Slower, smaller and lighter urban cars

P Moriarty* and **D Honnery**
Department of Mechanical Engineering, Monash University, Caulfield East, Australia

Abstract: Rising global car ownership levels generate a variety of problems, including traffic congestion, oil depletion, air pollution and traffic accidents. These problems are usually most severe in urban areas. This paper examines the potential for large reductions in maximum speed, size and mass of urban cars to ameliorate these problems. It is found that cutting maximum speeds would significantly lower the frequency and severity of traffic accidents, especially in the third world, where fatality rates per vehicle are very high. If cars carried a maximum of two to four persons, car length and width could be reduced. Such cars would require smaller lane widths and less parking space, thus helping to ease traffic congestion. The combination of smaller and slower vehicles means that car mass can also be greatly reduced, which in turn reduces fuel use and, with it, urban air pollution and carbon dioxide emissions.

Keywords: car design, traffic accidents, traffic congestion, fuel consumption

1 INTRODUCTION

Over the past century, car numbers worldwide have grown from a handful to over 460 million [**1**]. The numerous problems engendered by the resulting massive car use raise doubts that private car travel can continue for long in its present form, especially in urban areas. Cars are not only important contributors to oil depletion, air pollution and greenhouse gas emissions but are also the main cause of traffic accidents and congestion. Proposed solutions to these problems include alternative fuels and electric vehicles, super-efficient cars and even the use of the new information technology. Alternative fuels and electric vehicles save oil, but their air pollution and greenhouse gas reduction benefits are small or even negative, while costs are high [**2**].

Another, more comprehensive approach to solving these problems is the radical redesign of existing cars. By dramatically reducing vehicle mass (with lightweight materials) and aerodynamic drag and using electric drive with regenerative braking, Lovins [**3**] claims that fuel efficiencies 5–20 times greater than that for existing vehicles can be achieved, with similar benefits for reduction in emissions, both local and global. However, not only would purchase costs rise but, as is also true for alternative fuels and electric vehicles, road congestion and traffic accidents would not be addressed. Intelligent transport systems have been promoted as a means of remedying this deficiency, but the only approaches that would make a significant difference are very expensive, are several decades away from implementation and face problems of motorist acceptance.

Cars with high fuel economy are by no means new, but were originally introduced largely for economic reasons. In Europe after the last war, a number of mini cars were designed and produced. These cars had a kerb weight in the range 225–375 kg, fuel economies of 20–25 km/l and top speeds of 80 km/h or more. The Italian Isetta, for example, at 343 kg and 300 cc engine capacity, sold 30000 units in 1956. If the Citroen 2CV and the Fiat 500 and 600 series are included, mini cars represented 20 per cent of all new cars sold in Europe in 1956. Eventually they were replaced by larger cars, often made by the same car company. In the United States over the period 1974–82, a number of lightweight cars were designed and prototypes built, but they never went into production. These models, like all recent US and European prototypes, are designed to be relatively high-speed cars. Japan is the only country today making mini cars. There, designated small (*kei*) cars have maximum values of 1.4 m for width, 3.2 m for length, 590 kg for mass, 660 cc for engine capacity and 80 km/h for speed. In 1990 there were some two million of these cars in Japan, mainly in the congested cities [**4**].

The MS was received on 17 February 1997 and was accepted after revision for publication on 12 June 1998.

**Corresponding author: Department of Mechanical Engineering, Monash University, 900 Dandenong Road, Caulfield East, 3145 Australia.*

As in Japan, urban areas are also the focus in this paper for two reasons. Firstly, most of the world's cars are found in cities. In the Organization for Economic Cooperation and Development (OECD) countries, the population is highly urbanized, with about 75 per cent living in cities [**5**]. Although urbanization in third world countries is often below 50 per cent, most cars are owned by urban residents. Bangkok, for example, has 70 per cent of Thailand's cars, even though it contains only about 10 per cent of the population [**6**]. Secondly, traffic-generated problems, particularly air pollution, congestion and road accidents, are usually more serious in large cities.

The present paper therefore investigates the extent to which low-powered mini cars can ameliorate the various deleterious effects of urban car traffic, by examining in turn how urban traffic safety, congestion and fuel economy can be improved by using cars which are slower, smaller and lighter than today's cars. It is found that reducing traffic speeds can have dramatic effects on accident fatalities, especially in the third world. Reducing vehicle dimensions, particularly width and length, can help solve urban traffic congestion. Finally, reducing both peak speeds and vehicle dimensions not only directly improves fuel economy but, more importantly, indirectly improves it by decreasing the mass of the vehicle.

