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Dealing with existing theory: national fatality rates, vehicle standards and personal safety

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Declaration

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Dealing with existing theory: national fatality rates, vehicle standards and personal safety

Dinesh Mohan and Brian O'Neill

1 INTRODUCTION: THE WORLD OF CRASHES

The World Health Organization (WHO) released its World Report On Road Traffic Injury Prevention in 2004 (Peden et al., 2004). This report focussed on road traffic injuries (RTI) and fatalities as a worldwide health problem and included a summary of the known risk factors associated with road traffic crashes and possible countermeasures that should be put in place to control the problem. It also pointed out that "Without new or improved interventions, road traffic injuries will be the third leading cause of death by the year 2020". The publication of this report spurred some national and international agencies and civil society groups to give a little more attention to the problem of road safety and a number of resolutions have been passed by the United Nations General Assembly, World Health Assembly and the Executive Board of the WHO (United Nations, 2014, 2016; WHO, 2004, 2016). The WHO has released three Global Status Reports on Road Safety in 2009, 2013 and 2015 (WHO, 2009, 2013, 2015). These reports offer a broad assessment of the status of road safety in over 175 countries. The data were obtained from national governments using standardized survey forms.

The 2015 WHO Global Status Report shows that low-income and middle-income countries (LMICs) on an average have higher road traffic fatality rates (24.1 and 18.4 per 100,000 population, respectively) than high-income countries (HICs) (9.2 per 100,000 population). These estimates are based on regression models that rely on national death registration data and seek to correct for substantial underreporting in official government statistics that are usually based on traffic police reports. WHO's modelled estimates exceeded official statistics by more than 20% in 60% of the countries.

The 2015 Status Report estimates that 49% of those who die in road traffic crashes are pedestrians, bicyclists and users of motorized two-wheelers (MTW). However, this is likely an underestimate because WHO's estimates rely on official government statistics to estimate the proportion of different types of road users killed. For example, in the latest report the data for India includes the proportion for pedestrian and bicyclist deaths as 9 and 4% respectively. However, a recent research reports from India suggest that pedestrian and bicyclist deaths may be in the range 39-45% (Bhalla et al., 2016; Mohan, Tiwari, & Bhalla, 2015). Similarly, the Status Report and official statistics from China report that 26% of deaths are pedestrians. However, China's national burden of disease estimate, which are based on national health data, suggest that pedestrians comprise 53% of traffic fatalities (Zhou et al., 2016). Though some of the data and estimates in these Status Reports may not be entirely accurate, they do provide some information that was not earlier available.

1.1 RTI fatality rates and per capita income of countries

Figure 1 shows a plot of fatalities per 100,000 population versus per-capita income of various countries based on the official reports from countries as received by WHO (2015). Fatalities per 100,000 population is used for most comparisons in this paper because the index is a good indicator of the health burden on the population. Fatalities per population can also be used as proxy for risk of death per trip as international experience suggests that the average number of

