IMPACTS OF LOWER SPEED LIMITS IN SOUTH AUSTRALIA

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Australia has recently undergone a change of urban speed limits in most of its jurisdictions. The political and social shift in attitudes required for this change is significant in a country that has a strong reliance on the use of the private motor vehicle. At present five states and one territory have lowered the speed limit in urban areas from 60km/h to 50km/h. Of the remaining two states and territories, one has already implemented lower speed limits (40km/h) in small areas within cities. In the majority of cases, the only criterion for judging the success of such schemes is an observed reduction in both speeds and crash numbers.

This paper reports on a more holistic assessment of such schemes taking into account factors in addition to speed and crashes including: traffic volume displacement, physical road network characteristics, environmental factors, community ownership and acceptance, enforcement effort and impact on travel times. The research work has included the analysis of extensive traffic data, community surveys and focus groups, the collection of environmental and travel time data from an instrumented probe vehicle and the computer modelling of road networks. The work reported is based on over 10 years of working with a 40km/h lower urban speed limit area in South Australia. The paper expands the notion of using speed and crash outcomes as the only criteria for measuring the success of lower speed limit schemes.

Key Words: Speed limits, Impacts, Amenity, Traffic modelling, Environment

1. INTRODUCTION

In Australia, under its Federal system of Government, the responsibility for setting speed limits lies with individual States and Territories. Although there is some conformance with national road rules there have generally been different speed zoning philosophies applied in each state. Despite this, urban speed limits remained uniform at 60km/h across all states and territories until 1997.

For several years a debate had been brewing in Australia about the fact that the 60km/h urban limit was considered too high and a lower limit should be adopted. Community pressure in several Local Government Authorities (LGA) led to the introduction of isolated areas with lower speed limits as a solution to traffic calming and improvement of amenity and safety for residents. The speed limits adopted in such areas were frequently 40 or 50km/h and in general were not strongly supported with changes to the road environment.

In the meantime, Lower Urban Speed Limits (LUSL) have been applied on a large scale to residential areas in most jurisdictions in Australia including Queensland, New South Wales, Victoria, Australian Capital Territory, Western Australia and most recently, Tasmania. These States and Territories had successively decided to reduce their urban speed limits from 60km/h to 50km/h. The 50km/h limit was seen as an acceptable compromise in delivering net road safety benefits yet still maintaining high levels of network efficiency to motor vehicles and political efficacy.

Most of the implementations in Australia to date have only been considered in terms of the reduction in crashes they achieve – and even on this score the scientific assessment of crash reduction is not yet clearly demonstrated. Although commonly justified on the grounds of road safety, which is measurable[1,2] in the longer term 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 a proxy. This consideration is reflected in other approaches in Europe (e.g., the MASTER project[3]) where a framework for speed limits appears to have been evaluated in a more holistic light.

Past efforts to gain general compliance to ongoing speed limits have largely been unsuccessful in jurisdictions around the world[4,5]. Travelling over the speed limit is still endemic and has proved highly resistant to change. There are many reasons why this situation exists ranging from the very definition of speeding itself to various psychological factors[5].

Enforcement and deterrence play a key role in the management of speed but studies suggest that extremely high levels of enforcement are necessary before widespread compliance is achieved and enforcement should not be used in isolation[6,7]. Authorities always run the risk of causing a backlash if they were to over-enforce. Haight[8], for example, emphasises that many US drivers are now in the fourth generation of exposure to the motor vehicle and have extensive experience of speeding and not being involved in a crash. It is therefore unlikely that messages telling people that speeding is dangerous are going to be effective for the vast majority of drivers, as their own personal experiences suggest otherwise.

Other approaches to speeding involving Intelligent Transport Systems (ITS) are currently being trialled. However, the verdict is still out on whether such technology is feasible and what the human reaction to such technology will be. Much research is currently trying to answer this question[9–11].

This paper presents evidence quantifying the impacts of LUSL beyond crash outcomes based on over 10 years research into the citywide Unley 40km/h scheme in Adelaide, computer modelling and published literature.

2. COMPUTER MODELLING

2.1 Theoretical modelling

A starting point for consideration of the overall impacts of LUSL is given by Taylor[12], who reported 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 including: unit travel time (min/km), carbon monoxide emissions, fuel consumption, change in free flow travel time, and congestion indices*. The study suggested that all of the indicators, with the exception of congestion index CI, performed better for a 60km/h speed limit than for either 50 or 40km/h speed limits, with certain qualifications on these results (see Figure 1). 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[12]. 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**.