2 VEHICLE ACCIDENT REDUCTIONS

In 1994, Goodland [**7**] claimed that road accidents resulted in 265 000 annual fatalities worldwide. However, use of UN statistics [**8**, **9**] for countries reporting road fatalities, together with estimates for non-reporting countries based on vehicle ownership (as well as fatality rates for similar reporting countries), shows that a more realistic figure for 1990 is about 500 000 killed. Traffic injuries are probably 10–15 million.

Although the OECD countries own about 76 per cent of the world's motor vehicles, only 24 per cent of fatalities today occur in these countries. On average, therefore, the fatality rate per motor vehicle in the rest of the world is about ten times that in the OECD. Indeed, in some countries the rate is two orders of magnitude higher than in OECD countries such as the United Kingdom or the United States. Although annual road deaths have dropped dramatically in the OECD since the early 1970s, they have risen steeply elsewhere. Further, the reduction in serious traffic injuries in the OECD has been much more modest, while minor injuries have hardly changed [**10**].

The far higher fatality rates per vehicle in the third world, coupled with rapidly increasing vehicle ownership levels, explain why the World Health Organization expects traffic accidents to move from their present ninth leading cause of death and disability to third place globally, and second in the third world, by 2020 [**11**]. As an example, Navin *et al.* [**12**] developed a model which predicts a peak fatality rate for China of 180 000 annually, about three times the present figure. Past experience suggests that world road fatalities will continue to rise even if fatalities per 1000 vehicles decline.

Road fatality rates are also much higher than those for rail or air travel. World air travel today results in only about 0.4 deaths per billion passenger-km, compared with an estimated 30–35 for road travel. Even in the United States, with its relatively low road death rate, the corresponding values are 0.2 for air and about 8.0 for road [**8**, **13**]. From a global viewpoint, it is clear that existing traffic safety policies are not working and that a new approach is needed, as present casualty levels are (or should be) unacceptable.

In the OECD countries the majority of road fatalities, about 65 per cent in the early 1990s, were occupants of motor vehicles [**10**]. In the rest of the world, however, most of those killed were pedestrians, pedal cyclists and motor cyclists. Globally, more than 50 per cent of those killed are not vehicle occupants [**11**, **14**]. These other relatively unprotected road users need to be the main focus of innovative traffic safety policies. Non-occupant fatalities occur disproportionately in urban areas. In the USA in 1990, for example, although only 32 per cent of non-pedestrian deaths occurred in urban areas, almost 60 per cent of pedestrian deaths occurred there. Finally, night-time driving is more dangerous than daytime driving. In the urban areas of the United States, a night-time trip is four times as risky as the same trip by day [**4**].

2.1 Vehicle speeds

Vehicle speeds affect road safety in several ways. This discussion will first examine the ways in which higher speeds affect a driver's ability to respond to potentially dangerous situations, then look at speed's effect on accident severity.

Khisty [**15**] discusses several ways in which higher speeds affect the driver's perception. Firstly, peripheral vision decreases with increased speed. At 40 km/h, the horizontal angle encompassed by peripheral vision is about 100 degrees, but by 100 km/h it is less than 40 degrees. Secondly, as speed increases, foreground details begin to fade. At 65 km/h, the nearest point of clear vision is only 25 m away. At higher speeds foreground detail diminishes, and is negligible above 100 km/h. This combination of decline in both peripheral vision and foreground detail means that only large, simple shapes can be recognized at high speeds. Another obvious problem with higher speeds is that the time available for recognizing and reading road warning signs decreases.

Even if vision and information intake were not impaired by speed, higher speeds would still lower the time and distance available for braking in an emergency. At higher speeds, not only has the car travelled further during the time taken for perceiving and reacting to the emergency, so that less distance is now available for braking, but the speed reduction needed is itself greater. If the road surface is wet, the coefficient of friction which can be mobilized during braking is lower at higher speeds, further increasing collision speeds and kinetic energy requiring to be dissipated [**16**]. The crucial significance of collision speed is well illustrated by pedestrian accidents. At impact speeds of 32 km/h, only about 5 per cent of pedestrians are killed and injuries are minor. At 48 km/h, 50 per cent are killed and many are seriously injured, while at 80 km/h most do not survive the impact [**17**, **18**].

