecting the origin and the maximum flow rate (capacity) and extending the line for estimating the demand flow rate. The model estimates the demand flow rate (q_d) as a function of the surveyed (or estimated) density, k:

$$q_d = (Q / k_Q)\, k \qquad (1)$$

where Q = maximum flow rate (veh/h) and k_Q = density at maximum flow rate, or "optimum density" (veh/km).

This linear model means that, when density $k = k_Q$, the maximum flow rate, $q_d = Q$ is obtained. At this point, degree of saturation (or volume/capacity ratio, V/C) = 1.0.

The maximum service flow rate, Q and the density at maximum flow, k_Q can be found in Austroads Table 4.4 shown in Figure 9 (the table refers to kQ as "maximum density" which is misleading). For free flow speed of 100 km/h in the table, Q = 2,200 veh/h and k_Q = 25 veh/km, Q / k_Q = 88 km/h is the speed at capacity (shown as "average speed" in the table, which is not expressed clearly).

Figure 9 Austroads LOS criteria for multi-lane highways

Table 4.4: LOS criteria for multi-lane highways

Free-flow speed	Criteria	A	B	C	D	E
100 km/h	Maximum density (pc/km/ln)	7	11	16	22	25
	Average speed (km/h)	100.0	100.0	98.4	91.5	88.0
	Maximum volume to capacity ratio (v/c)	0.32	0.50	0.72	0.92	1.00
	Maximum service flow rate (pc/h/ln)	660	1080	1550	1980	2200
90 km/h	Maximum density (pc/km/ln)	7	11	16	22	26
	Average speed (km/h)	90.0	90.0	89.8	84.7	80.8
	Maximum volume to capacity ratio (v/c)	0.30	0.47	0.68	0.89	1.00
	Maximum service flow rate (pc/h/ln)	600	990	1430	1850	2100
80 km/h	Maximum density (pc/km/ln)	7	11	16	22	27
	Average speed (km/h)	80.0	80.0	80.0	77.6	74.1
	Maximum volume to capacity ratio (v/c)	0.28	0.44	0.64	0.85	1.00
	Maximum service flow rate (pc/h/ln)	550	900	1300	1710	2000
70 km/h	Maximum density (pc/km/ln)	7	11	16	22	28
	Average speed (km/h)	70.0	70.0	70.0	69.6	67.9
	Maximum volume to capacity ratio (v/c)	0.26	0.41	0.59	0.81	1.00
	Maximum service flow rate (pc/h/ln)	290	810	1170	1550	1900

Source: Exhibit 21-2 in HCM 2000; the content here is largely consistent with the LOS criteria in HCM 2016 (TRB 2016) (Exhibit 12-15 and Exhibit 12-38).

For example, if the surveyed traffic flow is 1,980 veh/hr and it is in region B, calculate using the simplified Flow-Density curve as follows with the following assumptions:

- Jam density = 1000 m / 6.7 (Austroads vehicle length) = 149 veh/km/ln, say 150 for this calculation
- The optimal density = 25 veh /km/ln
- Max flow = 2,200 veh/hr

Estimated density = 25 + (2,200 – 1,980) / (2,200 / (150 – 25)) = 37.5 veh/km/ln, and (1) gives an estimated demand flow rate of q_d = (2,200 / 25) x 37.5 = 3,300 veh/h.

The traffic speed (s_B) in region B can be calculated as a function of the flow rate q in Region B and density k in Region B:

