Introduction

Lower Urban Speed Limits (LUSL) are being applied to residential areas in many jurisdictions in Australia including parts of Adelaide, South East Queensland, areas of New South Wales and, more recently, Victoria and Perth. LUSL are seen as potentially having significant road safety advantages through traffic calming, and may therefore make a great contribution to 'vision zero' – if they can be made to work.

Given the current high amount of community support that the anticipation and implementation of such schemes enjoys, what is the emerging evidence to indicate if they are effective in terms of various measures? The purpose of LUSL is to reduce speeds, thereby calming traffic and enhancing road safety and improving the amenity value of local streets for residents. What is the magnitude of any benefits the implementations are achieving – and what costs are imposed? Is mobility restricted and travel time increased? If so by how much? Do we use more fuel and generate more air and noise pollution? How do LUSL compare in performance with the established local area traffic management practices involving the use of physical measures and devices? What do we mean if we say that 'the 40/50 km/h limit is working'?

Although commonly justified on the grounds of road safety, which is measurable (e.g. see McLean, Anderson, Farmer, Lee and Brooks (1994) and Kloeden, McLean, Moore and Ponte (1997)), the application of LUSL reaches well beyond the call for improved road safety statistics, and an assembly of less well defined factors is involved. Indeed, the support for such schemes could be seen as a cry from the community for some concept of improved amenity for which traffic speed is just an inverse proxy. This consideration is reflected in other approaches in Europe (e.g. the MASTER project, see Kallberg and Toivanen (1997)) where a framework for speed limits appears to be evaluated in a more holistic light.

This paper presents evidence quantifying the impacts of LUSL in terms of measured speeds and volumes, community attitudes, fuel and environmental impacts, travel times and road safety outcomes based on published and emerging evidence. Much of the evidence is based on research into the citywide Unley 40km/h scheme in Adelaide and the computer simulation modelling of the mobility and environmental effects of LUSL as comparisons with safety benefits.

A starting point for consideration of the overall impacts of LUSL is given by Taylor (2000), which reports a theoretical study which assessed traffic and environmental performance of test networks under different speed limits and traffic conditions. A number of performance indicators were used – these included unit travel time (min/km), carbon monoxide emissions, fuel consumption, change in free flow travel time, and congestion indices[1]. The study suggested that all of the indicators, with the exception of congestion index CI, performed better for a 60 km/h speed limit than for either 50 or 40

[1] Congestion index CI provides a dimensionless measure of traffic engineering delay, whilst index CI60 provides a dimensionless measure of delay relative to free flow under a 60 km/h speed limit – see Taylor (2000) for a full explanation of these (and other) traffic performance indicators.

km/h speed limits, with certain qualifications on these results. Figure 1 provides a summary outcome for the theoretical study. Travel times increase as speed limits are reduced, but not in direct proportion to the change in speed limits. Fuel consumption and emissions are higher under lower speed limits, although this result may have been biased to some extent by the specific fuel and emissions models available in the theoretical study (Taylor, 2000). A small 'paradox' was found in terms of delays. The congestion index (CI) which measures delay as a proportion of total travel time on a link decreased under lower speed limits – although overall travel times were longer under LUSL, time spent in delay was smaller[2].

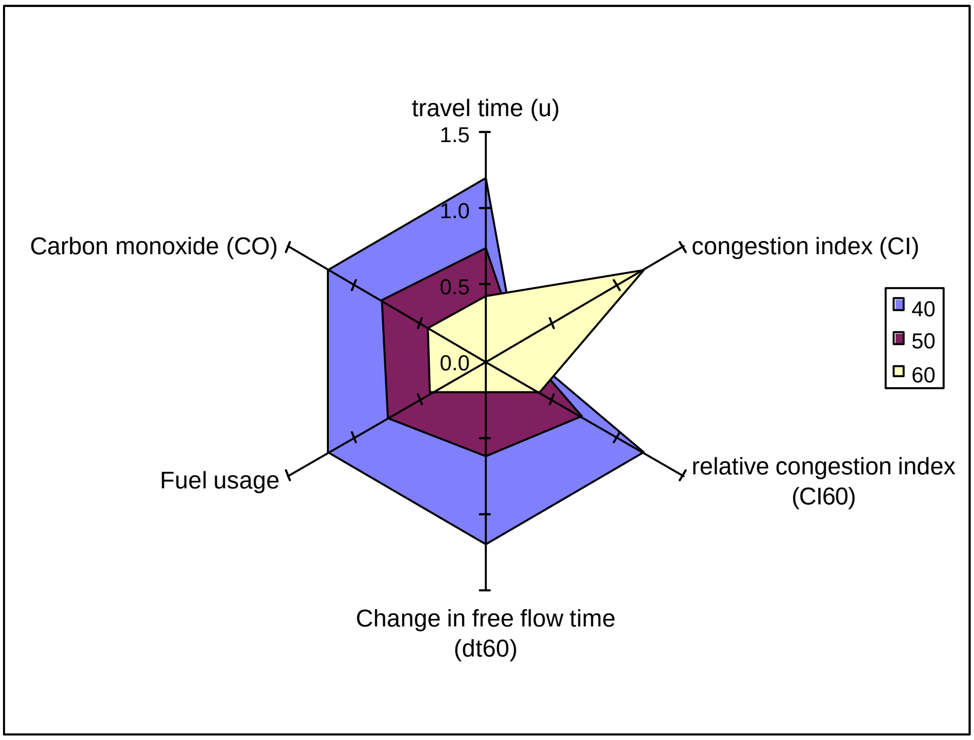

Figure 1. Starplot of modelled traffic performance indicators for different speed limits (60, 50 and 40 km/h) for test network C [source: Taylor (2000)] [The arms of the star represent the relative performance of a network under 40, 50 and 60 km/h speed limits on the six performance indicators of travel time, congestion index, relative congestion index (60 km/h datum), change in free flow travel time, fuel consumption and CO emissions]

---

[2] This outcome relates to the commonly accepted definition of delay used in traffic engineering (and in transport economics), which is that delay time is the excess travel time experienced above the free flow travel time. Lowering the speed limit increases the free flow travel time under an assumption of compliance with the limit. This result indicates that although total travel time is longer for lower speed limits, the increase in total travel time is less than the corresponding increase in free flow travel time, in either absolute or relative terms. This may be an indication of the 'traffic calming' impacts of LUSL?

This paper describes some new results from a set of more recent studies, for data collected in real world networks with lower speed limits and in the development of more detailed fuel consumption and emissions models for passenger cars.

