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Paper title: Measuring road congestion – some new ideas

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Abstract:

Congestion has been considered in ways new to Perth: relating SIDRA and SCATS measures of congestion; exploring a new level of service measure (F_{suffix}) to show 'how far we are into' level of service F, then relating this to peak spreading; setting targets for maximum congestion using a 'horses for courses' approach rather than a single target level for all road types; developing new efficiency measures based on time lost through congestion to different road user groups; comparing community perceptions of congestion to technical measures; and adopting two future traffic growth scenarios with solutions related to both scenarios. The F_{suffix} concept is theoretical, the practical manifestation of which is peak spreading. F_{suffix} provides a new term for professionals to use when considering high levels of congestion. Peak spreading can be understood by the community. The 'horses for courses' approach matches community perceptions of congestion better than the 'single level of service' approach. It targets lower congestion on more important and more vulnerable routes, and higher congestion on less important routes. Most of these concepts are believed to be new to Australia, some new internationally.

Introduction

The WA State Government wishes to cope with increasing movement of goods and people in a sustainable way, including an emphasis on solutions beyond just ‘building more roads’. One manifestation of this was a pre-election promise to delete the long planned Fremantle Eastern Bypass (FEB) from the planning scheme, which has now happened. Another was to hold a Freight Network Review (FNR) that included a major community participation exercise.

Results of the FNR included the Government announcing it would not construct another long planned major road link: Stage 8 of Roe Highway, west of Kwinana Freeway (Roe 8). As an alternative the Government produced a “Six Point Plan” which includes logistical actions, more freight on rail, building Roe Highway to the east of Kwinana Freeway (Roe 7), and improvements to some other major roads - Leach Hwy, South St, and Stock Rd (shown in green in Figure 1 below)



Figure 1 Study area

A major study is under way to address the last point, and to consider the impacts of increasing traffic on local communities. The study area, and the roads now not to be constructed, are shown below.

Parts of Leach Hwy, South St, and Stock Rd will have more traffic (less relief from traffic growth) in future than previously planned. The effects on other roads, shown in red above, were also reviewed.

The study included a major community survey as well as technical analysis. The study is unusual for two reasons: it is rare for congestion to be analysed at this level of detail over a relatively wide network, and it provides the opportunity to compare the results of technical analysis to community perceptions.

The community survey showed congestion was clearly the number one problem for residents and businesses in the area. The survey included many other traffic related problems, such as safety and noise, plus the opportunity for those surveyed to nominate ‘other’ problem types. Congestion was seen as a problem by 64% of the population; substantially higher than safety (23%) and noise (16%), which ranked second and third.

So there was a need for a substantial amount of work on congestion at the network level, including the very important question, “How much congestion can we accept before it becomes unacceptable?”

Which raises the secondary question; of how do we measure congestion in ways that can be understood by the community and politicians. That is a sophisticated question because congestion varies due to many factors including traffic volume, and volume varies depending on when it is measured.

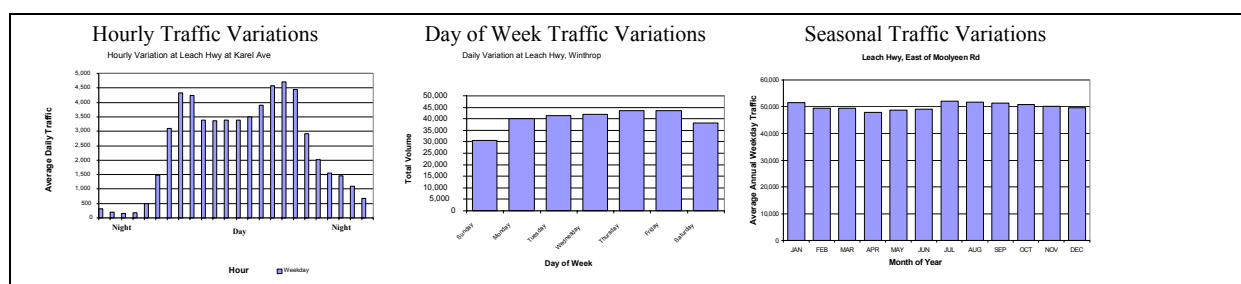


Figure 2 Typical traffic variations

The measures of congestion considered were level of service (LoS), length of peak period, traffic speed, and some new ‘efficiency’ measures. We started with LoS because most professionals understand it, community leaders understand it, and LoS can be illustrated by photos.

Level of Service

The LoS concept is based on the driver’s freedom to maneuver, travel at the desired speed, and avoid undue delays. It varies from LoS A (plenty of freedom) to LoS F (practically no freedom); it is measured differently for mid-block and intersections.

Mid-block Level of Service

A review of references indicated surprising differences in volumes for the same LoS on the same road type. References used were Austroads (1988), Highway Capacity Manual (HCM) (2000), and Road Reserves Review (RRR) (1991); the last being Perth specific.