As already mentioned, fatality rates per motorized vehicle are far higher in third world cities compared with those of the OECD. There are several reasons for this difference, which mainly stem from differences in average incomes. Although improvements to vehicle design and seat belts (if used) should help occupant safety, most road fatalities outside the OECD are not vehicle occupants. Further, vehicles are often poorly maintained, with defective tyres, indicator lights and headlights. The urban road system may itself be inadequate, with poor surfaces, alignment, intersection design, information and warning signs, and insufficient or non-existent street lighting. Driver training and traffic rules enforcement may be of low standard [**11**, **19**]. In essence, fatality rates in the OECD countries have fallen because of high investments in traffic engineering, education and enforcement, sustained over many years, together with better medical services. An important example is the improvement that has come from maximum blood alcohol legislation and enforcement, together with the resulting shift in public attitudes towards drink-driving. Large cuts in maximum speeds would allow third world cities dramatically to cut fatality rates without the OECD levels of investment in physical and social infrastructure. However, even the European Transport Safety Council recommends that member states adopt a 30 km/h or lower speed limit in residential areas [**20**].

2.2 Vehicle mass and size

The effect of vehicle mass on overall road safety is complex. There is little doubt that, other things being equal, in a two-vehicle collision, the occupants of the heavier vehicle are safer than those in the lighter vehicle [**21**, **22**]. The smaller mass vehicle experiences greater deceleration forces, because of its greater velocity change. But the mass disparity between a car and a train or loaded multi-axle truck will always be so large that an increased mass for the car will in itself be of little help in reducing accident severity. On the other hand, in collisions between pedestrians or cyclists and cars, the overall severity of the accident will be less if the mass difference between the car and the pedestrian, for example, is reduced, i.e. if the mass of the car is lowered. In two-car collisions the enhanced safety for the occupants of the heavier car is at the expense of those in the lighter car.

Lower mass (and narrower) cars could present potential stability problems particularly in conditions of significant side winds. These problems could be severe on the open highway but in urban areas such conditions will be rare. Other factors which affect vehicle stability such as variable payload (occupant ratio) and changes in direction will also be a problem at high vehicle speeds. But as the vehicle speed falls below 50 km/h these problems, as well as the various effects of wind forces, will be reduced.

Size and shape of vehicles are also relevant for non-occupant safety. Pedestrian injury depends on the interaction of many factors, including pedestrian height, walking direction and velocity, the location of the first impact on the car front, bumper height, size, shape and stiffness of the various car body parts and, of course, car velocity [**17**]. Generalization is clearly difficult, but to the extent that smaller-sized cars have shorter bonnets, pedestrian risk could increase, because if pedestrian rotation occurs, the impact point for the head will usually be on a stiffer part of the car than mid-bonnet. However, in low-speed car–pedestrian collisions (with impact speeds below 20 km/h), pedestrian rotation usually does not occur, so that injury is mainly caused by impact with the road, not the car bonnet [**17**]. Smaller-sized cars would also be expected to lead to more serious occupant injury in collisions with other vehicles or fixed objects. In general, both the vehicle crush zone and the free space inside the passenger compartment will be reduced. Together these provide the ‘ride-down’ distance needed to decelerate the occupants in a collision. Narrower cars are also more at risk in side impact collisions because the distance between the occupant and the intruding vehicle is decreased. However, accident severity should be greatly lessened by a combination of reduced impact velocity and, on average, lighter impacting vehicles.

Although in the United States fatalities are inversely related to car size, such is not the experience in Japan. There, mini cars not only have a lower pedestrian fatality rate (50 per cent of that for regular cars) but also a lower overall fatality rate per vehicle-km travelled. The lower speed limit in Japan (80 km/h) can only be a minor part of the explanation, since mini cars are largely found in the congested cities. Riley [**4**] suggests the explanation for this counter-intuitive finding is that mini car drivers are less aggressive, both towards other cars and pedestrians.

Traffic streams will always contain a significant proportion of larger vehicles (trucks, buses, taxis). For traffic flow reasons, all motor vehicles sharing a road need to have much the same maximum speed. Not only would safety benefits be enhanced, but, especially in third world cities, lower vehicle speeds would be more compatible with (and would encourage) non-motorized modes, which today and for the foreseeable future often form the majority of passenger travel [**7**, **23**, **24**].

3 REDUCING VEHICLE ROAD SPACE REQUIREMENTS

Traffic congestion is considered a serious problem in most of the world's large cities. In the United States, for example, the overall annual estimated cost of congestion is $300 billion [**7**]. Road building has been unable to keep pace with the growth in traffic, so that in most large cities road space per vehicle is declining. In a recent paper, Bly and Dasgupta [**25**] examined urban travel in 52 OECD cities and showed that car ownership per person has more than doubled in most of them in the last twenty years, usually with an accompanying increase in private vehicles' share of transport. As a consequence, average urban vehicle speeds have decreased in most of these cities and in some to below 20 km/h.