Road safety outcomes from LUSL

The major impetus for LUSL is based on expected improvements in road safety outcomes. For example, the lower the impact speed, the higher the survivability of pedestrians. This naturally translates to vehicle occupants and other road users involved in a crash. Hence a major selling point is a reduction in crash severity and the avoidance of a certain proportion of crashes altogether. There are possibly five factors involved in safety outcomes through lowered speed limits:

1. where impacts occur, speeds and accelerations/decelerations are likely to be lower and therefore survivability higher;
2. drivers obey the limits for reasons of expediency (enforcement), or because the lower speed seems inherently suitable due to the streetscape, or because they embrace the lower limit per se, or a combination. We do not yet know how or whether this choice affects road safety outcomes;
3. the existence of a special speed zone alerts drivers to circumstances where they are expected to show particular care. Some aspects of this may be temporary, until the novelty wears off; others may be relatively permanent. Any observed reduction in crash incidence may not necessarily be correctly attributed to reduced speeds only;
4. pedestrian adjustment to lower speeds affects their judgement of safe crossing opportunities on residential streets. They also need to be aware that drivers who do not respect the lower limit may be travelling *much* faster than the norm. The need to be ‘tuned’ to 40, 40-‘plus’ and 60 km/h may place additional demands on pedestrians;
5. increased ‘ownership’ of lower speed roads by residents may affect the on-road behaviour of pedestrians, cyclists, children at play, etc.

The first point has been well researched and discussed (e.g. McLean *et al*, 1994). The other four points are also likely to have considerable influence and the challenge remains for researchers to somehow quantify these.

In the context of this paper, it is still too early to draw any conclusions on crash outcomes and overall net road safety benefits from current experiences with LUSL in Australia. Many of the schemes in place have been operating barely one year and it would be inappropriate to draw any conclusions at this point in time. In the meantime, some results are emerging for other aspects of traffic systems operation.

Experiences in NSW and Queensland

Woolley, Dyson and Taylor (2000) summarised the findings of a number of recent studies of the impacts of LUSL in NSW and Queensland.

In NSW, 26 LGAs trialed a 50 km/h urban limit between October 1997 and March 1998 in cooperation with STAYSAFE and the NSW Roads and Traffic Authority (RTA). The trial achieved reductions in average speeds of between 1.5 and 2.0 km/h and a seven per cent reduction in casualties. Of the 26 councils involved in the trial, 15 supported the 50 km/h limit and three were against. Community opinion also varied, with two surveys showing 66 per cent and 41 per cent support for the lower limit (Walsh, 1999) and RTA (1998). As a result of the trial, the NSW Minister for Roads invited all NSW LGAs in June 1998 to implement the 50 km/h urban limit with all costs to be funded by the RTA. At present, 90 per cent of the NSW population is covered by a 50km/h speed limit. Consequent evaluation by the RTA has revealed the following outcomes in the 21 month implementation period in 22 council areas (RTA 2000):

- a reduction of 22 per cent in the risk of having a crash
- 262 fewer road crashes
- cost saving of $6.5 million in avoiding these crashes
- the proportion exceeding 60km/h in what have become 50km/h zones fell from 37.6 per cent to just over 15 per cent
- community support was strong rising from 73 per cent before implementation to 80 per cent after
- most believed that the lowered limit would improve safety (92 per cent)
- reduction in average mean speed (first sampling after change in limit) was **0.94 km/h** (to 56.2 km/h) and **1.08 km/h** in 85th percentile speed (to 64.5 km/h) – but this improvement had slipped by the time of the second sampling
- further public education is required to ensure that it is understood that the speed limit in these urban areas is 50 km/h unless otherwise indicated.

A 50 km/h limit was introduced to all built up areas in South East Queensland in March 1999. Initial results showed positive effects both in reduced mean speeds and in public acceptance. Reported support for the scheme seemed higher than in NSW and has increased since the introduction of the scheme. Mean speeds for sites in Brisbane have been reported to decrease from 49.3 km/h to 43.1 km/h. One aspect of the scheme was a high profile three month amnesty period which seemed to have been instrumental in the transition to the lower limit with ongoing public support. Although no formal evaluation seems to have been initiated, key stakeholders monitoring the new scheme include Queensland Transport, the Police and the LGAs (Walsh and Smith, 1999)

The City of Unley case study

The City of Unley (henceforth referred to as Unley) lies between two and five kilometres directly south of the Adelaide CBD. It traverses the whole southern quadrant and so lies in the path of access to the CBD for residents from the southern suburbs. The north-south arterials and collectors through Unley are somewhat constricted and barely cope with peak period traffic demand. Residents believe that much rush hour traffic diverts to residential streets, hence the desire to render residential areas less permeable. Further, the older parts of Unley contain narrow ‘pre-traffic’ streets on which a 60 km/h limit is largely inappropriate. Local Area Traffic Management (LATM) measures of all flavours have been used in Unley since the mid 1970s. Unley was a pioneer with LUSL and implemented a trial 40km/h zone on a north-south axis in 1991 (LASL Trial Working Party (1993), City of Unley (1996)). This zone was less than one km wide, bounded on the east by an arterial and on the west by an overworked collector. It was relatively easily avoided by most CBD oriented traffic. The trial indicated that a 40km/h LUSL was feasible and it was made permanent following traffic monitoring and surveys of resident opinion.

In 1998 Unley took the initiative, with the backing of strong community support and Transport SA approval, to extend the 40km/h LUSL across the municipality. The limit applies to all local streets in Unley but not to arterial roads or designated collector roads. It was implemented on 1 January 1999 after an extensive marketing campaign in combination with a three month amnesty period. As part of this implementation, the Transport Systems Centre (TSC) was invited to undertake monitoring and evaluation of the effectiveness of the new speed limit, in part using data already collected and to be collected by the council. See Dyson, Woolley, Roach, Taylor and Eddy (2000) for a full evaluation of the Unley city wide 40 km/h limit. The objectives of the 1999-2000 Unley study were to:

- analyse and interpret speed and traffic volume data, in the Unley city wide 40 km/h LASL and on 60 km/h limit collector roads, generated both before and after the extension of the 40 km/h LASL;
- assess the effectiveness of the 40 km/h speed limit on the basis of the data collected through the monitoring program, and
- monitor and assess community reaction to the program.