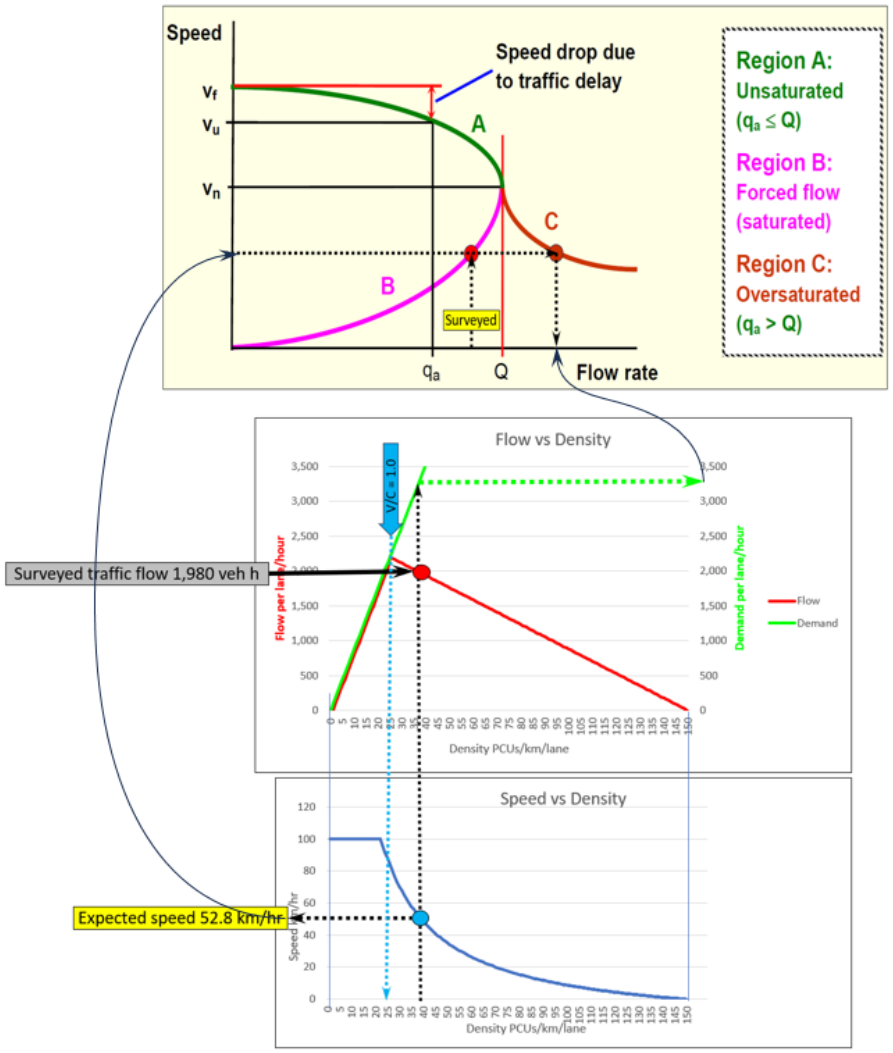
$$s_B = q / k \qquad (2)$$

In this example, using Equation (2) the traffic speed can be calculated as s_B = 1,980 / 37.5 = 52.8 km/hr.

This is an estimate of the speed measured at the detector (Region B). In this simplified approach, the assumption is that $s_d = s_B$, that is the same as the “travel speed” in Region C, as shown in Figure 2.

Figure 10 shows the process described above schematically.

Figure 10 Schematic illustration of calculating the travel demand from a traffic count in the forced flow region



While the method described here is an intuitive and easy approach, implementing this can result in excessive demand flow rates in future scenarios, implying very high degrees of saturation.

6 Speed-flow curves

Speed-flow curves are also known as travel time functions and are used interchangeably. Most of these speed-flow curves used in strategic models were developed in the “free-flow” era. The aim in the early strategic models was to force traffic onto parallel paths to ensure that the equilibrium fundamentals were preserved. This was achieved by having the speed-flow curves “falling off the cliff” when the flows are close to the link capacity.

During the calibration process, links need to be made more attractive so that it attracts more traffic. Similarly, if links have to reduce traffic, the links need to be made less attractive.

There are many ways of achieving those objectives. These include (1) changing the free-flow speed, which is useful only when the V/C ratio is very low but that does not occur very often, (2) changing the capacity, which in most cases has little theoretical basis other than trying to achieve the right results for the wrong reasons, (3) modifying the shape of the

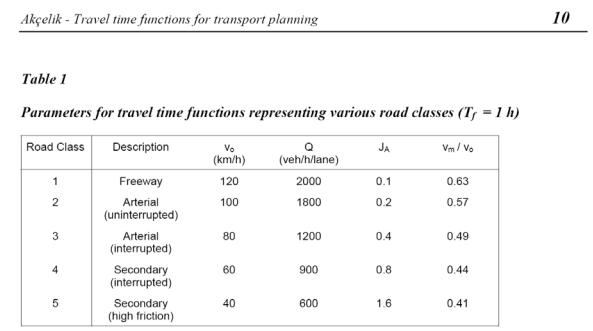
speed-flow curve, which the author encourages, or (4) modifying links upstream or downstream where no one expects network changes to be made and thus “miracle” calibration results can be achieved.