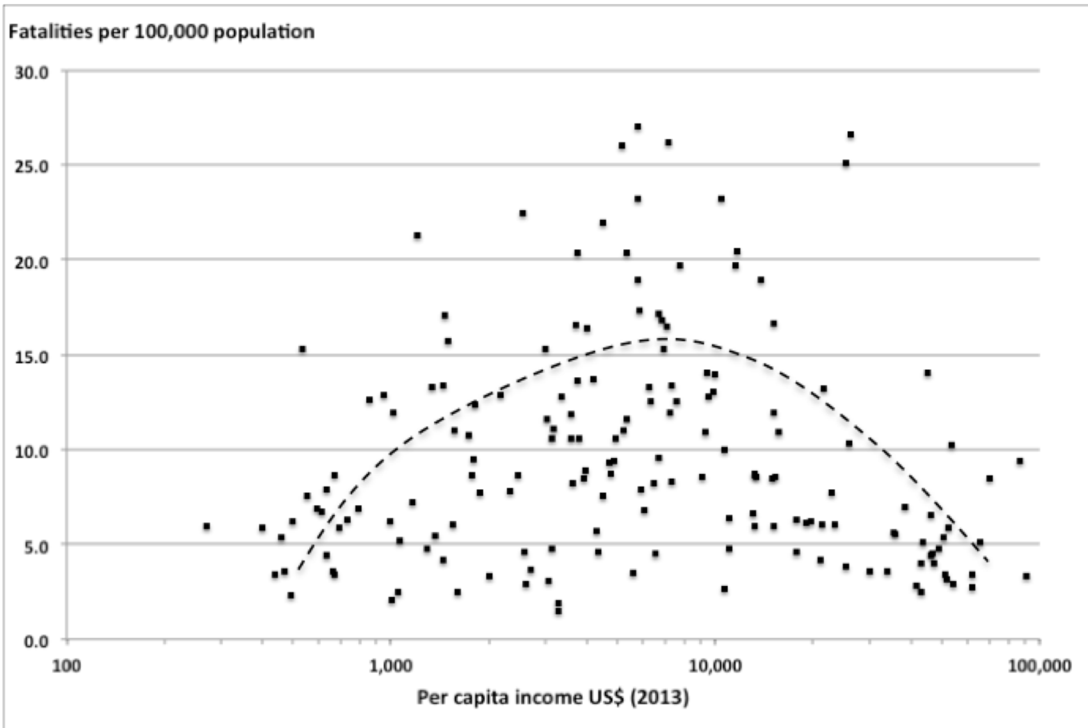

Figure 1. Fatalities per 100,000 population (official data from countries) vs. national per capita income for 171 countries (Source: WHO, 2015).

The Status Report (2015) estimates that 49 per cent of those who die in road traffic crashes are pedestrians, bicyclists and users of motorized two-wheelers (MTW). However, this is likely an underestimate because WHO's estimates rely on official government statistics to estimate the proportion of different types of road users killed.

trips per person per day remains relatively stable over time, incomes and place according to Knoflacher (2007). Knoflacher further states that average trip rates in cities around the world vary from 2.8 to 3.8. That total trip rates do not vary much and generally remain between 3 and 4 trips per person per day has been supported by many studies around the world (Giuliano & Narayan, 2003; Hupkes, 1982; Santos, McGuckin, Nakamoto, Gray, & Liss, 2011; Zegras, 2010).

Data presented in Figure 1 suggest that road traffic fatalities per unit population increase initially as societies become richer but begin to decline after the society reaches a certain developmental threshold. However, it must be noted that 60% of these countries, especially low and middle-income ones, may have underestimated the total number deaths as mentioned earlier. Furthermore, the ranges of the fatality rates at any income level are very large.

Figure 2 shows the WHO estimates of road traffic fatalities for the same countries as in Figure 1 plotted against national per capita income (WHO, 2015). These data have a very different distribution from that in Figure 1. The fatality rates for many countries with incomes less than USD 3,000 per year are much higher than for the same countries in Figure 1. Therefore, now we see a general tendency of a decrease in fatality rates with increasing incomes across countries. The initial rise and subsequent decrease in RTI deaths rates in Figure 1 appear to be largely due to underreporting of traffic deaths in LMICs. These new data suggest that the earlier understanding of the