The evaluation was conducted over a year involving two stages. The first stage monitored the short-term performance of the scheme between six and 12 months after implementation. Traffic data collected by Unley were compared with historical data from 1998. The full sample of 112 mid block sites comprised 73 on streets whose limits were reduced in 1999; 13 on streets whose limits had been reduced in 1992; and 26 on collectors with unchanged limits (at 60 km/h). In the set of streets with changed limits, quieter ones were under represented so that overall mean changes in speed and volume parameters are not properly representative. The second stage extended the monitoring period to 21 months and incorporated enforcement outcomes, from the viewpoints of both SA Police and residents, and interim crash statistics. Traffic data will continue to be collected in 2001 to address possible seasonal effects in the data.

Measures of the success of the scheme hinged on reduced traffic speeds and volumes, ongoing community support, perceptions of improved amenity and, if feasible, demonstrated reductions in crash incidence.

Notion of Amenity

Amenity is difficult to define, with many factors contributing to it. Relevant factors and their relative importance clearly vary among individuals, as revealed in free responses in the questionnaire surveys. The notion of reducing the incidence of intrusive or threatening vehicle speeds, as a partial proxy measure of improved amenity, is seen by the community as reducing the 'ills' of living in a certain area. The evaluation of amenity is often best achieved through carefully designed questionnaire surveys and focus group sessions, although Klungboonkrong and Taylor (1999) described analytical procedures that can be applied to studies of amenity.

Reduction in measured speeds

The change in the 85th speed percentile on each street after the reduced limit was introduced was related to its value before the reduced limit, as shown in Figure 2(a). The corresponding change in the mean speed is shown in Figure 2(b). Streets with the highest major speed parameters before the reduction in the speed limit have shown reductions in these parameters of much greater magnitude than those with moderate speeds. The streets with the lowest speeds have shown a small increase in their mean speed. The authors attribute this to some drivers choosing a speed to match more closely the prominent signage. The net effect has been to reduce the variation across streets in their major speed parameters.

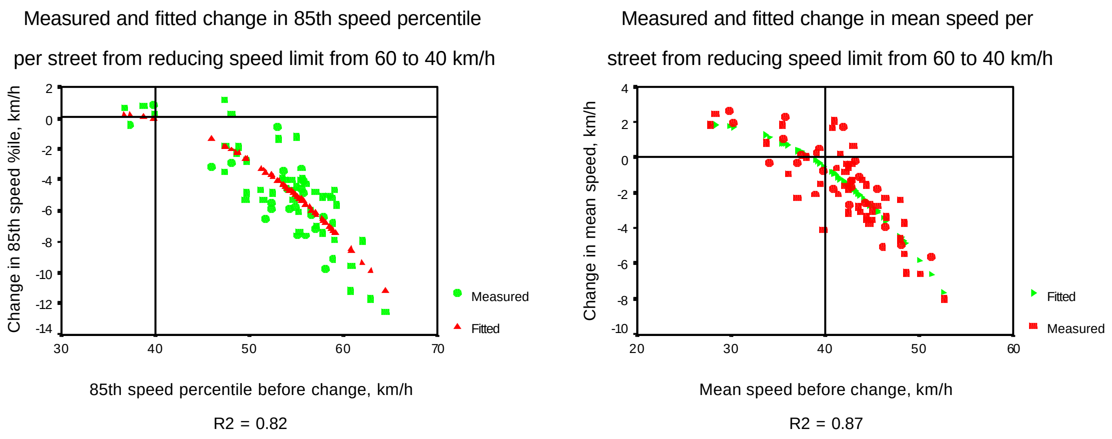

Figure 2. Measured and fitted changes in speed parameters on 60® 40 streets
(a) 85th percentile speeds (b) mean speeds

The results may be summarised as follows:

- streets which carried low speed traffic in 1998 (mean speeds less than 40 km/h) showed little change in 1999-2000, although some streets exhibited small increases in mean speeds, of the order of 1-2 km/h towards the 40 km/h limit (see Figure 2(b))
- streets which carried slightly faster traffic in 1998 (mean speeds in the range 40-45 km/h) have shown small reductions in mean and 85th percentile speeds, of the order of 2-3 km/h
- streets which carried faster traffic in 1998 (mean speeds above 45 km/h) showed a greater falling away in the 85th percentile speed and from a relatively lower threshold (85th percentile > perhaps 45 km/h, see Figure 2(a)). The 85th percentile usually exceeds the mean in these conditions by 7-11 km/h

In NSW the <u>second</u> session of speed monitoring after the change in limit showed a rise in speeds compared with the first session after the change in limit (0.4 km/h for the mean and 0.3 for 85th percentile. We found that in Unley speeds continued to fall (except for mean speeds on the slower streets).

Changes in measured volumes

Streets with a 40 km/h limit have been characterised by their Average Daily Traffic (ADT): minor < 800 veh/day; major > 2000 veh/day. Observed reductions in volumes are summarised in Table 1.

Table 1 Unley observed reductions in traffic volume through reducing speed limit on residential streets to 40 km/h

Street characteristic	No of sites	Mean volume reduction	Comments
Minor residential	46	3 per cent	Very wide ranging change
Medium residential	24	7 per cent	Consistent effect
Major residential	9	9 per cent	Consistent effect
Collectors (@60 km/h)	*7*	*4 per cent*	*Wide ranging change (1 to 9 %)*

The comparisons in Table 1, and in Figures 2(a) and 2(b), are not completely rigorous since the monitoring before and after the change in limit did not take place at the same time of the year. Thus the overall volume and/or speed reduction may be exaggerated but the *relative* reduction according to street type should be reliable. The busier 60 km/h streets showed bigger reductions in volume with the changed limit than the minor ones. This implies that traffic was diverted to other routes but apparently not all onto the collectors. The arterials through and around Unley may have picked up additional traffic (as would have been intended) but this has not been monitored.

As minor streets were under represented to a high degree in the sample of streets monitored, there would not have been a large proportion of residents who have experienced a sizeable reduction (> 7 per cent, say) in traffic on their street. We note also that much of the reduction in volume and speed measured on the major 40 km/h streets took place *outside* rush hours. This has the effect of ***increasing the contrast*** between rush hours and other periods of the day, so the effect on amenity in a perceptive sense is not necessarily deduced as beneficial. An example is provided to emphasise this point.

We define the measure 'rush' per hour as the sum of the speeds of all vehicles passing in an hour, in either one direction of interest, as used here, or in both directions as a measure of total disturbance. Figures 3(a) and 3(b) represent contrasting patterns, measured since the change in speed limit. Figure 3(a) shows a street about which complaints are voiced and which attracts rush hour traffic from a crowded collector. Figure 3(b) shows a transverse street with no specific complaint that we are aware of.