The author has used what is known as the "Akçelik Function" (Akçelik 1991, 2002, 2006) because it is a time-dependent travel demand model with a queuing theory basis and because it is simple to modify the curve’s characteristics. While the mathematical equation appears complex, it only requires three parameters: the free flow speed, the link capacity and the J_A factor. See Figure 11.

Figure 12 shows that generally speaking at low flows, say when the V/C is less than 0.65 the free-flow speed does not change much. When the V/C is greater than 0.85, the speed of the link reduces quickly.

In many cases in the calibration process, it is in this part of the speed-flow curve that the hard work is done. If the flow on the link is close to capacity and it needs say, a little more traffic. In that case, the curve needs to be raised a little to give it more speed, making the link more attractive. The opposite also applies, to reduce the traffic, make the link curve a little steeper and thus reducing the speed.

Figure 11 Parameters for the Travel time functions for transport planning, more commonly referred to as speed-flow functions



Akçelik - Travel time functions for transport planning **10**

Table 1

Parameters for travel time functions representing various road classes (T_f = 1 h)

Road Class	Description	v_o (km/h)	Q (veh/h/lane)	J_A	v_m / v_o
1	Freeway	120	2000	0.1	0.63
2	Arterial (uninterrupted)	100	1800	0.2	0.57
3	Arterial (interrupted)	80	1200	0.4	0.49
4	Secondary (interrupted)	60	900	0.8	0.44
5	Secondary (high friction)	40	600	1.6	0.41

Figure 12 Typical shapes of the Speed - flow functions

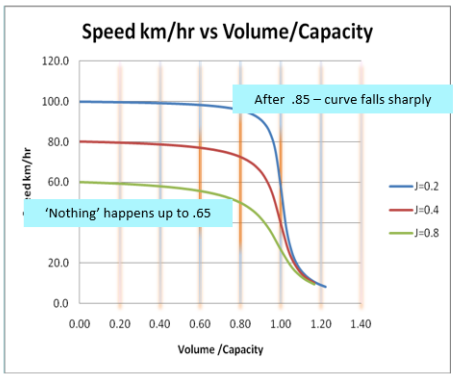


Figure 13 Calibrating models often require making links more or less attractive

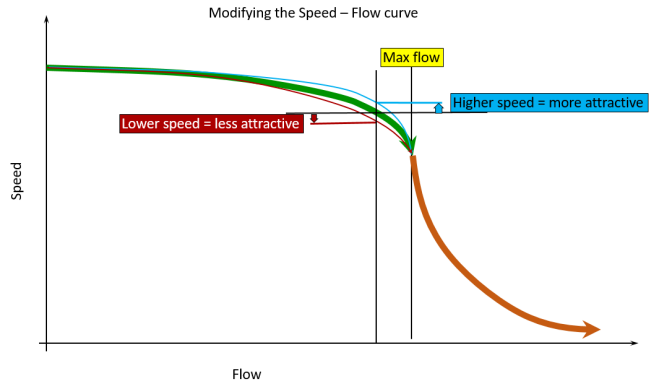


Figure 14 The J_A factor can change the curve significantly

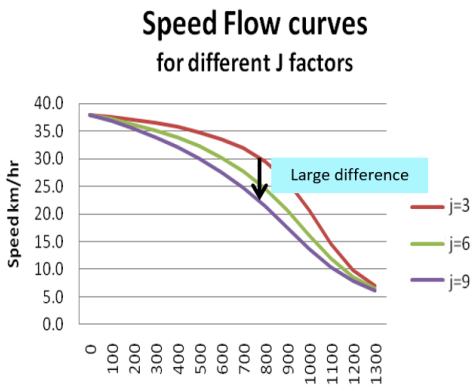


Figure 13 shows that using the Akçelik curves only the J_A parameter needs to be changed which deals with the shape of the curve.

Figure 14 shows that the curve can be changed drastically – for a 40 km/hr link the difference between a “good” performing link and a “bad” performing link is about 15 km/hr by changing the J_A factor from $J_A = 3$ to $J_A = 9$.

Typically, the author develops the network in the Dynameq software, and calculates the matrices in EMME. It is common for the network to be extracted from OpenStreetMap for use in the mesoscopic network. This network can contain the very minor streets in the network. These minor street types will provide very large road capacities in strategic models, but should not be used by through traffic. This is solved by making those links perform very poorly, and thus making them very unattractive to through-trips.