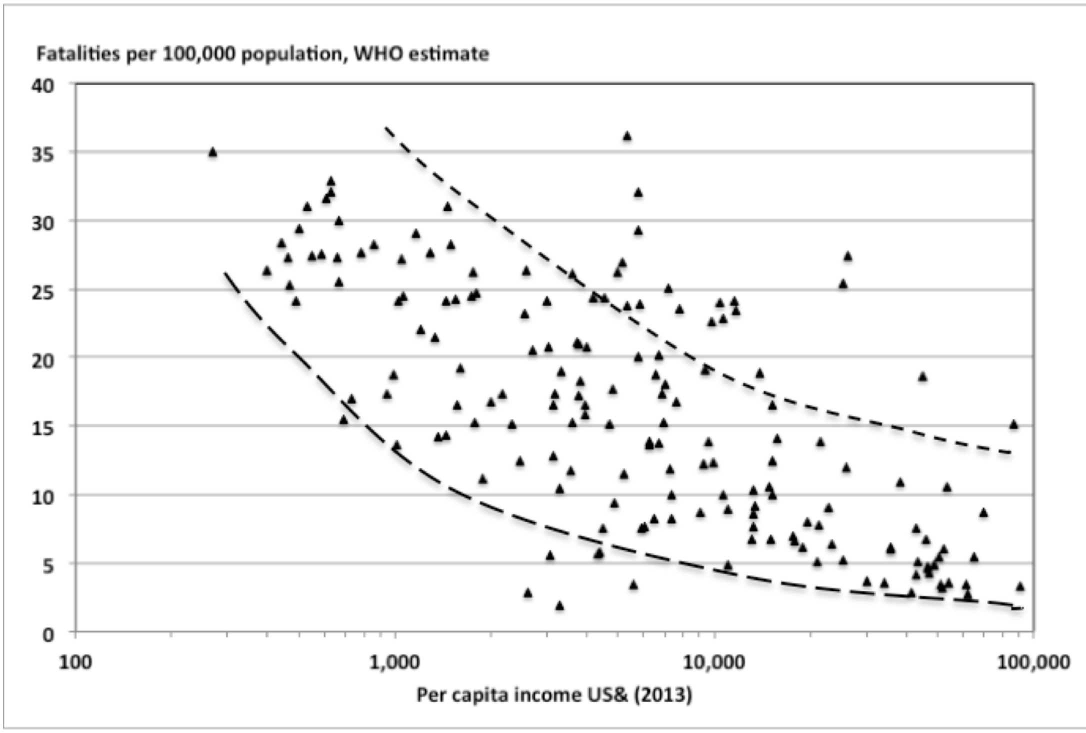

Figure 2. Estimated fatalities per 100,000 population (WHO estimates) vs. national per capita income for 171 countries (Source: WHO, 2015).

relationship between national income and RTI fatality rates (initial increase in deaths with increasing incomes and a subsequent decrease) may not be entirely correct.

Such multi-country data and historical data from some high-income countries from Western Europe and North America have been used by many researchers to model the relationship between per capita income and RTI fatality rates (e.g. Koornstra, 2007; Kopits & Cropper, 2005). The model developed by Kopits and Cropper (2005) predicted that the income level at which traffic fatality risk first declines is US$ 8,600 (1985 international prices). According to this model they predicted that the "road death rate in India, for example, will not begin to decline until 2042". Using a more complex model Koornstra (2007) predicted that road traffic fatalities may start declining in countries like India around 2030 if corrective actions are taken by policy makers in a 'learning scenario'. These predictions are based on the assumption that the relationship between fatality rates and income follows a pattern as shown in Figure 1. However, if the pattern is more like the one shown in Figure 2, then then these predictions would not be reliable.

Therefore, it is possible that the earlier claims that fatality rates will continue to increase until societies reach income levels between US$ 10,000-20,000 (2013 international prices) before decreasing are probably not correct. A study by Castillo-Manzano, Castro-Nuño, and Pedregal (2014) examining the trends in road traffic fatality rates in a sample of European states over the 1970–2010 period shows that "the convergence of EU countries as a whole on road safety being a clear empirical fact, as the countries with traditionally higher fatality rates at the beginning of each period have experienced a more negative average rate of change". They conclude that convergence on road safety is possible even without economic convergence, but the exact reasons for this are not clear.

1.2 RTI rate variability at similar income levels

It appears that there is there is not necessarily a very strong relationship between income and road safety performance when other factors are controlled. In addition, both Figures 1 and 2 show a very large variation in road safety performance of countries at the same income level. This is true for countries at all income levels. The reasons for such variation are poorly understood but are likely due to a wide range of structural factors that affect road safety outcomes.

These new data suggest that the earlier understanding of the relationship between national income and RTI fatality rates (initial increase in deaths with increasing incomes and a subsequent decrease) may not be entirely correct.

A study from the US suggests that many states and high-income countries in Europe had similar safety programs and practices in place for some time by 2013 but the fatality rates per 100 million vehicle miles travelled were very different (C. J. Kahane, 2016). The authors show that these differences are only to a limited extent readily attributable to safety practices (e.g., low fatality rates in places with high use of seat belts) and that other factors may be overwhelming the impact of the safety interventions. The less densely populated, less urbanized places had a substantially higher fatality risk. Another study comparing the RTI fatality rates for different cities in the US shows that cities with higher proportion of wider roads and large city blocks tend to have higher traffic fatality rates, and therefore in turn require much more efforts in police enforcement and other road safety measures (Mohan, Bangdiwala, & Villaveces, 2017).