The contrast shown in Figure 3(a) between morning rush hour and the rest of the day, is substantially greater than it was before the speed limit was reduced. From the street shown in Figure 3(a), since the change in the limit, some non-rush hour traffic appears to be successfully diverted to the collector.

The total rush on the transverse street, shown by the area under the curve in Figure 3(b), is greater than that on the street in Figure 3(a) but the rising contrast to 9:00 am is far less, by a factor of at least six. The contrast is far less pronounced on the transverse street.

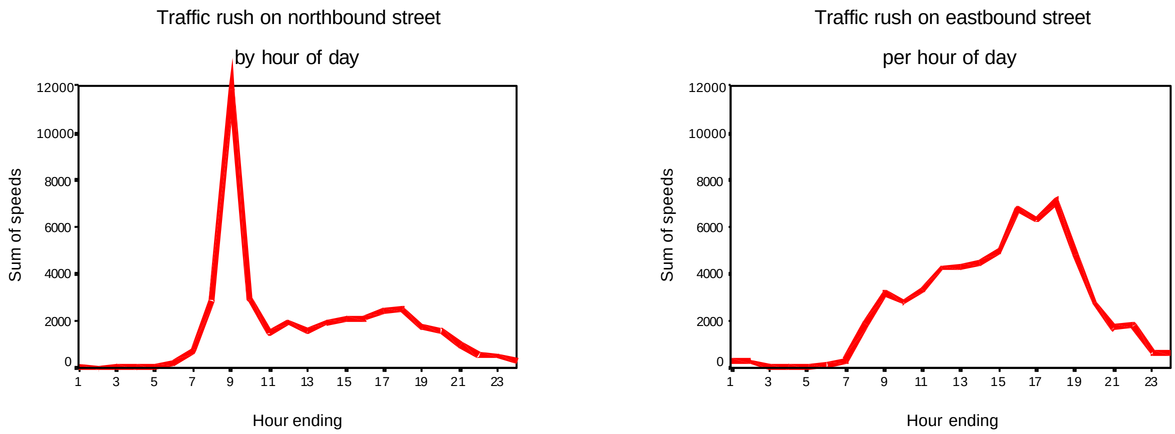

Figure 3. Traffic rush in Unley: (a) northbound street with resident complaints
(b) eastbound street without resident complaints

Enforcement

Enforcement is another aspect of LUSL which requires attention. In the case of the Unley implementation, surrounding councils still maintained a 60km/h speed limit. Therefore Unley stood out as a unique area but arguably an area large enough so that people would only dramatically alter their chosen route around the municipality at great inconvenience. Speed camera enforcement has been conducted on the minor street system in Unley since the introduction of the LUSL. A common perception amongst residents was that 'outsiders' did the bulk of speeding. The reality, using SA Police data, is that 40 per cent of speeding notices issued from speed camera enforcement were for vehicle owners residing within the 40kmh boundary and only 30 per cent for those residing south of Unley (i.e. those presumably commuting to the city).

Surveys of residents' perceptions and attitudes

The results presented above summarise the outcomes of the traffic studies conducted in the Unley evaluation. In addition, questionnaire surveys and focus groups were conducted to gauge the attitudes and perceptions of Unley residents. Full details of these surveys may be found in Dyson *et al* (2000).

Questionnaire surveys

Support for 40km/h speed limits in Unley has been strong and broadly matches levels reported throughout Australia (AUSTROADS, 1996). Surveys were conducted in 1999 (a sample of 880 residents) and in 2000 (a different sample of 882 residents). In 2000, belief that speeds had fallen was steady at 65 per cent, but there was a decline in those thinking residential streets are safer (60 per cent) and in those supporting the citywide 40 km/h limit (58 per cent). All three approval ratings stood at 67 per cent in 1999. Approval was at 71 per cent before the change of limit took place. There was polarisation between those who want more enforcement and those who are critical of the way enforcement is currently managed – predominantly on wide, busy 40 km/h limit streets. A notorious stretch of wide street (13 m wide, 600 m long) brought the comment from one respondent that '*obstructions should be erected down the centre to stop the planes landing*'.

Thus community support for the 40 km/h scheme in Unley has fallen more between 1999 and 2000 (20 months after the change) than it did between 1998 and 1999 (seven months after the change). This is despite speeds having continued to fall, albeit marginally, between 1999 and 2000 (Dyson *et al*, 2000). By September 2000, after 17 months, 16 per cent of survey respondents said they had been fined for speeding on a 40 km/h street. Those who had been fined tended to be much more critical of the scheme but this observation cannot as yet be claimed to be a causal connection[3].

With regard to driving behaviour, survey respondents in Unley pointed to the additional burden on the driver in selecting the best gear for driving at the lower limit. This has some implications for environmental impacts. The question of which speed limit produces more emissions is a complex one. Many begin by reasoning that a lower speed limit equates to lower emissions as vehicles are travelling at lower speeds and should thus produce less emissions, but this is not necessarily so for vehicles cruising at constant speed: see Watson (1995) and Taylor (2000). However, under normal suburban driving conditions where cruising opportunities are limited, higher speeds produce the potential for more emissions as acceleration tends to dominate differences in different cruising speeds. Thus the driving phases (acceleration, cruise, deceleration and idle) during the journey become critical in the consideration of emissions. Previous research at TSC has considered the effects of LATM devices on fuel consumption and indicated that significant savings can be made if a LASL is implemented in preference to LATM devices (Zito and Taylor, 1996). Questions of fuel and emissions performance of LUSL are considered in a subsequent section of this paper.

[3] This rate is, to put it in context, about half the rate in Adelaide on 60 km/h roads as revealed in similar questionnaire surveys - but exposure rates have not been assessed. However, willingness to accept the appropriateness of being fined in relation to a 40 km/h limit appears to be much diminished.

Summary of the Unley experience

The implementation of the 40km/h speed limit in the City of Unley generally appears to have been a success in terms of reducing vehicle speeds, volumes and improving resident amenity, though there is some polarisation of residents' views and some questions of equity. The verdict is as yet undecided regarding the appropriateness of the LUSL on vehicle emissions and road safety outcomes.