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We selected RRR for arterial roads because it made allowance for Perth roads having mainly flared intersections, HCM (2000) because it is the most up to date reference for freeways, and Austroads for expressways because it fitted best when compared to the RRR and HCM for the other road types. The result is as follows:-

Table 1 Proposed Mid-block Traffic Volumes (5% Heavy Vehicles - Austroads Class 3 and above)

Road Type	Upper Limits of Hourly One-way Traffic Volumes for Level of Service					Source
	A	B	C	D	E	
2-lane undivided	527	615	702	790	878	RRR
2-lane divided	585	683	780	878	976	RRR
4-lane undivided	(527)	(615)	(702)	(790)	(878)	RRR
4-lane divided	(703)	(820)	(937)	(1,054)	(1,170)	RRR
6-lane undivided	(527)	(615)	(703)	(790)	(878)	RRR
6-lane divided	(703)	(820)	(937)	(1,053)	(1,171)	RRR
4-lane freeway	(615)	(970)	(1,410)	(1,840)	(2,055)	HCM, 2000
6-lane freeway	(633)	(993)	(1,447)	(1,857)	(2,067)	HCM, 2000
4-lane expressway	(685)	(1,075)	(1,365)	(1,710)	(1,950)	Austroads

Values not in brackets are per direction.

Values in brackets are per lane

It happens that this combination gave us the maximum capacities. We were comfortable with this because it fits the general philosophy of not building/widening roads prematurely, and because Buchanan (2003) shows evidence of maxima increasing over time:

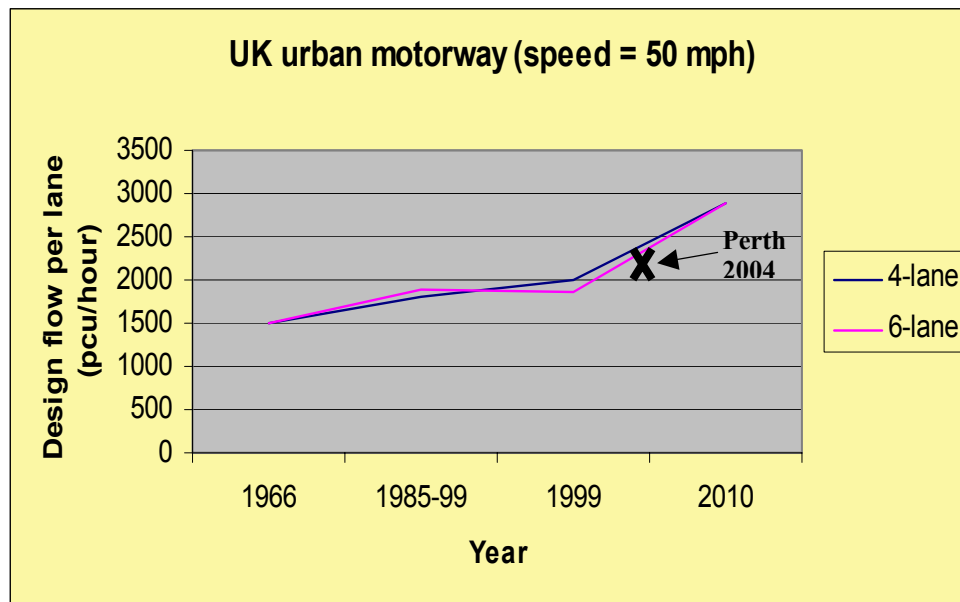


Figure 3 - Changing estimates of road capacity

So, we have *mid-block* capacities from Table 1, but the references imply something about *intersections*, in our case that they are mainly modern layouts with separate turning slots. Our

interpretation of this is that ‘major’ intersections will have a substantial effect on the network capacity, so should be analysed separately; whereas ‘minor’ intersections may be considered covered by the mid-block analysis, so do not need to be analysed separately - at least for a strategic network analysis such as this.

Intersection Level of Service

HCM (2000) gives intersection LoS using overall delay per vehicle passing through the intersection:

- from LoS A – less than 10 secs
- to LoS F – over 80 secs

Note that *mid-block* LoS F is physically determined, *intersection* LoS F is not. In other words the mid-block volumes at LoS F are at, or close to, their physical limit, whereas the 80 second delay for intersection LoS F can be substantially exceeded.

Initially we selected 17 major intersections for analysis. Analysis used aaSIDRA, video counts of actual turning volumes, and actual SCATS signal phasings, so we were reasonably confident of the results. Delays from SIDRA gave us the LoS for each intersection. And we did SIDRA calculations for future LoS at these intersections, using estimates of future through traffic growth from the Main Roads WA ‘Regional Operations Model’ (ROM), and making adjustments to turning volumes based on ROM combined with professional judgment.

Combined mid-block and intersection LoS

We mapped the mid-block and intersection results as shown in Figure 4.



Figure 4 – Current mid-block and intersection LoS

We also did the same for future years. So now we have a comprehensive picture of mid-block and intersection congestion – or do we?

No. We have only covered peak hours, we don't really know if we have covered all the 'major' intersections, and we don't know 'how far we are into LoS F'. All the other LoS ranges have a bottom and a top, but LoS F has no top to its range. More of this later, first have we covered all the major intersections?