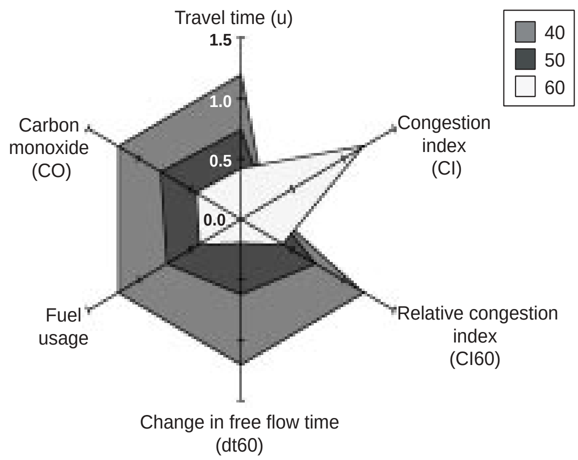

Fig. 1 Starplot of modelled traffic performance indicators for different speed limits (60, 50 and 40km/h) for a test network

2.2 Real world modelling

Further work has since been conducted with the creation of a *Paramics*[12] microsimulation model of a real world road network. The figure below shows the model for the entire Unley 40km/h area including all local roads, collectors and arterial roads. The model consists of over 1,892 nodes, 2,538 links and is approximately three kilometres from north to south and six and a half kilometres east to west at its longest dimension.

The model was set up for the morning peak period from 8 am to 9 am and incorporates fully signalised intersections, signal linking and individual junction control to the detail of individual lanes as shown in Figure 3. Input data for the traffic was based on previous studies of vehicle trips in the Unley area.

In Australia, lower urban speed limits have tended to be implemented by imposing a reduction in speed limits on residential streets while some collector roads and all arterial roads have remained at 60km/h. The modelling performed with the real world network investigated the following scenarios for the morning peak period (8 am to 9 am):

* 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 60km/h speed limit.

** 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.

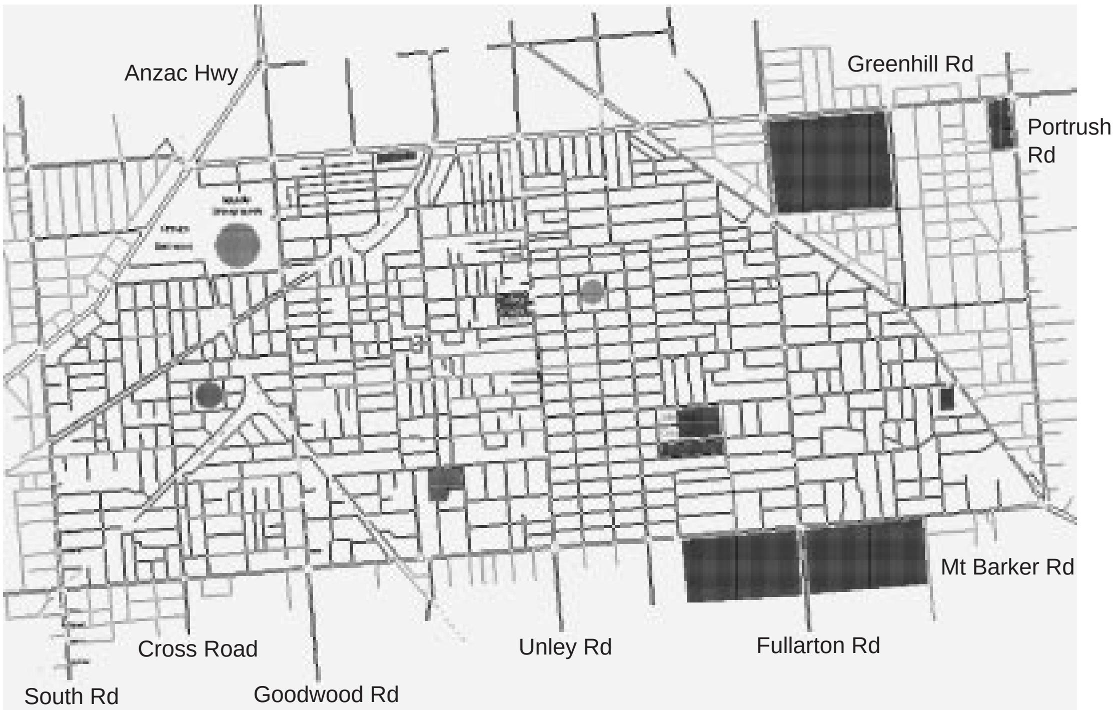

Fig. 2 Extent of the *Paramics* microsimulation model network for Unley showing local, collector and arterial roads