The lesson learnt from the Unley experience is that the 40km/h limit works sufficiently well at most times of the day. The morning peak period provides the greatest contrast in vehicle volumes and speeds and it seems the lower speed limit is not sufficient to deter through traffic at this time. The pertinent question is how traffic can be influenced during this peak period to improve amenity of the residents. Enforcement may well be a solution targeted on the morning peak but as with all enforcement this is subject to community backlash and available police resources. The future challenge for Unley and (perhaps) beyond seems to be how to encourage self regulation to drive as appropriately, or considerately, during the morning peak as at other times of the day.

Impacts of LUSL on emissions

A related research project at TSC is expressly concerned with the impacts of LUSL on fuel consumption and emissions (Primerano and Zito, 2000). This project, undertaken for Transport SA, is considering the relationships between emissions and driving behaviour under two speed limit regimes (60 km/h and 40 km/h) in residential areas, given that these are the regimes currently employed in South Australia.

Using steady speed data to determine the emissions at different speed limits does not reflect the real driving conditions encountered on the road network, where there are constantly differing acceleration and deceleration phases as well as cruise (Andre and Hammarstrom, 2000). Watson (1995) discusses the issues relating to cruise speeds and shows how a decrease in speed will increase emissions when the cruise speeds are maintained for long periods of time (and hence long travel distances). Such conditions are seldom experienced in residential street networks, where street sections lengths are relatively short, perhaps a few hundred metres or less. In these conditions a vehicle will accelerate and decelerate for a longer period to reach or descend from higher speeds.

The Biggs-Akcelik instantaneous model of fuel consumption and emissions may be used to explain this behaviour (Taylor and Young, 1996). The variables in the model include instantaneous values such as speed $v(t)$ and acceleration $a(t)$ at time t. The instantaneous model gives the rate of emission/consumption (E/C) of pollutant/fuel type X, including components for:

(a) the fuel used or emissions generated in maintaining engine operation, estimated by the idle rate (α);
(b) the work done by the vehicle engine to move the vehicle, and
(c) the product of energy and acceleration during periods of positive acceleration.

The energy consumed in moving the vehicle is further divided into drag, inertial and grade components. Part (c) allows for the inefficient use of fuel during periods of hard acceleration. The model is

$$\frac{dE(X)}{dt} = \alpha + \gamma_1 R_T v + \left[\frac{\gamma_2 M a^2 v}{1000}\right]_{a>0} \qquad R_T > 0$$
$$\frac{dE(X)}{dt} = \alpha \qquad R_T \leq 0 \tag{1}$$

where v is speed in m/s; a is instantaneous acceleration in m/s^2; R_T (kN) is the total tractive force required to drive the vehicle, which is the sum of the drag, inertial and grade forces; M is vehicle mass in kg; α is idling fuel consumption or pollutant emission rate; γ_1 is an engine efficiency parameter (mL or g per kJ), relating E/C to energy provided by the engine, and γ_2 is a second engine efficiency parameter (mL or g per ($kJ.m/s^2$)) relating E/C during positive acceleration to the product of inertia energy and acceleration.

R_T is given by

$$R_T = b_1 + b_2 v^2 + \frac{Ma}{1000} + g\left(\frac{M}{1000}\right)\left(\frac{G}{100}\right) \tag{2}$$

where g is the gravitational acceleration in m/s^2; G is the percentage gradient (negative downhill); b_1 (kN) is a drag force parameter relating *mainly* to rolling resistance, and b_2 (k/gm) is a drag force parameter relating *mainly* to aerodynamic resistance. Both of the drag force parameters also reflect some component of internal engine drag. The five parameters α, γ_1, γ_2, b_1 and b_2 are specific to a particular vehicle, and the idling rate and energy efficiency parameters (α,γ_1 and γ_2) depend on the type of fuel or emission as well.

TSC has used chassis dynamometer tests to determine engine maps of fuel and emissions (including CO, CO_2, HC and NO_x) various levels of engine power and speed, and thus provide specific fuel and emissions models based on equation (1) for its instrumented vehicle (a GMH VS Commodore sedan). This vehicle is driven in real traffic conditions to observe pollutant emissions for those conditions.

Primerano and Zito (2000) discussed emissions models and their verification. They analysed the differences in emissions performance between 40km/h and 60km/h speed limits, on the basis of comparisons of speed profiles over different lengths of residential street, including acceleration, cruise and deceleration phases, and different acceleration behaviour (simulating driver behaviour in terms of a parameter known as the 'beta-value', see Primerano and Zito (2000) for details). Summary results from this study are presented in below. Three different speed behaviour profiles (scenarios) were adopted for the 40 and 60 km/h speed limit cases in order to compare differences between emissions:

- Scenario 1 - a slow conservative driver, who accelerates slowly to the speed limit (beta-value =7) then cruises for a period of time at the limit, then decelerates slowly to rest
- Scenario 2 - an average driver who accelerates at an average rate (beta-value =15), cruises at the speed limit, then decelerates at the average deceleration rate (-3.5 km/h/sec), and
- Scenario 3 - an aggressive driver who accelerates hard to the speed limit (beta-value = 25), cruises at the speed limit for a period of time then decelerates at a high rate (-6.5 km/h/sec).

Each of these scenarios was applied to the two speed limit cases (60 km/h and 40 km/h). The additional variable that needs to be included is the street section length, as a measure of intersection geometry and traffic control.

Table 2 shows the amount of time taken for a vehicle to perform the speed profile scenarios for a given street length of 1250m. This street section length was chosen as it is the minimum length of street required to enable a cruise phase to occur when accelerating to 60km/h under Scenario 1.

Table 2. Time taken to accelerate, cruise and decelerate for a 1250m street

Scenario	Beta	Speed limit	Time (s)			Decel rate	Total time	Mean speed
		(km/h)	Accel	Cruise	Decel	(km/h/s)	(s)	(km/h)
1	7	40	38.40	80.71	26.67	-1.5	145.78	30.9
		60	82.00	1.80	40.00		123.80	36.4
2	15	40	11.13	100.23	11.43	-3.5	122.79	36.7
		60	21.80	53.07	17.14		92.01	48.9
3	25	40	5.94	106.35	6.15	-6.5	118.44	38.0
		60	10.49	64.51	9.23		84.23	53.4

Figure 4 shows the total emissions of CO_2 for the three speed scenarios and the two different speed limits versus street length, where the street length varies from 250m to 1500m. The figure shows a number of interesting phenomena. The total CO_2 emissions produced for hard and medium acceleration scenarios for a speed limit of 40 km/h were similar, as were the hard and medium acceleration scenarios for 60 km/h. In each case this was due to a smaller amount of emissions being produced in the hard acceleration and deceleration phases, due to a shorter amount of time spent in each of those phases. This was then balanced out with more emissions being produced in the cruise phase of the hard acceleration scenario since a longer time was spent cruising

Another interesting result is the occurrence of a crossover point. For street lengths exceeding 550 m street the total CO_2 emission for the 40km/h limit exceeds that for 60 km/h, for both medium and hard acceleration scenarios, and vice versa for shorter section lengths In these cases the amount of time spent cruising for the lower speed limit is now so significant that it more than compensates for the extra emissions produced in accelerating from 40 to 60 km/h and decelerating from 60 to 40 km/h. Hence when the street length reaches a certain critical value - influenced by the value of the emission rates for the phases - emissions for the cruise phase will dominate and become the influencing factor for total emissions on the street.