SCATS and Congestion

We did not have the resources to do a SIDRA analysis on all intersections in the study area; we only selected 17, considered the worst by a small group of experienced professionals.

In an effort to be more objective we then selected additional intersections, for which we were able to obtain SCATS data. This gave an indication of actual congestion; but not in terms of LoS.

SCATS System Monitoring data includes 'Unusually Congested Minutes', which shows when the degree of saturation exceeds 100% (i.e. is over saturated) for each cycle on each leg. We were able to compare 12 intersections with both SIDRA and SCATS results, for AM and PM peaks, a total of 24 comparisons. We looked for the following correlation, see Table 2.

Table 2 - Hypothesized relation between SIDRA and SCATS congestion measures

SIDRA LoS	SCATS over saturated cycles
better than E	less than 20%
E	20% to 40%
F	greater than 40%

This relation was hypothesized using professional judgment, and then tested.

The results were better than expected; with 82% of the comparisons showing either good agreement (identical LoS) or reasonable agreement (LoS one level difference). In fact the results were probably even better than this because it turned out there were reasons for poor agreement at two intersections. One had experienced a significant change in traffic volume in the several months between taking the counts for SIDRA and receiving the SCATS data, and the other had a malfunctioning SCATS detector.

These results enabled us to add eight intersections to the congestion map, including four congested intersections which would otherwise have been omitted, see Figure 5.

This work indicates that SCATS can provide a new way of monitoring network congestion at the strategic level, in addition to its use in day-to-day operations. This is a significant finding. It is a finding that could warrant further comparisons of SCATS/SIDRA data.



Figure 5 – Current mid-block and intersection LoS, with SCATS results added

How far into LoS F?

We can see from the LoS maps (Figures 4 or 5) that Perth already has places with LoS F. So it is not practical to simply say “We cannot accept LoS F” or even LoS E, as some transport professionals say.

So what do we say? The first thing this paper says is we need to develop a language by which to debate LoS in the context of not simply “building more roads” to cope with increasing congestion. We need this language because we know that the LoS E/F boundary is being exceeded, but we don’t know by how much. The initial response from traffic engineers is that you cannot physically exceed LoS F, so it is not appropriate to talk about it.

We have already seen that this is not true for intersections; it is commonplace to exceed 80 secs delay. And most traffic engineers agree, for mid-block flow, that you can get about 10% more traffic through than the textbook LoS E/F boundary shows, but the flow tends to become unstable. What is less commonly recognized is that, when analyzing future traffic estimates from 24 hour traffic models, it is commonplace for peak hour LoS E/F to be exceeded in theory: in practice mid-block LoS E/F will not be exceeded greatly, rather peak spreading will occur.

So we developed a new approach. Table 1, showing the various traffic volumes for each LoS, can be represented graphically. This was done by taking the mid-block ‘capacity’ for each road type as being 10% more than the volume at the LoS E/F boundary, so this represents where the volume/capacity ratio (VCR) is 1.0. Other mid-block VCRs were then calculated

for the other LoS boundaries. Similarly the intersection VCR of 1.0 was taken as being 10% more than 80 secs (i.e. 88 secs). The result is Figure 6.1 below. This represents the practical working range. This was then extended above the practical range as shown in Figure 6.2.