There is a large variation in road safety performance of countries at the same income level. This is true for countries at all income levels. The reasons for such variation are poorly understood but are likely due to a wide range of structural factors that affect road safety outcomes.

These recent studies suggest that different patterns of built environment, settlement patterns and commuting modes and distances play a very significant role in RTI fatality rates in addition to vehicle and road design issues.

Therefore, it would be very useful to understand why countries (and cities) at similar income levels perform very differently as that would give us very important clues for policy makers for design of cities and highways as systems are renovated and new ones planned (Bhalla & Mohan, 2016). The above analysis suggests that if the LMICs adopt the latest evidence based road safety policies adapted to their local conditions and develop new understanding of structural factors influencing road safety, it is possible that they would be able to decrease their RTI rates before increasing their incomes substantially.

Different patterns of built environment, settlement patterns and commuting modes and distances play a very significant role in RTI fatality rates in addition to vehicle and road design issues.

2 ROLE OF VEHICLE CRASHWORTHINESS STANDARDS (ECE AND NCAP) IN PROMOTING ROAD SAFETY WORLDWIDE

The 2015 WHO Report suggests that “Changing road user behaviour is a critical component of the holistic “Safe Systems” approach advocated in the report. Adopting and enforcing good laws is effective in changing road user behaviour on key risk factors for road traffic injuries – speed, drink–driving, and the failure to use helmets, seat-belts and child restraints properly or at all.” These recommendations are similar to those included in earlier reports and have been adopted by most international agencies promoting road safety in low- and middle-income countries (for example, Bloomberg Initiative for Global Road Safety and Global Road Safety Partnership). Focus on these five risk factors is unexceptionable, as they would work in every country if controlled successfully. However, all these interventions require implementation and enforcement of traffic laws that is not as straightforward or easy. For enforcement to create a meaningful deterrent threat, enforcement activity needs to be increased substantially and maintained over a long period so that

If in a country vehicle occupant deaths contributed only 20% instead of 64% of the total count, then it is possible that reduction in deaths due to automobile safety standards would be less than 15%.

road users perceive a high risk of being ticketed (Zaal, 1994). It is relatively easy to pass laws, but much harder to make them work. Much more work is necessary to suggest guidelines for enforcement methods and enforcement priorities for LMICs.

2.1 Role of the 'safer' automobile

In this section, we examine the role of automobile safety standards in decreasing RTI death rates around the world. An important stream in global intervention is in the promotion of universal motor vehicle safety standards. There are two approaches to improving car design: (1) legislation that prescribes requirements with which vehicle manufacturers need to comply, and (2) information programs by organisations like New Car Assessment Programmes around the world (ASEAN NCAP, Euro NCAP, Global NCAP, Latin NCAP, US NCAP, etc.) and the Insurance Institute for Highway Safety that provide safety ratings for cars and create a market for safer vehicles.[1] Until recently almost all of the vehicle safety improvements were crashworthiness designs.

Agencies like NHTSA try to influence car design through two mechanisms (1) prescribing standards that manufacturers must comply with; (2) NCAP-like programs that are primarily aim to create a market for safety. The regulatory aspects have the possibility of being applied across the board to vehicles (e.g. for pedestrian safety, including bus-pedestrian). However, the NCAP safety market applies primarily to occupants and is difficult to extend to pedestrians.

Safer cars have had a major role in reducing RTI fatality rates in HICs over the past forty years. In the US alone, estimates suggest that the fatality risk in the average car or light transport vehicles in 2012 was 56% lower than in the average vehicle on the road in 1960, even given the same exposure, drivers, roadways, and medicine (Charles J. Kahane, 2015). The report estimates that vehicle safety technologies saved 613,501 lives from 1960 through 2012, including 27,621 only in in 2012. In the US, there were 33,561 fatalities on roadways during 2012, which means an estimated 45% were prevented due to automobile safety standards. If in a country vehicle occupant deaths contributed only 20% instead of 64% of the total count, then it is possible that reduction in deaths due to automobile safety standards would be less than 15%.