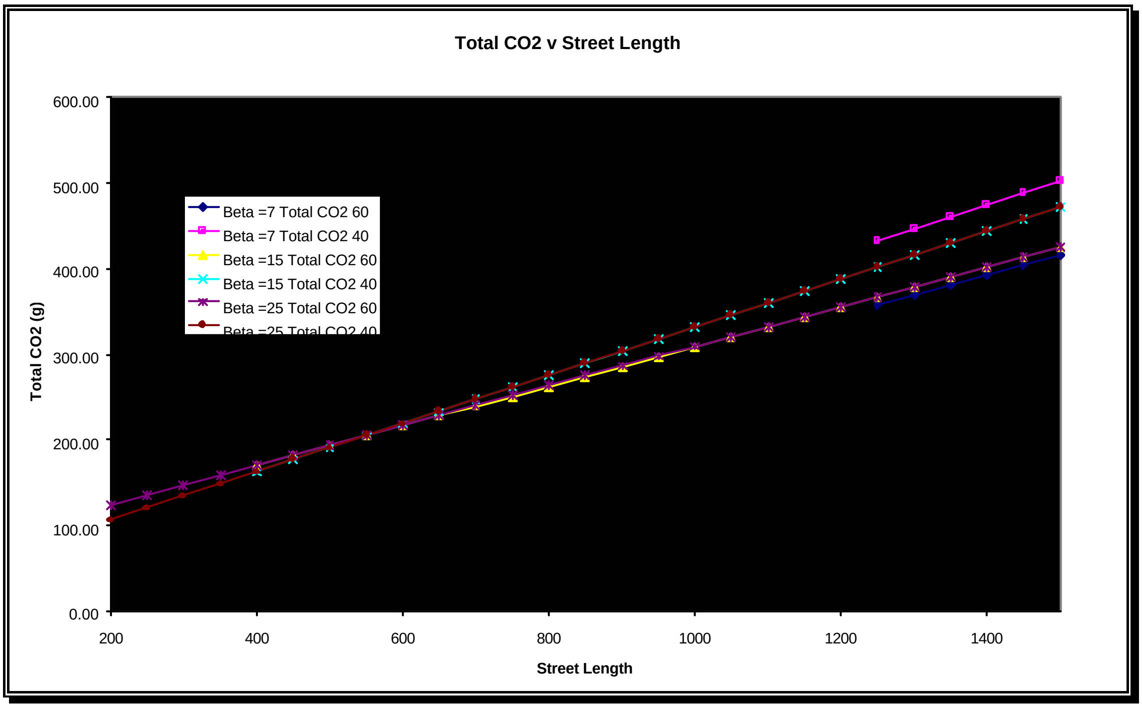

Figure 4. Total CO_2 emissions and street length, showing crossover effect at 550 m

Figure 4 also indicates that there is no cross over effect for the slow acceleration scenario - the emissions for 40 km/h speed limit are higher than for 60 km/h. For this scenario only street lengths that are greater than 1250m long have had their total emissions determined, as the acceleration and deceleration rates are so slow that a minimum street length of 1250 m is required in order to be able to fit in a cruise phase. For shorter street lengths there can be no cruise phase as the acceleration phase does not reach the speed limit. For the medium acceleration scenario the minimum street length was 400 m.

Figures 5 to 7 show the graphs of total emissions versus street length for CO, NO_x and HC respectively. While these emissions do not exactly follow the trend shown for CO_2 in Figure 4, there are similarities. CO emissions (Figure 5) show quite a different set of lines, largely due to the specific shape of the engine map for this pollutant. Emissions under the 40 m/h limit are always lower than those for 60 km/h. NO_x and HC show similar characteristics to CO_2 but their cross over points occur at different street lengths.