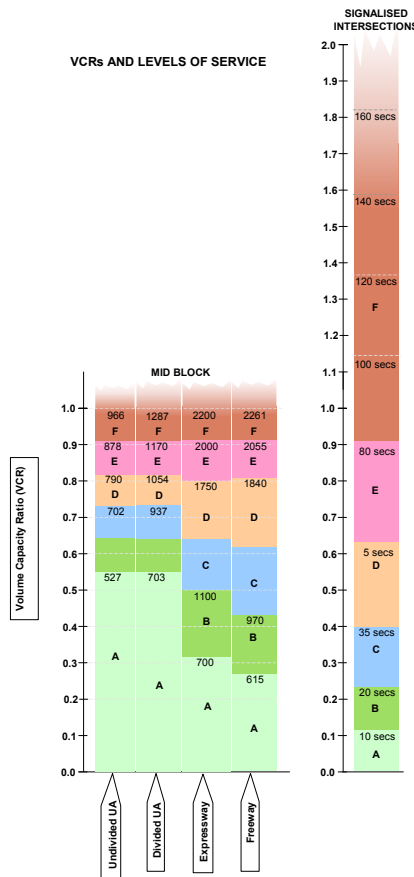


Figure 6.1 LoS shown as VCRs practical range

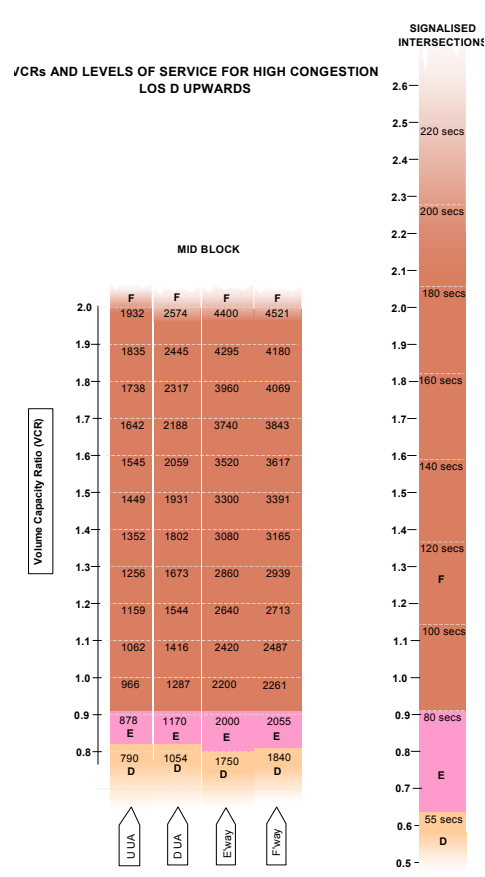


Figure 6.2 – LoS shown as VCRs theoretical range

These charts show the flow *per hour* for each road type.

The notation LoS F_{suffix} has been used to describe ‘how far into LoS F we are’. The suffix is the VCR above. For example LoS F_{1.0} describes the practical maximum mid-block flow. F_{2.0} describes double that flow: clearly not practical in one hour, rather indicating peak spreading to significantly more than one hour. The suffix may also be used to consider LoS E intersection congestion, which ranges from approximately E_{0.6} to E_{0.9}, while mid-block congestion only varies from about E_{0.8} to E_{0.9}.

Applying F_{suffix} to the previous congestion maps resulted in Figure 7, which shows a surprising result:-

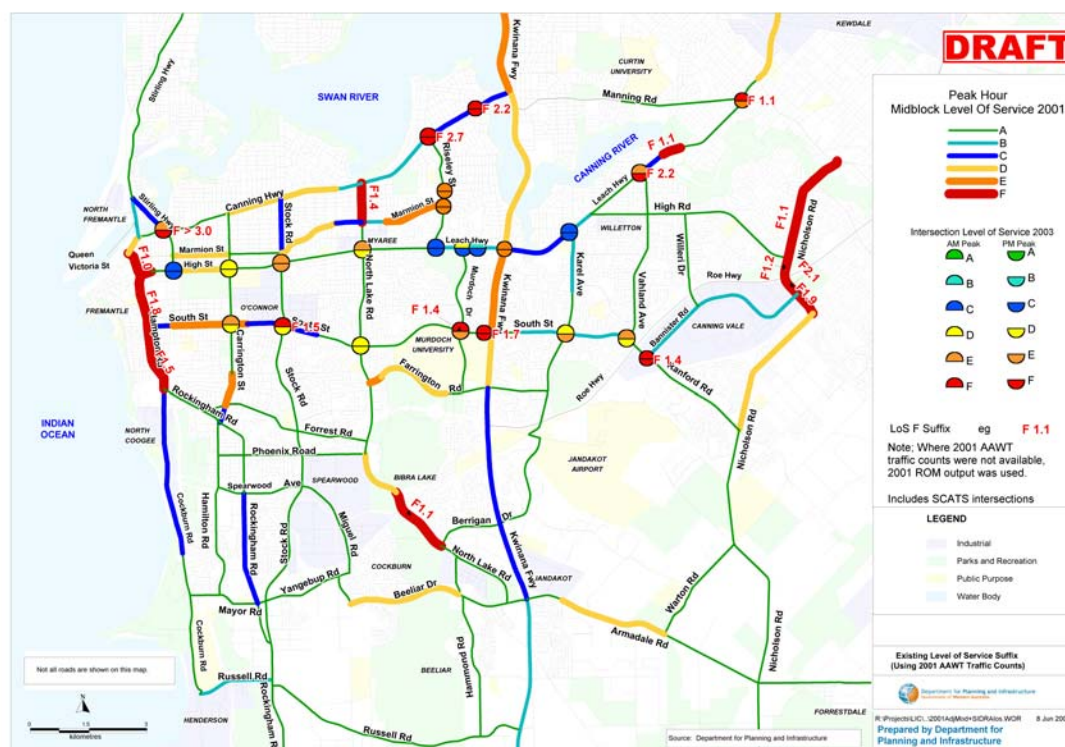


Figure 7 – Congestion map using LoS F_{suffix}

The surprise is by how much LoS $F_{1.0}$ was exceeded. At intersections this is simply because of long delay times. The reason for mid-blocks is that the LoS calculation is based on assumptions of peak to 24-hour traffic ratios and directional splits. We did measure typical ones, and applied those: obviously they are different at the very congested locations. So, again, this is a theoretical approach; never the less a very useful one at the strategic level. It is similar to the suggestion by Cameron (1996) of using LoS G, H, and I; but our suggestion of using VCRs (as the suffix) arguably provides a better theoretical basis.

We could, given more resources, measure the actual peak period flows in each direction at each location and do more accurate calculations for today. But we would still not know the future peak to 24-hour traffic ratios and directional splits, so we would still have to make some theoretical assumptions about peak flows from a 24-hour traffic model. So we did not consider this further.

Rather we followed up the general implication that, if LoS $F_{1.0}$ is exceeded by much, then the practical manifestation will be peak spreading.