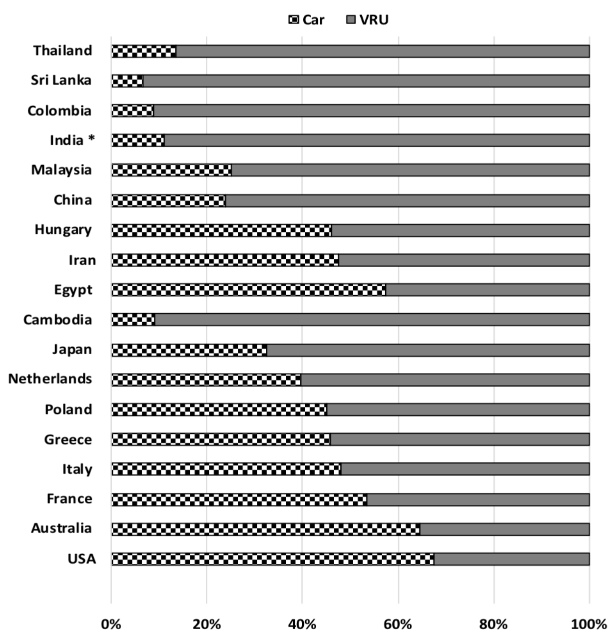

Figure 3. Proportion of car and vulnerable road user (VRU: occupants of 2-3 wheelers, cyclists and pedestrians) fatalities in selected countries (Source: WHO, 2015 and Mohan et al, 2015 for India).

Almost all our understanding of road safety issues derives from the experience of about a hundred years of motorisation in the HICs of today. This experience is based on traffic systems where the safety of car occupants remained the central concern. In these countries cars have been the dominant part of traffic systems unlike in many of the LMICs where MTW and para-transit vehicles like three-wheeled taxis (TWT in this paper), *tuk-tuks, jeepeneys* constitute a significant proportion of traffic on roads. Since we do not have detailed

[1] New Car Assessment Program, https://en.wikipedia.org/wiki/New_Car_Assessment_Program. Accessed 13 September 2017.

While it is important to establish the latest vehicle safety standards worldwide, it should be noted that this alone will not reduce overall death rates in LMICs as the HICs experience indicates.

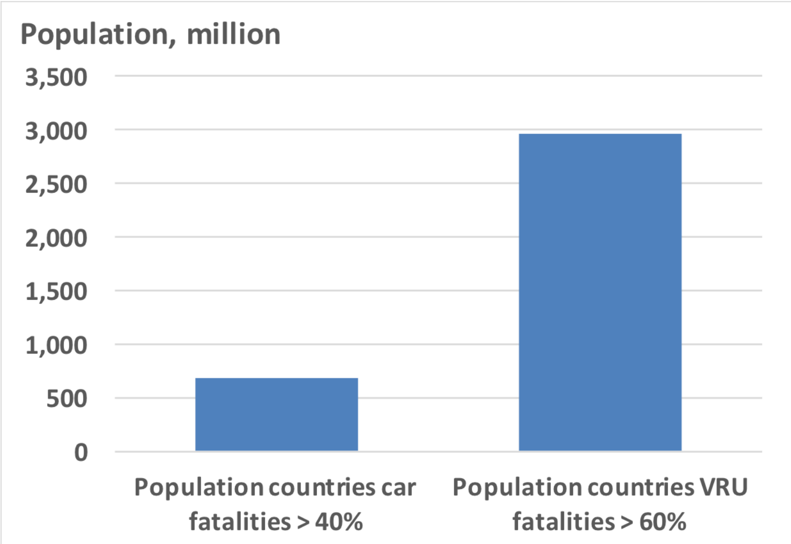

Figure 4. Population of countries included in Figure 3 according to proportion of car occupant and VRU fatalities.

These results indicate that significant gains in traffic safety in HICs are partly due to reducing exposure of VRU and not only due to effect of safety policies.

epidemiological studies on the effect of these latter vehicles on traffic safety in LMICs we do not have a good understanding of risks faced by occupants of these vehicles where these vehicles are a dominant mode of transport.