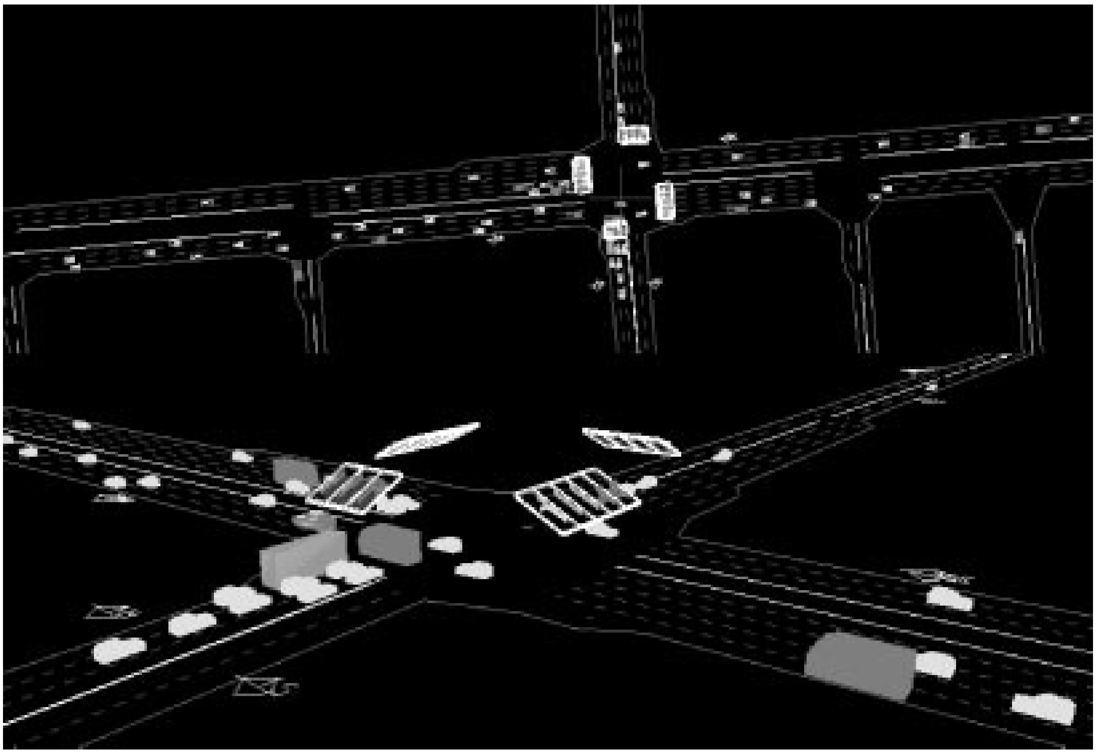

Fig. 3 Modelling detail of the *Paramics* microsimulation model for Unley with plan view (above) and three dimensional view (below) showing the representation of individual vehicles on the road network

a) Local roads in the Unley area with a speed limit of 30km/h (collectors and arterials and external local roads remain at 60km/h);
b) Local roads in the Unley area with a speed limit of 40km/h (collectors and arterials and external local roads remain at 60km/h) [*this is the current real world scenario*];
c) Local roads in the Unley area with a speed limit of 50km/h (collectors and arterials and external local roads remain at 60km/h);
d) All roads with a speed limit of 60km/h;
e) All local roads with a speed limit of 40km/h and collectors with a speed limit of 50km/h (arterials remain at 60km/h);
f) Local roads in the Unley area with a speed limit of 40km/h, collectors and external local roads at 50km/h and arterials at 60km/h;
g) All local roads and collectors with a speed limit of 50km/h (arterials remain at 60km/h).

The issue of increased travel times is often used as an argument against implementing lower speed limits. While this may be the case for trips within the area with the lower speed limits, the reductions in travel time for trips out of or into the area are small in comparison. Taking the case of Unley as an example, the network was split into a series of zones as shown in Figure 4 for travel time modelling.

Results were collated into internal trips (zones 14 to 19) and an external trip (any of zones 14 to 19 northbound to zone 3). The latter simulated trips from the Unley area into the Central Business District (CBD) of Adelaide during the morning peak period. Figure 5 shows the internal area travel times and Figure 6 external travel times for the scenarios listed previously.

Inter-area trips (between zones 14 to 19) can be seen to increase progressively as the speed limit is reduced from 60km/h. It should be remembered that the first four scenarios (a to d) maintain collector roads at 60km/h and when the speed limit on the collector roads is reduced to 50km/h travel times increase (scenarios e to f). The internal zones nearer the centre of the Unley study area (i.e., zone 17 then 16 and 18) have the lower travel times as vehicles in this zone have shorter travel paths to neighbouring zones. Vehicles from the zones at the extremities (zones 14 and 19) have to travel further to get to the other zones and consequently have longer travel times. If the travel time from all zones are combined together, there is a maximum difference in travel time of 60 seconds between scenario a and d.