Peak Spreading

If we have an amount of peak hour traffic which theoretically exceeds what the road can take, say $F_{1.3}$, it will be as shown in Figure 8.1.

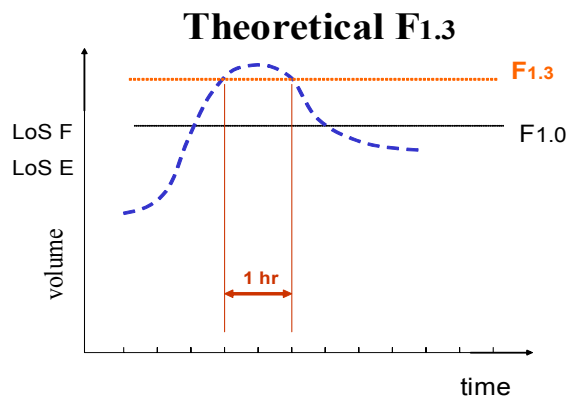


Figure 8.1

But, in practice, peak spreading will occur. The extra traffic will have to be accommodated either before the peak ('active spreading' according to Bollard and Ashmore 2002) or after the peak ('passive spreading') as shown in Figures 8.2 and 8.3.

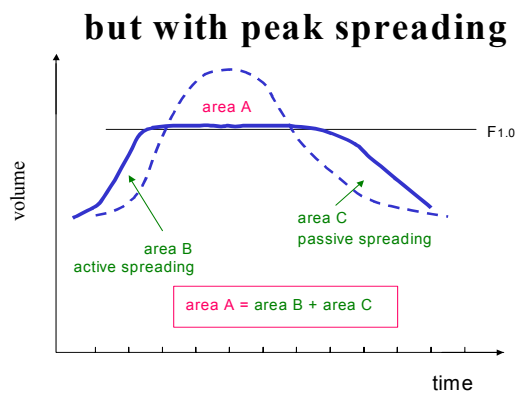


Figure 8.2

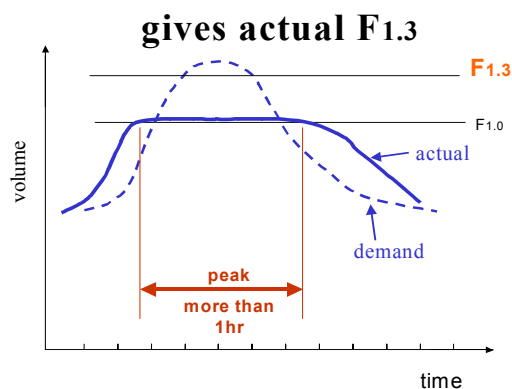


Figure 8.3

The extent of the spread will depend on the shape of the demand curve. If it is very peaky (for example, a radial arterial serving mainly commuter traffic from a dormitory suburb) the peak spread will not be great. On the other hand, if the demand curve is fairly flat, with significant demand during most of the day (for example, a busy ring route serving mixed traffic, such as Leach Hwy), then the peak spread will be considerable.

From inspection of several real curves the amount of spread is very sensitive to the shape. For a reasonably flat curve an increase from F1.0 to only F1.15 showed an increase in peak *period* from one hour to over four hours, which for AM and PM peaks would indicate congestion for all of the working day.

Such a high degree of sensitivity is another significant realization from this work. It suggests that we should be able to accept higher levels of peak *hour* congestion on some types of roads than others.

Some argue that this high degree of sensitivity is not realistic, because alternative routes will be found, or modal shift will take place to reduce this effect. True; however, the Perth traffic model (ROM) already allows for route changes based on congestion. These are averaged over a 24 hour period, not the peak hours, but there is an allowance. And ROM already allows for some increase in walking, cycling, and public transport for personal trips in future; and it seems impractical to expect a significant degree of modal shift for commercial and freight traffic in future (a shift of some freight to rail has already been allowed in ROM). So this argument has already been addressed to some extent.

Rather than try to refine this argument further, which could take almost endless debate, we are following another approach – a more simple ‘horses for courses’ approach to setting maximum congestion targets.

Congestion targets

The ‘horses for courses’ approach indicates we need to consider a range of LoS targets, depending on the road function and type.

One acceptable level of congestion for all roads is not logical; we should accept different levels of congestion for different roads. For example, it would be logical to accept higher congestion on the radial Kwinana Freeway with dedicated public transport in the median than on Leach Hwy, which is a ring route with buses in the general traffic.

If the route is important to all user groups (freight, light commercial traffic, public transport and commuters) and it is likely to have fairly high use over much of the day, then the target should be only moderate congestion. If the route is of low importance to any of these groups then it is unlikely to have much congestion. So this is not a consideration.

For routes of ‘high’ and ‘medium’ importance, suggested targets for maximum congestion are given in Table 3.