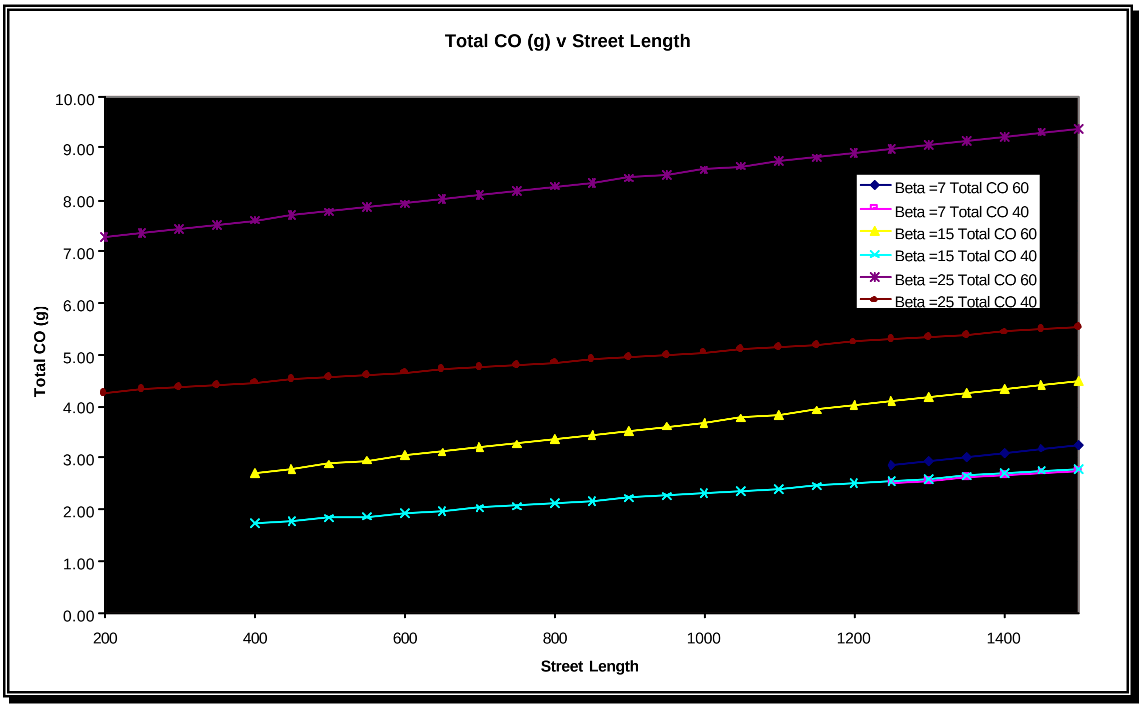

Figure 5. Total CO emissions and street length, no crossover effect

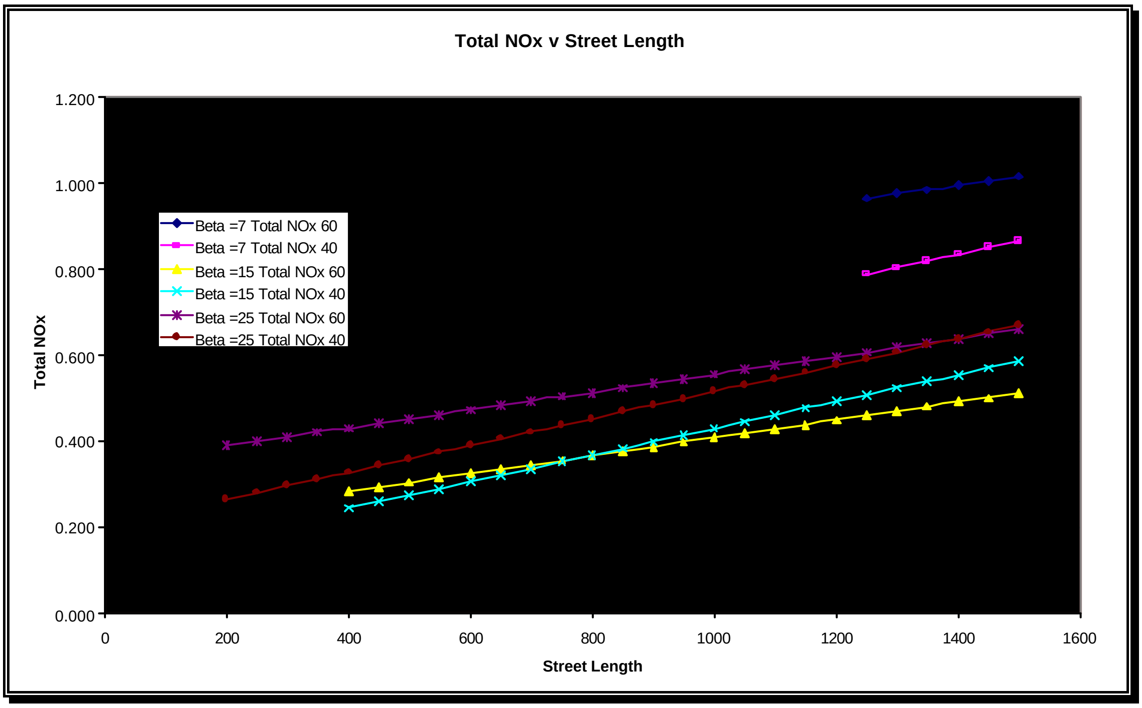

Figure 6. Total CO_2 emissions and street length, showing crossovers at 750 m (Scenario 2) and 1350 m (Scenario 3)

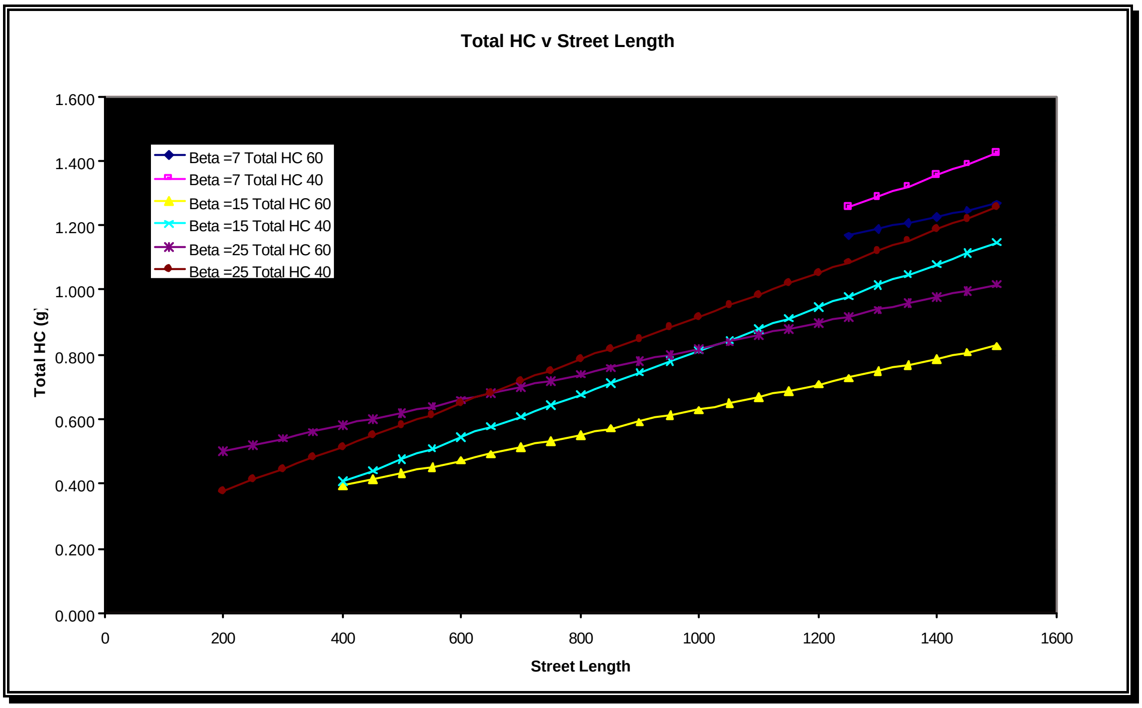

Figure 7. Total HC emissions and street length, showing crossovers at 390 m (Scenario 2) and 620 m (Scenario 3)

The plots in Figures 4-7 indicate that determining precise emissions outcomes for LUSL is complex. However, a general result is that for short street section lengths (say 350 m or less) emissions under a 60 km/h speed limit exceed those under 40 km/h, while for very long section lengths (say 1000 m or more) the opposite applies. The combination of network geometry and driver behaviour should be taken into account, probably on a case by case basis, in specific network studies. The use of microsimulation modelling (e.g. Woolley, Taylor and Zito, 2001) is recommended as a powerful approach given the availability of suitable modelling platforms (e.g. Paramics) and the emissions models described above.