The variation between scenarios for trips out of the Unley area to the CBD (i.e., all trips to zone 3) is much

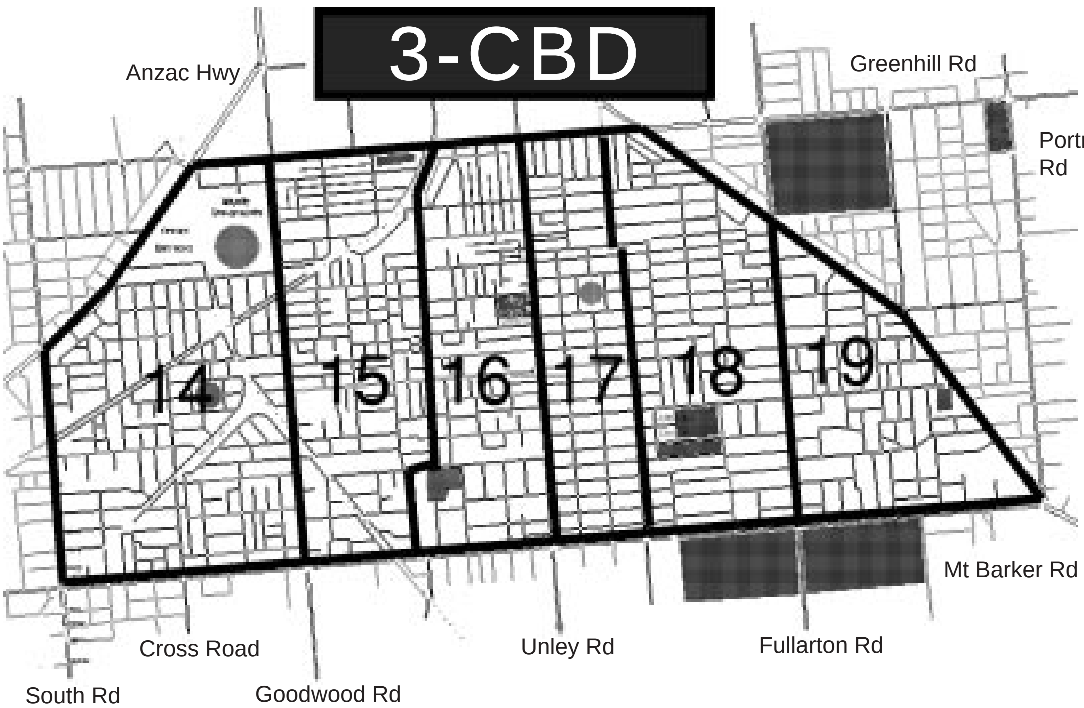

Fig. 4 Zones used for travel time modelling in the Unley road network

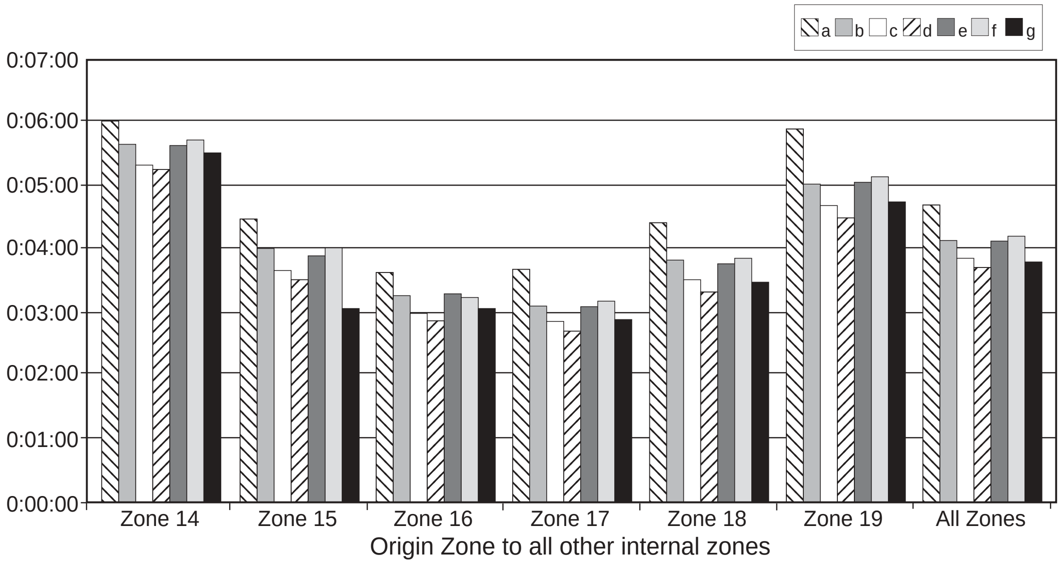

Fig. 5 Average travel times within the Unley network

[(a) Unley local street limit 30km/h, all others 60km/h, (b) Unley local street limit 40km/h, all others 60km/h = current situation, (c) Unley local street limit 50km/h, all others 60km/h, (d) all roads 60km/h, (e) local street limit 40km/h, collectors 50km/h, arterials 60km/h, (f) Unley local streets 40km/h, collectors and external local streets 50km/h, arterials 60km/h, (g) all local streets and collector roads 50km/h, arterials 60km/h]

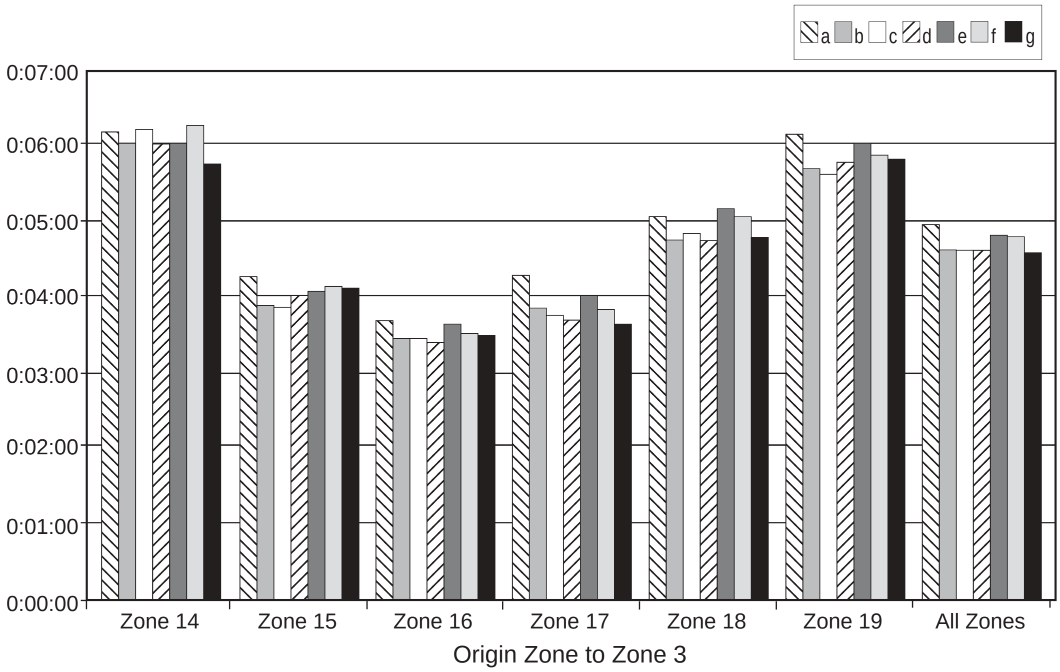

Fig. 6 Average travel time from all internal zones to the CBD (Zone 3)

[(a) Unley local street limit 30km/h, all others 60km/h, (b) Unley local street limit 40km/h, all others 60km/h = current situation, (c) Unley local street limit 50km/h, all others 60km/h, (d) all roads 60km/h, (e) local street limit 40km/h, collectors 50km/h, arterials 60km/h, (f) Unley local streets 40km/h, collectors and external local streets 50km/h, arterials 60km/h, (g) all local streets and collector roads 50km/h, arterials 60km/h]

less than for internal trips. This is understandable given the amount of time spent on local roads for such trips is less than for internal trips. This theory is backed up by other research at the TSC which has suggested that 10–15% of total trip distance in Adelaide is on local roads based on the analysis of Geographic Information System

(GIS) models.

The internal zones closest to zone 3 have the lowest travel times (zone 17 then 16 and 18) while the zones farthest away have the highest (zones 14 and 19) as expected. The differences between the scenarios can be seen to be a function of the distance to zone 3. When all the zones are combined it is interesting to observe that with the exception of the 30km/h limit (scenario a), there is very little difference between the travel times of the other scenarios (b to d). This dispels the argument that lower speed limits in urban areas pose a significant penalty in relation to travel times.

Similar patterns emerge when considering delays for internal trips. However, some variation occurred when considering the delay for external trips to zone 3. The worst delay does not necessarily always correspond to the lowest speed limit. The variability in the delay is likely to be due to the interaction of numbers of vehicles using the local roads and the arterial roads. The 60km/h scenario d frequently has high delays relative to the others due, it is thought, to the amount of traffic ‘cutting through’ on 60km/h local roads.