Table 3 - Congestion targets (the ‘horses for courses’ approach)

	Route type			Route type	
High importance to	Ring route	Radial route	Medium importance to	Ring route	Radial route
freight & commercial traffic	low/mod congestion D	moderate congestion E	freight & commercial traffic	moderate congestion E	mod/high congestion F1.0
public transport ¹	moderate congestion E	mod/high congestion F1.0	public transport ¹	moderate congestion E	mod/high congestion F1.0
car commuters ²	mod/high congestion F1.0	high congestion ¹ F1.3	car commuters ²	mod/high congestion F1.0	high congestion F1.3

¹ For buses or trams in the general traffic. Clearly if there are exclusive transit facilities it will not matter to public transport users if there is traffic congestion on the route, some would argue this would even be an advantage.

² Public transport alternatives for car commuters are more likely on radial routes than ring routes
In this table 'congestion' means 'the average maximum congestion in the peak hour'; it may be exceeded for short periods within the peak hour. 'Congestion' will be less than this outside the peak periods

The places worse than these targets are shown in Figure 9.

**Figure 9 - Map showing places of unacceptable congestion 2001/03**

Figure 9 was produced using Table 3 plus knowledge of which routes are important to

freight, public transport and car commuters. As will be seen later, this view of congestion is closer to the community view than a 'straight' LoS view (eg Figure 4).

Congestion and efficiency

Congestion has the effect of slowing traffic. Using Tables 4.1, 5.1, and 7.2 from Austroads (1988) we produced Table 4:

Table 4 - Mid-Block Speed Ranges (km/h) for LoS A through F

Road Type	Posted Speed (km/h)	LoS A	LoS B	LoS C	LoS D	LoS E	LoS F
2L, 4L & 6L urban arterial (interrupted flow)	50	40	40	30	20	15	10
2L, 4L & 6L urban arterial (interrupted flow)	60	40	40	30	20	15	10
2L, 4L & 6L urban arterial (interrupted flow)	70	55	50	40	30	20	15
2L, 4L & 6L urban arterial (interrupted flow)	80	65	55	45	35	25	20
2L, 4L & 6L urban arterial (interrupted flow)	90	80	80	67	62	56	45
Freeway	100	100	100	80	69	64	45

Taylor (1992) indicates that, although delay time is an essential parameter of congestion, it is almost certainly not a complete measure. Our delay time parameter has been calculated by taking the difference between the speed at which traffic would flow at LoS A and speed at the prevailing LoS. This was done for each road section, and multiplied by the number of vehicles using the road (per peak hour in the peak direction), to give a measure of time lost per km per peak hour. Measures were calculated for freight/commercial traffic (vehicles above Austroads Class 3), public transport (buses which run in the general traffic, not exclusive bus lanes or railways), and general traffic (all vehicles).

It was interesting to note that the time lost by general traffic was in vehicle *days* whereas the time lost for freight was in vehicle *hours*. The time lost by buses barely showed up even when measured in hours, but multiplying bus time lost by 20, to represent typical peak hour passengers per bus, gave a picture of passenger hours lost which was comparable to freight vehicle hours lost. The factor 20 is an approximation based on nearly full buses in one direction and few passengers in the other direction. The exact figure is not critical.

A typical result for general traffic is shown in Figure 10.

It would be possible to produce results for the difference between a moderately congested situation, say LoS C, and the prevailing LoS. And it could be argued that this may be a more realistic measure of time lost, because it is unrealistic to expect metropolitan roads to operate at LoS A in peak periods. This is true, but the differences in speeds between LoS A and C are relatively small, compared to the differences in speeds between LoS C and F (see Table 4), so comparing to LoS C would not make a large difference.