Goodland [**7**] proposes solutions to congestion, such as encouraging urban residents to shift to more space-efficient public transport, car-pooling and road pricing. Public transport and car-pooling would be of benefit, but in the OECD countries at least, both public transport's share of urban travel and car occupancy rates are falling [**4**]. Urban road pricing in OECD countries would be politically unpopular because of its adverse effects on equity. It is thus useful to examine the extent to which changes in vehicle dimensions and peak speeds can ameliorate the shortage of road and parking space.

The main vehicle parameter relevant to land use efficiency is width. If all cars were narrower, lane widths for cars, which are normally 3.3–3.5 m, could be greatly reduced [**15**]. Indeed, in the case of Japanese mini cars, with a maximum legal width of 1.4 m, present lane widths could be halved. The length of the car is less important for road space (in Japan the maximum legal length of mini cars is 3.2 m) but, together with reduced width, will greatly lower parking space needs.

There is a price to pay for smaller cars, since their passenger carrying capacity is greatly reduced. If, for example, it is assumed that the new cars are only two-seaters, extra cars will be required to deliver the same passenger-km volumes. Fortunately, at peak hours when road congestion is worst, this increase will be small, at least for the OECD countries. In Melbourne, for example, peak-hour commuter vehicle occupancy rates are only 1.1 [**26**]. For Australian urban car occupancy distribution frequencies, only about 2 per cent extra vehicles would be required. Between the peak hours, about 10 per cent extra vehicles would be needed, and during the evening when occupancy rates are highest about 30 per cent. For four-seater cars, however, extra vehicles needed would be negligible at all times [**27**]. These figures will decrease if occupancy rates continue to fall. Therefore, because existing occupancy rates are lowest when traffic congestion is worst, smaller cars would mainly add some extra vehicles when the roads are least congested.

Even maximum speed will have an impact on road space requirements. As maximum speeds fall, required lane widths can also fall, since there is less lateral movement of vehicles. But lower maximum speeds (and accelerations) would have a small adverse effect on traffic capacity, i.e. vehicles per lane per hour. To the extent that at peak hours, traffic congestion already severely limits peak speeds, road capacity will be little affected. Benefits from smaller and slower cars will really only be significant when there are enough small cars to justify at least one separate lane on roads carrying through traffic. Lower motor vehicle speeds will enhance the safety and amenity of non-motorized modes, as well as improving the relative speeds of both these modes and rail travel, which should help prevent any congestion relief from being negated by traffic growth.

4 REDUCING ENERGY REQUIREMENTS OF URBAN VEHICLES

An understanding of the interaction of vehicle speed, size and mass on vehicle energy consumption in the urban traffic environment can be gained by examining driving patterns typical of such traffic. Average urban traffic speeds as presented by Bly and Dasgupta [**25**], for example, do not give an indication of the real urban traffic environment, which may range from multilane freeways where speeds could reach 100 km/h to narrow roads heavily controlled by traffic signals where average speeds may be less than 10 km/h. In some European and Asian cities, traffic flow is further complicated by the addition of a significant number of non-motorized vehicles. In such traffic, vehicles may therefore encounter large variations in traffic conditions, which result in large variations in speed. For example, Kent [**28**] has shown that fuel consumption in urban traffic with an average speed of 31.5 km/h is 25 per cent higher than that of traffic travelling at a constant equivalent speed over the same distance.

To determine the influence of urban traffic conditions on vehicle energy consumption, four urban driving