It should be noted that in this modelling, signalised intersections ran fixed cycles which were optimised for the traffic regime existing under scenario b (the current real world situation). Therefore the results do not include potential gains which could be made by altering signal settings for the new traffic regimes under the different scenarios. The modelling also highlights the importance of maintaining an adequate and functional road hierarchy. The reduction of speeds on the collector roads always results in increased travel times throughout.

3. EXPERIENCES IN AUSTRALIA

Previous work in the Adelaide area[13] has indicated that the Local Area Traffic Management (LATM) treatment of an area (predominantly with speed humps) had the following effects (in comparison to a control area):

- the LATM area experienced a statistically significant reduction in injury crashes (for the internal links, intersections, internal networks and on an area-wide basis);
- The reductions in crash frequency were found to be statistically insignificant for all the network levels compared with those of the control area;
- the LATM scheme had no effect on crash type, time of day of crash nor type of vehicle involved.

Woolley, Dyson and Taylor[14] summarised the findings of a number of recent studies of the impacts of LUSL in NSW and Queensland. In NSW, the 50km/h limit was implemented in June 1998 following a successful six month trial. Reductions in mean speeds of between 1.5 and 2.0km/h were achieved during the trial with a corresponding 7% reduction in casualties. Of the 26 councils involved, 15 supported the 50km/h limit and three were against. Community opinion also varied, with two surveys showing 66% and 41% support for the lower limit[15,16]. As a result of the trial, all LGAs were invited to implement the 50km/h limit in June 1998. At present, 90% of the NSW population is covered by a 50km/h speed limit. Consequent evaluation suggested considerable reductions in crash risk and the number of crashes. Community support has increased and speeds have declined (by 0.94km/h to 56.2km/h for the mean and by 1.08km/h to 64.5 for the 85th percentile)[16].

A 50km/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 although no formal scientific evaluation was initiated. 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 49.3km/h to 43.1km/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[17].

A recent report released for the Victorian 50km/h general urban limit suggests that crash frequency for all crashes has reduced by 13% relative to roads that have remained at 60km/h and 12% relative to all roads not affected by the change[18]. When considering casualty crash frequencies involving pedestrians these figures increase to 22 and 19% respectively, and 46 and 40% respectively for pedestrian fatal and serious injury crashes. It should be noted that these results represent only the first five months of the implementation.

One problem in drawing conclusions on the success or otherwise of the LUSL schemes is the fact that they are still in their infancy and more time is needed to obtain a clearer picture on net road safety outcomes. Furthermore, it remains to be seen if the reduction in speeds is sustained over longer periods of time without the need to significantly increase enforcement efforts. Following the advice of other researchers[13,19–22], perhaps three years each of before and after crash data are required for proper statistical evaluation of changes to the incidence of crashes in local street traffic networks.

4. THE CITY OF UNLEY CASE STUDY

The City of Unley (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 commuters from the south. The north-south arterials and collectors through Unley are somewhat constricted and congestion occurs at peak periods. Residents believe that much peak period traffic diverts to residential streets, hence the desire to render residential areas less permeable. 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[23,24]. This zone was less than one kilometre wide and 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 State Government 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 council initiated detailed monitoring and evaluation studies. The evaluation was conducted over a 21 month period in total. 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 1991; and 26 on collectors with unchanged limits (at 60km/h). In the set of streets with changed limits, quieter streets were underrepresented so that overall mean changes in speed and volume parameters are not properly representative.

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

4.1 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 evaluation of amenity is often best achieved through carefully designed questionnaire surveys and focus group sessions, although Klungboonkrong and Taylor[25] described analytical procedures that can be applied to studies of amenity.

4.2 Reduction in measured speeds

The 85th speed percentile is often used in traffic engineering to represent the higher speeds encountered at a location. It is, by definition, the speed below which 85% of all the speeds recorded lie. There is a strong desire to reduce the 85th speed percentile more than the overall mean speed in residential streets to reduce the obtrusiveness of the faster traffic whilst preserving the function of the street.

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 7a. The corresponding change in the mean speed is also shown in Figure 7b. Each street appears as one point in each figure. The diagonal lines indicate where there was no change in the speed parameter.

Streets with the highest major speed parameter values 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 an 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 among streets in their major speed parameters.