7 Conclusion

We now have significant data for Region B (see Figure 4) which could be used to calibrate the oversaturated part of the speed-flow curve (Region C). The method to estimate demand flows described in Section 5 could be useful towards this as it is based on the observation that, once optimal density has been reached, adding more cars to the roadway increases the density while reducing the flow below capacity.

It may be useful to investigate to see if splitting the speed-flow curve into two parts (the free flow Region A and the oversaturated Region B / C) offers some advantages. Various two-regime models were investigated in Akçelik, Roper and Besley (1999).

The author's main concern with any modelling is that it revolves around the (base) travel demand matrix. If this travel demand matrix is wrong, there is not much hope – no matter what model is used.

As shown in the fundamental Flow - Speed - Density diagrams included in this paper, a surveyed traffic flow:

- cuts the Speed-Flow curves at 2 points (free-flow and forced-flow), and
- cuts the Flow-Density curve at 2 locations at a point of a low density and at a point of high density.

Almost all strategic modelling software packages assume that the traffic survey data with low volumes are in the free-flow (low density) region used in the calibration process. This implies that some more traffic can be added to the roadway before maximum flow is reached.

However, looking at even outside peak hours, or at any road major road in Sydney, we can see that the cars are not travelling close to the posted speed limit – but rather at a much lower speed. This means that the traffic flows are in the forced flow region. Therefore, any more traffic added to the system would result in more congestion.

The important message in this paper is that, if the volume data for a congested road based on roadside observations or on-road detectors is used without being transformed to demand flows, the model calibration process will give wrong travel performance results.

For example, by extrapolating the historical flows, we could guess that a traffic survey of the Sydney Harbour Tunnel, AM peak southbound traffic flow in 2024 is likely to give volume data less than those observed in 2007, and these are likely to be in the forced flow region.

It is recommended that modellers should give high priority establishing understanding if the traffic is operating in the free-flow or forced flow conditions and calibrating the models accordingly.

Acknowledgements

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I presented in Section 5 have been invaluable in shaping the direction and outcomes of this paper.

I would also like to thank Steven Piotrowski, for his persistent encouragement to write down some of my modelling experiences that can be shared with other modellers.

8 References

AKÇELIK, R. (1991). Travel time functions for transport planning purposes: Davidson's function, its time-dependent form and an alternative travel time function. *Australian Road Research* 21 (3), pp 49–59.

AKÇELIK, R. (1996). Relating Flow, Density, Speed and Travel Time Models for Uninterrupted and Interrupted Traffic. *Traffic Engineering and Control* 37(9), pp 511-516.

AKÇELIK, R. and BESLEY, M. (2002). Queue Discharge Flow and Speed Models for Signalised Intersections. In: *Transportation and Traffic Theory in the 21st Century, Proceedings of the 15th International Symposium on Transportation and Traffic Theory*, Adelaide, 2002 (Edited by M.A.P. Taylor). Pergamon, Elsevier Science Ltd, Oxford, UK, pp 99-118.

AKÇELIK, R. (2006). Speed - Flow and Bunching Models for Uninterrupted Flows. Paper presented at the *Transportation Research Board 5th International Symposium on Highway Capacity and Quality of Service*, Yokohama, Japan, July 2006.

AKÇELIK, R. (2024). SIDRA Multimodal Capacity and Performance Analysis for Roundabouts. Presentation at *TRB 103rd Annual Meeting, Session 3068: Multimodal Operations and Capacity of Roundabouts in the US and Beyond*, Washington D.C., USA, January 2024.

AKÇELIK, R., ROPER, R. and BESLEY, M. (1999). *Fundamental Relationships for Freeway Traffic Flows*. Research Report ARR 341. ARRB Transport Research Ltd, Vermont South, Australia.

AUSTROADS - AGTM02-20 (2020). *Guide to Traffic Management Part 2: Traffic Theory Concepts*. Association of Australian State Road and Transport Authorities, Sydney.

TRB (2016). *Highway Capacity Manual Edition 6 - A Guide for Multimodal Mobility Analysis, Version 6, Chapter 25 (Freeway Facilities: Supplemental)*. Transportation Research Board, National Research Council, Washington, DC, USA.