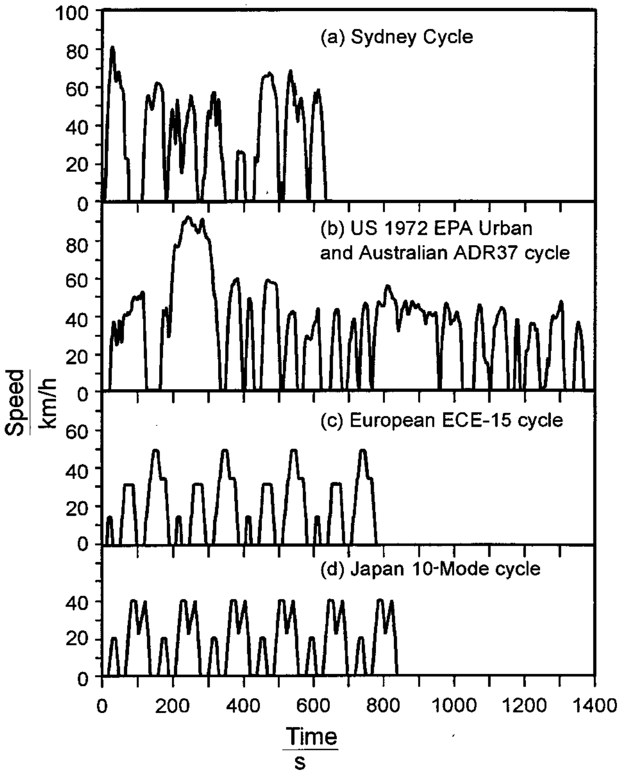

Fig. 1 Urban driving cycles used in vehicle emission and fuel consumption tests

cycles from four different continents have been used. These cycles are shown in Fig. 1 and their properties summarized in Table 1. Much has already been written on these cycles (see, for example, Watson [**29**]), and how well they represent urban traffic. Apart from the inability of any single driving cycle to represent the large variation in driving patterns found in any one city, the major limitation of the cycles, except for the Sydney cycle developed by Rule *et al.* [**30**], is the smaller than actual maximum acceleration rate experienced by the vehicle during the cycle. As can be seen in Table 1, all cycles have a significant proportion of the overall drive time spent idling, as would be expected in urban traffic. Cruising time, unlike freeway driving where it would often be close to 100 per cent, ranges from a minimum of 12 per cent in the Sydney cycle to a maximum of 31.5 per cent in the ECE-15 cycle. The balance of drive time is spent accelerating and decelerating.

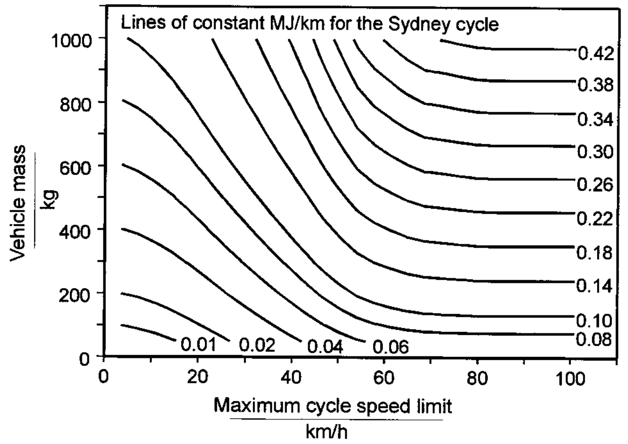

Fig. 2 Energy per kilometre (MJ/km) required to overcome the road load for a vehicle of varying mass and limited maximum cycle speed operating on the Sydney cycle. Vehicle effective frontal area $C_dA = 0.4$ m^2 and rolling resistance coefficient $C_{rr} = 0.01$

As discussed, significant differences in energy use occur between vehicles moving in urban traffic, as represented by the speed–time cycles in Fig. 1, and ideal traffic which moves at a constant speed. This is particularly true if vehicle speeds increase to the point where drag forces become significant. The higher inertial forces needed to accelerate vehicles to higher speeds must also be considered, as must the increased mass required for such engines. Imposing limits on the maximum vehicle speed in urban traffic, as represented by the drive cycles, will have the effect of reducing variations in speed and hence energy consumption per kilometre.

The effect of limiting the maximum speed during the Sydney drive cycle on energy consumption per kilometre is shown in Fig. 2. Energy consumption is based on a road load calculation, which includes the effects of rolling resistance (assuming a coefficient of 0.01), aerodynamic drag (assuming a C_dA of 0.4 m^2, e.g. a vehicle drag coefficient C_d of 0.25 and a projected frontal area A of 1.4 m width and 1.15 m height), and vehicle inertia due to acceleration (assuming a vehicle equivalent mass of 1.05). For the purposes of calculation, it is assumed that the road surface is level, no energy is used during idling and the spatial locations of the idle points in the

Table 1 Driving cycles

	Cycle distance (km)	Cycle time (s)	Average speed (km/h)	Maximum speed (km/h)	Maximum acceleration (m/s^2)	Time cruising† (%)	Time idling† (%)
Sydney cycle*	5.92	648	33.5	81.0	2.5	12.9	18.4
US 1975 test cycle (ADR37)	12.07	1372	31.6	91.2	1.5	20.9	17.3
ECE-15 cycle	4.10	780	18.7	50.0	1.0	31.4	29.0
Japan 10-mode cycle	4.00	810	17.7	40.0	0.8	26.5	26.0

* After Rule *et al.* [**30**].
† Balance of time is made up of accelerations and decelerations.