The results may be summarised as follows:

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

In NSW, the second session of speed monitoring

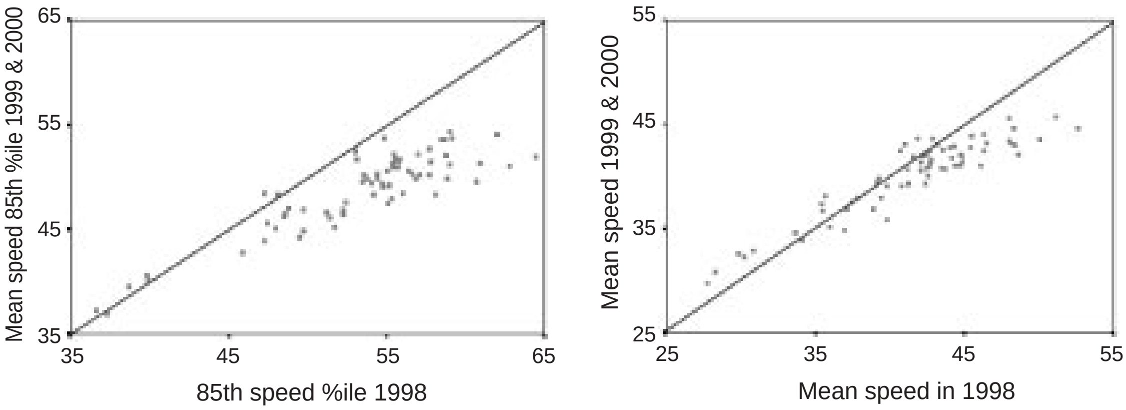

Fig. 7a and b Changes in 85th percentile speeds (left) and mean speeds (right) as a result of the new 40km/h speed limit – observed results for Unley

after the change in limit showed a rise in speeds compared with the first session after the change in limit (0.4km/h for the mean and 0.3 for 85th percentile). It was found that in Unley speeds continued to fall (except for mean speeds on the slower streets).

4.3 Changes in measured volumes

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

The comparisons in Table 1, and in Figure 7, 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 60km/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 underrepresented 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%, say) in traffic on their street.

Much of the reduction in volume and speed measured on the major 40km/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.

4.4 Enforcement

Enforcement is another aspect of LUSL that requires attention and its role in influencing behaviour has been well documented[6,7,23]. 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 city at great inconvenience. A common perception was that it was 'outsiders' that were doing the bulk of speeding in the 40km/h area. The reality is that 40% of speeding notices issued by police from speed camera enforcement within and immediately around Unley (predominantly on the arterial roads) were for Unley residents and only 30% for those residing south of Unley (largely those commuting to the CBD).

The experience in NSW[5] and this study support the optimism that LUSL have been successfully implemented in the absence of high levels of enforcement activity. Com-

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

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

munity acceptance has remained high and reductions in mean speeds have been observed. Reductions in 85th speed percentiles in Unley are notable, as described above.

4.5 Surveys of residents' perceptions and attitudes

Telephone questionnaire surveys (two groups each of 880 residents) and focus groups were conducted to gauge the attitudes and perceptions of Unley residents. Support for 40km/h speed limits in Unley has been strong and broadly matches levels reported throughout Australia[26]. Community support for the 40km/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[27].

By September 2000, over a period of 17 months, 16% of survey respondents said they had been fined for speeding on a 40km/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[*]. 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 40km/h limit streets. 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.

4.6 Lessons from 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 residential amenity, though there is some polarisation of residents' views and some questions of equity (on non-40km/h collector roads). The verdict is still out 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, available police resources and the ability to sustain it. The future challenge appears to be how to encourage motorist's self regulation to drive as appropriately, or considerately, during the morning peak as at other times of the day.

* This rate is, to put it in context, about half the rate in Adelaide on 60km/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 40km/h limit appears to be much diminished.

5. IMPACTS OF LUSL ON EMISSIONS

5.1 Fuel consumption and air emissions

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[12,28]. However, under normal urban 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[29].

A related research project at TSC is expressly concerned with the impacts of LUSL on fuel consumption and emissions[30]. This project considers the relationships between emissions and driving behaviour under two speed limit regimes (60km/h and 40km/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[31]. Watson[28] 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[32]. The 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 the Biggs-Akcelik model for its instrumented vehicle (Holden VS Commodore sedan). This vehicle is driven in real traffic to observe pollutant emissions for those conditions.

Primerano and Zito[30] discuss the emissions models and their verification. They analyse 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')[30]. Three different speed behaviour profiles (scenarios) were adopted for the 40 and 60km/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 (– 3.5km/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 (– 6.5km/h/sec).

Table 2 shows the amount of time taken for a vehicle to perform the speed profile scenarios for a given street length of 1,250m. 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 60 km/h under Scenario 1.