Noise

As with air emissions, relationships of a LUSL with noise are not straightforward. For a single average passenger vehicle passing a point at a constant speed, each 10 km/h increase in speed increases noise by three dB(A). Therefore vehicles passing a house at 60 km/h are likely to be six dB(A) louder than vehicles travelling by at 40 km/h.

One aspect of acoustics which is less intuitive is that sound intensity is logarithmic. This means that sound levels cannot be added linearly so sound level *per se* is not an intuitive measure of noise pollution. Two noise levels of the same magnitude added together produce an increase of three dB(A) (e.g. 60 dB + 60 dB = 63 dB) which is just noticeable. To double the apparent loudness requires a tenfold increase in the noise energy emitted by traffic. Other complicating factors are the nature of the noise itself and the context in which it occurs. Freely flowing vehicles in residential streets are unlikely to cause unusual disturbances, while a heavily accelerating vehicle in the middle of the night can generate many complaints. Therefore the time at which the noise occurs and the nature of the noise (namely accelerating and hard braking) are the most important factors when considering annoyance.

Conclusions

We note that the studies of LUSL described in this paper are still in progress. It is, however, possible to draw a number of conclusions from them, even if certain qualifications may still apply to some of them:

- in terms of road safety outcomes, LUSL are expected to produce reductions in crashes and crash severity in treated areas, but there is as yet no firm empirical evidence because of the short periods of time that LUSL have been in operation (and the known low frequency of crashes on residential streets). This lack of data will change quickly and more definitive analysis will be possible in the next few years. The initial experiences in NSW (e.g. RTA, 2000) show positive signs in this regard
- traffic performance in terms of travel time (‘mobility’) declines under LUSL, but to a small degree not directly proportional to the reductions in posted speed limits. The quality of traffic flow (e.g. as suggested by standard measures of delay) may possibly improve and requires further study
- the Unley experience demonstrates that LUSL can achieve significant and sustained reductions in volumes and speed behaviour in residential areas, although there is evidence of increased differences between peak (commuter) period and off peak behaviour in some streets
- again based on Unley, community acceptance of LUSL is strong and can be maintained, although some polarisation of attitudes, especially with respect to enforcement strategies, may arise
- emissions (and fuel) outcomes are complex but can be analysed, and some general results are available (for short street section lengths, say 350 m or less, emissions are reduced under a 40 km/h LUSL compared to 60 km/h). Street section length is an important consideration for network design but there are slightly different effects for different pollutants. Further research is needed on this, including the consideration of a 50 km/h LUSL. Microsimulation modelling is required for full investigation of specific networks.

References

Andre, M and Hammarstrom, U (2000) Driving speeds in Europe for pollutant emissions estimation *Transportation Research D 5D* (5), 321-335

City of Unley (1996) *40 km/h local area speed limit continuing trial* Unley, SA: City of Unley

Dyson, C B, Woolley, J E, Roach, G, Taylor, M A P and Eddy, C (2000) An evaluation of the Unley city wide 40 km/h limit *Report to Unley City Council* Adelaide: Transport Systems Centre, University of South Australia

Kallberg, V-P and Toivanen, S (1997) Framework for assessing the effect of speed *Working Paper R.1.2.3 MASTER (Managing Speeds of Traffic on European Roads) Project* Helsinki: VTT Communities and Infrastructure

Kloeden, C N, McLean, A J, Moore, V M and Ponte, G (1997) Travelling speed and the risk of crash involvement *Report CR172* Canberra: Federal Office of Road Safety

Klungboonkrong, P and Taylor, M A P (1999) An integrated planning tool for evaluating road environmental impacts. *Journal of Computer-Aided Civil and Infrastructure Engineering 14*, 335-345.

LASL Trial Working Party (1993) *40 km/h local area speed limit trial Unley – South Australia: final report and recommendations* Walkerville, SA: Department of Road Transport

McLean, A J, Anderson, R W G, Farmer, M J B, Lee, B H and Brooks, C G (1994) Vehicle travel speeds and the incidence of fatal pedestrian collisions *Report CR146* Canberra: Federal Office of Road Safety

Primerano, F and Zito, R (2000) Final report: proposal for the evaluation of environmental impacts of speed limit changes *Report to Technology Development Section, Transport SA* Adelaide: Transport Systems Centre, University of South Australia

RTA (1998) *50 km/h urban speed limit trial – evaluation report* Sydney: NSW Roads and Traffic Authority

Taylor, M A P (2000) Network modelling of the traffic, environmental and energy effects of lower urban speed limits *Road and Transport Research 9* (4), 48-57.

Taylor, M A P and Young, T M (1996) Developing a set of fuel consumption and emissions models for use in traffic network modelling, pp 289-314 of Lesort, J-B (ed) *Transportation and Traffic Theory* Oxford: Pergamon-Elsevier

Walsh, D (1999) The 50 km/h speed limit in NSW: a joint partnership between councils, their communities and the NSW Roads and Traffic Authority, pp 695-707 of *Proceedings of the Research Policing Education Road Safety Conference Vol 2*, Canberra

Walsh, D and Smith, M (1999) Effective speed management the next step forward: saving lives by decreasing speeds in local streets, pp 685-694 of *Proceedings of the Research Policing Education Road Safety Conference Vol 2*, Canberra

Watson, H L (1995) The effect on vehicle emissions of reducing urban speed limits. *Motoring Directions 1* (4), 17-22

Woolley, J E, Dyson, C B and Taylor, M A P (2000) Lower urban speed limits – what are the pieces of the jigsaw telling us at this point in time? *Proceedings of the Road Safety Researchers and Enforcement Conference*, Brisbane

Woolley, J E, Taylor, M A P and Zito, R (2001) Modelling of Southern Expressway using Paramics microsimulation software *Journal of the Eastern Asia Society for Transportation Studies 4* (in press)

Zito, R and Taylor, M A P (1996) Speed profiles and vehicle fuel consumption at LATM devices, pp 391-406 of *Proceedings of the Australian Road Research Board 18th Conference 18* (4), Christchurch