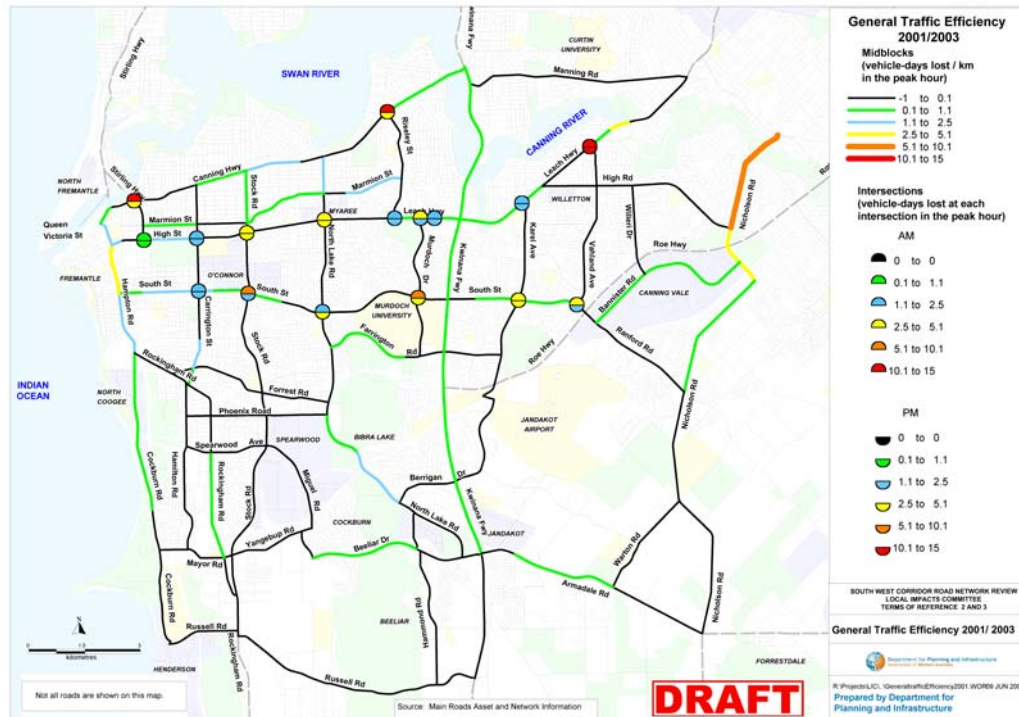


Figure 10 - Typical 'efficiency' map

Congestion as a proxy for air pollution

This general traffic efficiency map is a good proxy for relative amounts of air pollution, if not absolute amounts. For intersections the map is based on time losses from SIDRA analysis multiplied by the amount of traffic. This is similar to the way SIDRA calculates the amounts of CO₂ and NO_x pollutants, so general traffic efficiency at intersections may be taken as a fair proxy for intersection air pollution. In fact, R² results showed very good correlations for CO₂, between 0.84 and 0.98; and fair correlations for NO_x, between 0.65 and 0.94. Since mid-block general traffic efficiency is similarly calculated it has been taken as a reasonable proxy for mid-block air pollution.

Note that efficiency has been measured relative to LoS A. This is probably better than measuring relative to LoS C, because LoS A has least stop/starts and somewhat more fuel efficient speeds (see Table 4).

Congestion as a proxy for access problems

Access problems were defined as the difficulty in getting on/off roads due to vehicular traffic along these roads. The major roads with high traffic volumes (>30,000 AAWT) and a high proportion of heavy vehicles were the only roads considered.

The number of driveways, and the number of properties served by each driveway, were counted from aerial photographs. These were expressed per kilometer and multiplied by the volume of traffic in the kerbside lane. The result is an index of access difficulty, shown in Figure 11.



Figure 11 – Access problems caused by high traffic volumes

The results are comparable across the roads considered, but relative figures for other areas are not available. This could be an area for future investigation.

Relating to community perceptions

A telephone survey of residents and businesses in the study area asked what type of problems were perceived to be the worst, and where they occurred. As previously noted, congestion was perceived to be the number one type of problem. The locations of the congestion problems are shown in Figure 12.

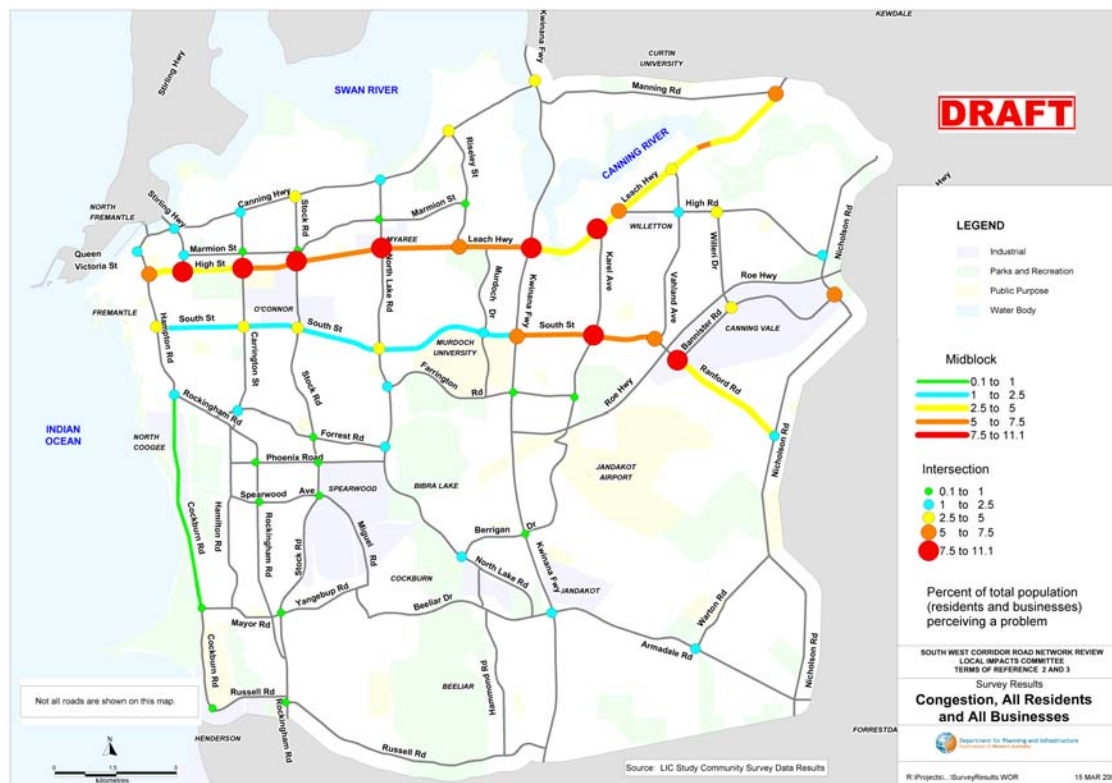


Figure 12 – Community perceptions of congestion problems

A comparison of Figure 12 with the LoS maps (Figures 4, 5 or 7) shows poor correlation. For Leach Hwy the LoS is better than on several other roads, yet the community clearly see Leach Hwy, followed by South St, as the main congestion problem areas. It could be that community perceptions tend to relate ‘congestion’ to stop/start conditions associated with traffic lights and the number of heavy trucks, rather than to the straight engineering measure of LoS.