Figure 3 shows the proportion of car and vulnerable road user (VRU - occupants of 2-3 wheelers, cyclists and pedestrians) fatalities in selected countries (for India only - Mohan et al., 2015; WHO, 2015). In Cambodia, Colombia, India, Sri Lanka and Thailand car occupants comprise less than 20% of road traffic fatalities. Even in HICs like Japan, Netherlands, Hungary, Poland and Greece VRU constitute more than 50% of the fatalities. Figure 4 shows the total population of countries included in Figure 3 with car occupant fatalities greater than 40% and VRU fatalities greater than 60%. We would probably get similar population ratios if we included all the countries in the world, however, it is not

It may not be possible for LMICs to reduce fatality rates below ~7 per 100,000 population along with high exposure of VRUs unless there are innovative developments in road design and vehicle safety standards including all vehicle types with special emphasis on VRU protection.

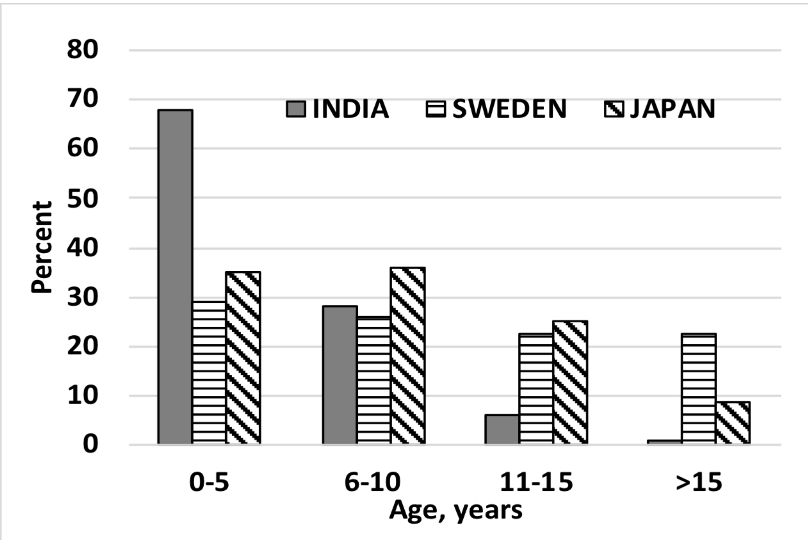

Figure 5. Age of cars on the road in India and Sweden and Japan in 2015.

possible to make an accurate assessment as reliable figures for modal share of fatalities are not available for all countries.

The above analysis indicates that while it is important to establish the latest vehicle safety standards worldwide, it should be noted that this alone will not reduce overall death rates in LMICs as the HICs experience indicates. However, it is important to understand that though automobile safety standards may not result in as dramatic a reduction in fatality rates in LMICs as in HICs, hundreds of thousands of people are maimed and killed in cars all over world and they must have access to the best safety systems available as soon as possible. Another reason why implementation of the latest safety standards in LMICs would be beneficial for car occupants is that many of these countries have a much younger fleet than HICs (Figure 5). While car sales have plateaued in HICs, sales are still increasing in most LMICs. Therefore, early implementation of latest safety standards would result in a faster fleet replacement with the best safety features in LMICs than in HICs.

3 RELATIONSHIP BETWEEN MTW SHARE IN VEHICLE FLEET, PEDESTRIAN EXPOSURE AND FATALITIES RATES

A thought experiment can be conducted to examine what would happen if the countries with very low fatality rates today had a much higher proportion of MTW in the fleet and a much higher exposure of pedestrians. Here we take the example of India, Japan and Sweden. India, Japan and Sweden had fatality rates of ~12, 4.7 and 2.8 per 100,000 persons respectively in 2013. If we keep the total number of vehicles constant in Sweden and Japan but change the fleet composition to 75% MTW and 25% cars, double the exposure of pedestrians, and then calculate overall fatality rates using risk of fatalities per unit vehicle and pedestrian per population constant for both countries, then we get results as shown in Figure 6.