Table 2 Driving cycle road load energy requirements per kilometre

Mass (kg)	1000	300	1000	300	300
C_dA (m^2)	0.4	0.4	0.4	0.4	0.8
Maximum speed (km/h)	Unlimited	Unlimited	50*	50*	50
Sydney cycle (MJ/km)	0.43	0.16	0.32	0.12	0.16
US 1975 cycle (MJ/km)	0.34	0.14	0.29	0.11	0.14
ECE-15 cycle (MJ/km)	0.28	0.10	—	—	0.12*
Japan 10-mode cycle (MJ/km)	0.32	0.10	—	—	0.12*

* ECE-15 and Japanese cycles have maximum speeds of 50 and 40 km/h respectively.

cycle are maintained. It can be seen that energy consumption per kilometre falls as the maximum cycle speed falls for a vehicle of constant mass. For example, for a vehicle of 300 kg, the energy per kilometre required to overcome the road load is 0.16 MJ/km if the maximum speed during the cycle is unlimited, which for the Sydney cycle is effectively 80 km/h. If the maximum cycle speed is limited to 50 km/h, the figure falls to 0.12 MJ/km. For a 1000 kg vehicle, the energy required falls from 0.43 to 0.32 MJ/km as the maximum speed is reduced to 50 km/h. Similar reductions are found for the US cycle which are shown in Table 2.

Figure 3 shows the effect on the average cycle speed and trip time, expressed as cycle drive time per kilometre, of limiting the maximum cycle speed. For the Sydney and US cycles it is apparent that a maximum cycle speed limit of 50 km/h has little effect on the average cycle speed, but below this value the average speed during the cycle starts to fall. For the lower speed ECE and Japanese cycles, average speeds start to fall only when the maximum speed limit falls below 30 km/h. Thus, imposing speed limits on such traffic environments represented by these drive cycles will not alter trip times by a significant amount.

The influence of vehicle size on energy consumption can also be estimated from these cycles for urban traffic environments. Changing the vehicle C_dA from 0.4 to 0.8 m^2 for a 300 kg vehicle speed-limited to 50 km/h increases the energy requirements from 0.12 to 0.16 MJ/km for the Sydney cycle. This difference will increase as maximum vehicle speed increases and so, as expected, the lower speeds of the ECE and Japanese cycles give smaller energy savings (Table 2).

Figure 2 shows the effect of increasing vehicle mass on energy consumption, where there is a clear trend of increasing energy with mass (see also Table 2). In vehicles used for private transport, however, there is a correlation between vehicle size, mass and passenger loadings, with larger, heavier vehicles generally able to carry greater numbers of passengers. If it is assumed that a 1000 kg vehicle is able to carry four nominal 100 kg passengers, the energy required to overcome the road load is 0.15 MJ/passenger-km, and for a 300 kg vehicle with two 100 kg passengers 0.12 MJ/passenger-km. Thus, for the present case, the increased carrying capacity of the larger vehicle is offset by its increased mass and hence higher energy consumption per passenger-km.

From the estimates of energy consumption presented, it is clear that significant savings could be made in urban traffic environments by limiting vehicle speeds and reducing both vehicle size and mass. An estimate of the actual energy savings can be obtained from the measurements of vehicle efficiency (expressed as a percentage of available fuel energy used to overcome road load) made by Boam [**31**] for a 1134 kg, 2 l petrol engine vehicle operating on the ECE-15 cycle. For a cold start it was found that 60 per cent of the energy was used to heat the engine and transmission (a total mass of 148 kg wet), 12 per cent was rejected as unburnt fuel and 8.5 per cent was used as useful work. The balance was used during idling and overrun. Assuming this efficiency for the data presented here, a 1000 kg vehicle will require around 2.5 MJ/passenger-km for the ECE-15 cycle assuming a passenger occupancy of 1.5 and passenger mass of 150 kg. This requirement is similar to that found by Moriarty and Honnery [**32**] for private transport in Australia. For a 300 kg vehicle the requirement falls to 1.1 MJ/passenger-km for the same conditions. For vehicles with reduced mass and hence smaller engines and transmissions, less energy would be lost to engine heating. Thus, the efficiency of the lower-mass vehicles would be higher than that of high-mass vehicles and so actual energy use would be lower than 1.1 MJ/passenger-km for these vehicles. This represents a reduction in average energy consumption per passenger kilometre of over 60 per cent. Maximum energy savings would require not only full penetration of these lower-mass mini cars but also all other motor vehicles to be redesigned for lower peak speeds.

Energy savings lead to reductions in carbon dioxide and local air pollution emissions. Although CO_2 reductions will vary directly with fuel use, changes in emissions should be proportionally greater. Firstly, as mentioned, smaller engines require less time to warm up and so use less fuel. They also reach optimum fuel mixture conditions sooner, with a consequent drop in emissions, particularly HCs. Secondly, the proposed vehicles have engines which will operate at or near their peak power output and so should have lower emissions per unit of fuel.