Figure 8 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 1,500m. 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 40km/h were similar, as were the hard and medium acceleration scenarios for 60km/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 550m the total CO_2 emission for the 40km/h limit exceeds that for 60km/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 60km/h and decelerating from 60 to 40km/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 8 also indicates that there is no crossover effect for the slow acceleration scenario – the emissions for 40km/h speed limit are higher than for 60km/h. For this scenario only street lengths that are greater than 1,250m long have had their total emissions determined, as the acceleration and deceleration rates are so slow that a minimum street length of 1,250m 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 400m.

This general form exists for other emissions however with individual variations. This indicates that determining precise emissions outcomes for LUSL is complex. However, a general result is that for short street section

Table 2 Time taken to accelerate, cruise and decelerate for a 1,250m street

Scenario	Beta	Speed limit (km/h)	Time (s)			Decel. rate (km/h/s)	Total time (s)	Mean speed (km/h)
			Accel.	Cruise	Decel.			
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

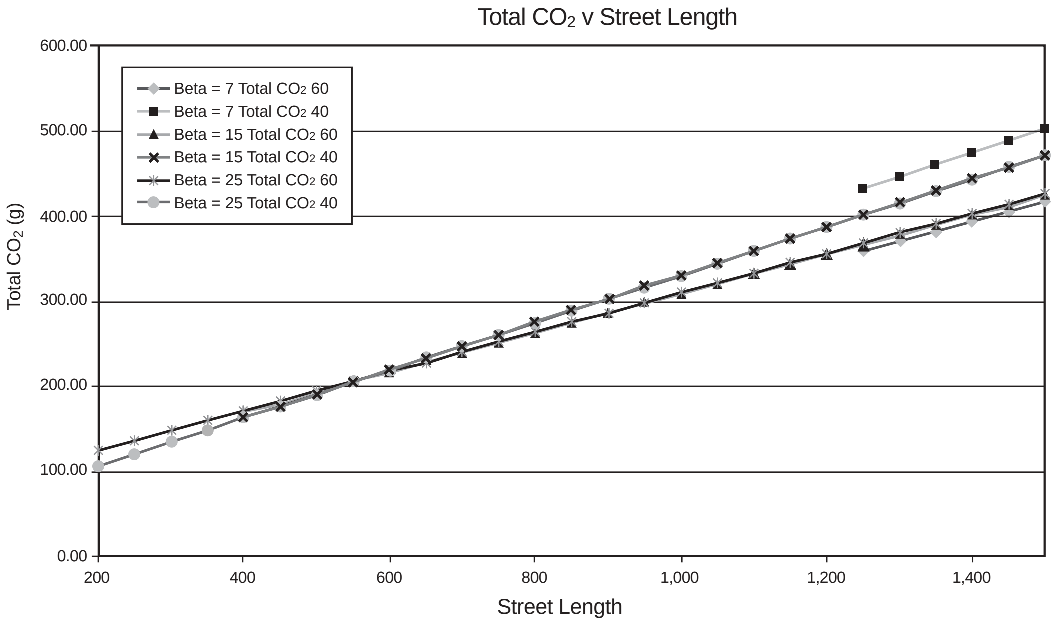

Fig. 8 Total CO_2 emissions and street length, showing crossover effect at 550m

lengths (say 350m or less) emissions under a 60km/h speed limit exceed those under 40km/h, while for very long section lengths (say 1,000m 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[19]) is recommended as a powerful approach given the availability of suitable modelling platforms and the emissions models described previously.

5.2 Noise

There are many complications when considering noise and annoyance which are beyond the scope of this paper. It is generally assumed that lower speed limits will equate to lower noise levels. While this would be the case for free flowing traffic, it is important to avoid interrupted flow traffic. Area wide speed limits have a considerable advantage over physical LATM devices in this regard.

6. CONCLUSIONS

Some of 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;
- 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 period and off peak behaviour in some streets;
- Again based on Unley, community acceptance of LUSL is strong and can be maintained, although polarisation of attitudes, especially with respect to enforcement strategies, may increase;
- Emissions (and fuel) outcomes are complex but can be analysed, and some general results are available (for short street section lengths, say 350m or less, emissions are reduced under a 40km/h LUSL compared to 60km/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 50km/h LUSL. Microsimulation modelling is required for full investigation of specific networks.

7. FURTHER WORK

The study of the Unley area is still incomplete and the following form part of the current ongoing research program:

- Further clarification on benefits in terms of crash outcomes;
- Benefit cost ratios for the 40km/h area;
- The impact and potential of enforcement;
- Modelling the impact that Intelligent Speed Adaptation could have for such a network;
- Investigation of further measures of network performance including Congestion Indices and delay parameters;
- Further environmental modelling using the Unley microsimulation model.

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