A comparison of Figure 12 with Figure 9, which is based on the ‘horses for courses’ approach, shows better correlation. So the ‘horses for courses’ approach has enabled LoS to be used in a way which relates better to community perceptions than using a single LoS as the measure of what is ‘congested’.

Future Traffic Growth

So far we have assumed a certain amount of traffic growth for future years. Years 2006, 2011, and 2031 were specifically considered and maps for these years were produced. Future traffic volumes were from the ROM. ROM includes future estimates of land use, trip generation, and some increased use in public transport and freight rail, and this we called ‘scenario 1’. However, it is possible, and many argue it is highly desirable, that this amount of traffic growth may be curtailed. This could be achieved either by education programs, increases in fuel prices, or other actions. We do not know what these may be, but we felt the need to allow for them in principle. This we called ‘scenario 2’.

The two scenarios were selected by considering strategic analysis previously done for Perth, and interpreting this against what was considered practical. The result was a scenario 2 in which the 2031 growth happened to be close to the 2011 growth in scenario 1. This saved

work because all the 2011 analysis for scenario 1 also applies to 2031 in scenario 2. This is shown in Figure 13.

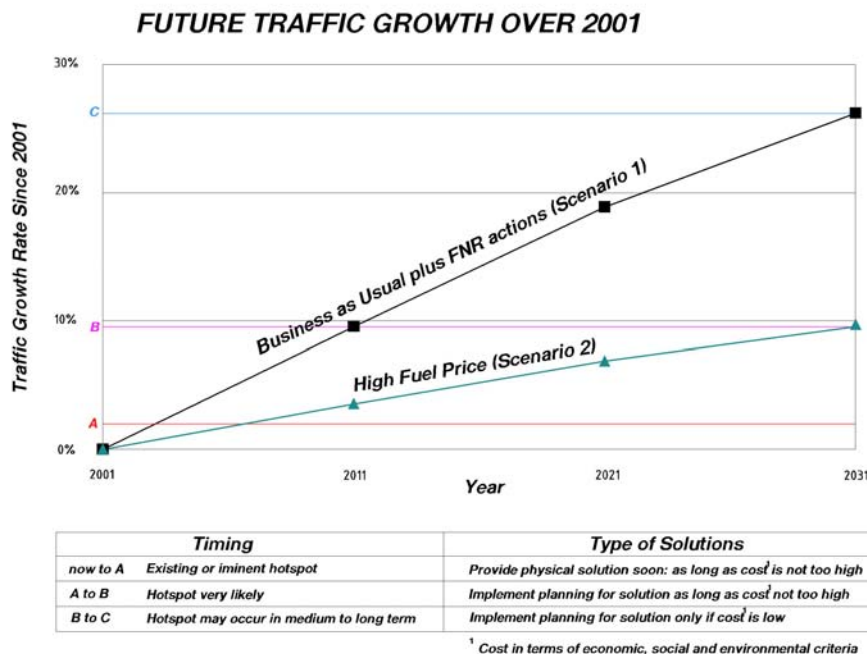


Figure 13 - Future growth scenarios and associated solutions

Note that the type of solution is linked to the likelihood of the growth occurring, and so creating a problem. This is shown under ‘Timing’ and ‘Type of Solutions’ at the base of figure 13.

Conclusions

Congestion has been considered in ways new to Perth. This includes relating SIDRA and SCATS measures, exploring the use of a new level of service measure LoS(F_{suffix}) to try to relate high congestion to peak spreading, considering future targets for congestion based on a ‘horses for courses’ approach rather than a single target LoS for all road types, developing new efficiency measures, comparing community perceptions to technical measures, and adopting two future traffic growth scenarios with associated solutions.

Most of these concepts are believed to be new to Australia, some may even be new internationally.

Qualification

At the time of writing the study has not been finalized. This paper does not represent final details, hence the ‘Draft’ stamp on most maps. This paper has been prepared to allow peer review of the new concepts, and enable their use elsewhere.

Acknowledgments

This work was carried out under the supervision of staff from the Department for Planning and Infrastructure and Main Roads Western Australia. Staff used consultants to do part of the work, including Maunsell Australia Pty Ltd and ARRB Transport Research Ltd for the technical work on congestion, and ERM Australia Pty Ltd and Patterson Market Research for the community survey.

Particular appreciation is extended to John Devney, Maunsell, who conceived of the ‘efficiency’ measures; and Dr James Luk, ARRB, who provided the technical sophistication to enable the SCATS/SIDRA comparison.

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