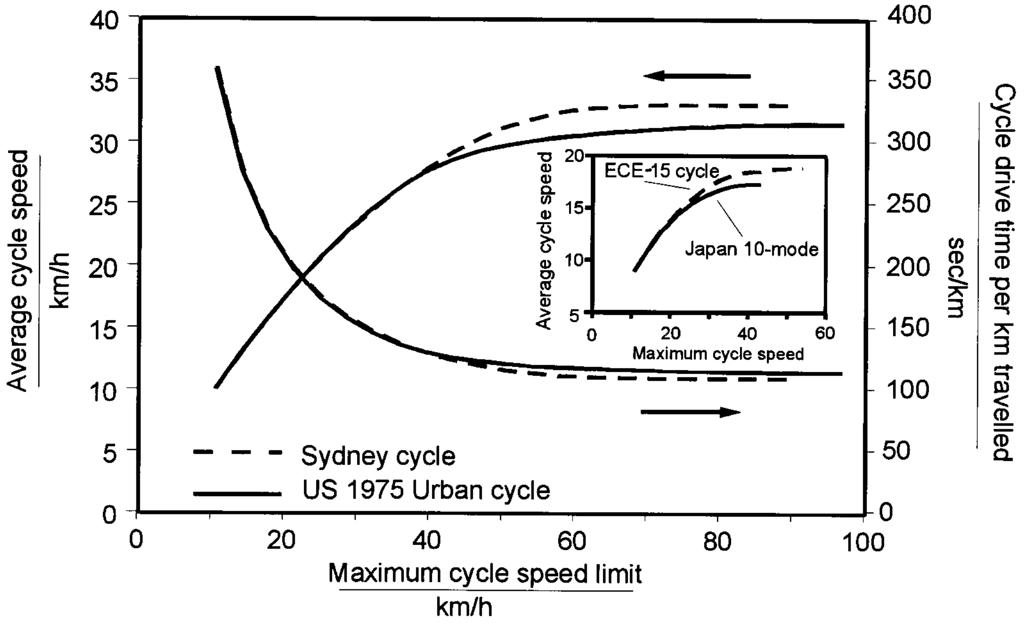

Fig. 3 Effect of limiting the maximum speed during the drive cycle on the average cycle speed and travel time per kilometre for each urban drive cycle

5 CONCLUSIONS

Rising car ownership worldwide has intensified the problems of traffic accidents, traffic congestion and air pollution. Because these problems are usually most serious in cities, this paper has examined whether fundamental changes to urban vehicle design can offer a better approach to solutions.

It is argued that urban cars should be made slower, smaller and lighter. Reducing the maximum speed (to 30–50 km/h) would yield large benefits in reducing traffic fatalities. The impact would be greatest in third world cities, where fatality rates are high, especially among non-motorized road users. In all cities, however, lower speeds are the most cost effective way of saving lives. Smaller cars, with lower seating capacity, could be made both narrower and shorter. In conjunction with reduced speeds, lane widths could then be narrowed, even halved, and parking spaces made smaller. Smaller, slower cars would directly help fuel efficiency by reducing air drag, but more importantly would indirectly lower fuel consumption (and thus air pollution and greenhouse gas emissions) by enabling kerb mass to be reduced.

For maximum benefit, all passenger cars should eventually be mini cars. In the transition period, remaining conventional vehicles should have their speeds reduced as well (except perhaps on urban freeways). Eventually all motor vehicles should be designed for lower peak speeds, with accompanying mass and dimension reductions, if feasible. Not only would road fatalities, congestion and air pollution be reduced, but vehicle purchase and operating costs would also fall. The proposed changes, while radical, may well be the only way for car travel to survive in the world's large cities.

REFERENCES

1 United Nations *Statistical Yearbook*, 40th Issue, 1995 (UN, New York).
2 **Moriarty, P.** Can alternative car fuels reduce greenhouse gas emissions? *Int. J. Veh. Des.*, 1994, **15**, 1–7.
3 **Lovins, A.** Supercars. In *Encyclopedia of Energy Technology and the Environment* (Eds A. Bisio and S. Boots), 1995 (John Wiley, New York).
4 **Riley, R. Q.** *Alternative Cars in the 21st Century: A New Personal Transportation Paradigm*, 1994 (SAE, Warrendale, Pennsylvania).
5 The World Bank *World Development Report 1995*, 1995 (Oxford University Press, New York).
6 **Hayashi, Y.** Economic development and its influence on the environment: urbanisation, infrastructure and land use planning systems. In *Transport, Land-Use and the Environment* (Eds Y. Hayashi and J. Roy), 1996 (Kluwer Academic Publishers, Dordrecht).
7 **Goodland, R. J. A.** Urgent need for environmental sustainability in land transport in developing countries: an informal view. *Transpn Res. Rec.*, 1994, **1441**, 44–52.
8 United Nations *Demographic Yearbook 1994*, 1996 (UN, New York).
9 United Nations *Statistical Yearbook for Asia and the Pacific 1995*, 1996 (UN, Bangkok).
10 European Conference of Ministers of Transport (ECMT) *Statistical Report on Road Accident Trends in 1990*, 1992 (ECMT/OECD, Paris).

11 **Seymour, J.** Trafficking in death. *New Scientist*, 14 September 1996, 34–37.

12 **Navin, F., Bergan, A.** and **Jinsong, Q.** Fundamental relationship for roadway safety: model for global comparisons. *Transpn Res. Rec.*, 1994, **1441**, 53–58.

13 **Famigetti, R.** (Ed.) *The World Almanac and Book of Facts 1997*, 1996 (World Almanac Books, Mahwah, New Jersey).

14 **Hutchinson, T. P.** *Road Accident Statistics*, 1987 (Rumsby Scientific Publishing, Adelaide, South Australia).

15 **Khisty, C. J.** *Transportation Engineering: An Introduction*, 1990 (Prentice-Hall, Englewood Cliffs, New Jersey).

16 **Grime, G.** *Handbook of Road Safety Research*, 1987 (Butterworth, London).

17 **Kaeser, R.** and **Gaegauf, M.** Motor car design for pedestrian injury prevention. *Int. J. Veh. Des.*, Special Issue on Vehicle Safety, 1986, 215–231.

18 **Navin, F., Bergan, A., Jinsong, Q.** and **Li, J.** Road safety in China. *Transpn Res. Rec.*, 1994, **1441**, 3–10.

19 **Breen, J.** and **Condon, C.** Possibilities for future developments in primary safety requirements. *Proc. Instn Mech. Engrs*, *Part D*, *Journal of Automobile Engineering*, 1996, **210**(D1), 1–9.

20 **Anon.** The European Transport Safety Council Reports. *Int. J. Veh. Des.*, 1996, **17**, 333–342.

21 **Neilson, I. D.** Vehicle safety—a review for 1993. *Proc. Instn Mech. Engrs*, *Part D*, *Journal of Automobile Engineering*, 1993, **207**(D2), 117–126.

22 **Anon.** Technical Note: automobile safety and CAFE. *Int. J. Veh. Des.*, 1993, **14**, 281–287.

23 **Replogle, M.** Bicycles and cycle-rickshaws in Asian cities: issues and strategies. *Transpn Res. Rec.*, 1992, **1372**, 76–84.

24 **Thomas, C., Ferguson, E., Feng, D.** and **DePriest, J.** Policy implications of increasing motorization for nonmotorized transportation in developing countries: Guangzhou, Peoples Republic of China. *Transpn Res. Rec.*, 1992, **1372**, 18–25.

25 **Bly, P. H.** and **Dasgupta, M.** Urban travel demand: a growing business, but can it last? In *Urban Transport and the Environment for the 21st Century* (Ed. L. J. Sucharov), 1995 (Computational Mechanics Publications, Southampton).

26 Australian Bureau of Statistics *Travel to Work*, *School and Shops*, *Victoria*, *October 1994*, 1995 (Australian Government Publishing Service).

27 Australian Bureau of Statistics *Survey of Motor Vehicle Use*, 1986 (Australian Government Publishing Service).

28 **Kent, J. H.** Relationships between driving cycles and urban driving patterns. Charles Kolling Research Laboratory Technical Note ER-33, Department of Mechanical Engineering, The University of Sydney, 1980.

29 **Watson, H.** Vehicle driving patterns and measurement methods for energy and emissions assessment. Occasional Paper 30, Bureau of Transport Economics, 1978 (Australian Government Publishing Service).

30 **Rule, G., Allen, G. H.** and **Kent, J. H.** A driving cycle for Sydney. Charles Kolling Research Laboratory Technical Note ER-15, Department of Mechanical Engineering, The University of Sydney, 1976.

31 **Boam, D. J.** Energy audit on a two-litre saloon car driving an ECE 15 cycle from a cold start. *Proc. Instn Mech. Engrs*, *Part D*, *Journal of Automobile Engineering*, 1996, **200**(D1), 61–67.

32 **Moriarty, P.** and **Honnery, D. R.** Social factors in household energy consumption. In Proceedings of 13th International Clean Air and Environment Conference, 22–25 September 1996, Adelaide, South Australia.