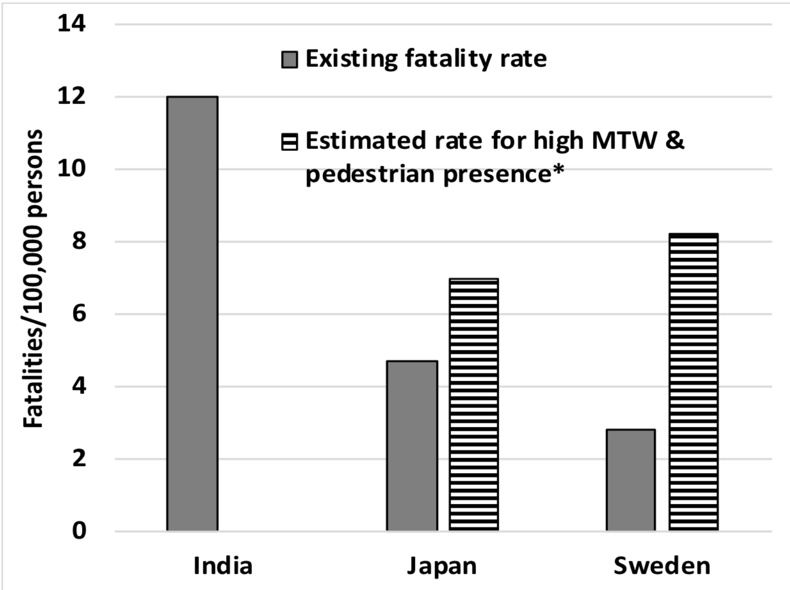

Figure 6. Existing fatality rates in India, Japan and Sweden and estimated rates in Japan and Sweden if they had 75% MTW in their fleet and 2 times the exposure of pedestrians.

**Assumption: Occupant risk per vehicle and pedestrian risk per population remain constant.*

The estimated results show that the total number of deaths increase significantly in Japan and Sweden and the estimated fatality rates increase to 7 and 8.2 respectively. These results indicate that significant gains in traffic safety in HICs are partly due to reducing exposure of VRU and not only due to effect of safety policies. Since a large number of LMICs are not likely to reduce VRU exposure significantly in the next decade, exclusive focus on NCAP standards will not produce as dramatic results in LMICs as they did in the HICs in the past. This thought experiment also suggests that it may not be possible for LMICs to reduce fatality rates below about 7 per 100,000 population along with high exposure of VRUs unless there are innovative developments in road design and vehicle safety standards including all vehicle types with special emphasis on VRU protection.

4 FATALITY RATES FOR DIFFERENT VEHICLE OCCUPANTS IN OECD COUNTRIES AND INDIAN CITIES

There are no clear explanations available why car occupant risk rates differ by a factor of five and MTW rates by a factor of six in these OECD countries.

Table 1 shows data for selected OECD countries for fatalities of MTW and car occupants per billion vehicle km (OECD/ITF, 2015). Car occupant fatality rates range from a low of 2.1 in United Kingdom to a high of 10.5 in Czech Republic, and, for MTW riders from a low of 39 in Switzerland to a high of 253 in Czech Republic. There are no clear explanations available why car occupant risk rates differ by a factor of five and MTW rates by a factor of six in these OECD countries. The last column in Table 1 gives the ratio between car and MTW fatality rates per billion vehicle km for each country. In Israel MTW riders have 9 times higher risk of dying than car occupants and in United States this ratio is 31.[2]

Detailed epidemiological data are not available at present to account for these differences. It would be very useful if data are obtained to understand the reasons for the differences between high rate and low rate cities for each category of vehicles.

If all cars in India were similar to those in OECD countries in 2014 and seat belt laws were being enforced we would have saved about 5,000-6,000 (~4%) lives annually.

Table 1. MTW and car occupant fatalities per billion vehicle km in OECD countries (Source: OECD/ITF, 2015)

Country	Fatalities/billion vehicle km		MTW/ Car Ratio
	MTW	Car	
Australia	71.8	5.2	14
Austria	59.7	4.7	13
Belgium	76.9	5.9	13
Canada	62.9	4.9	13
Czech	252.6	10.5	24
Denmark	49.5	4.2	12
France	72.4	4.9	15
Germany	59.5	3.3	18
Ireland	60.8	2.5	24
Israel	45.7	5.1	9
Netherlands	64.0	3.0	21
Slovenia	112.5	4.3	26
Sweden	43.9	2.2	20
Switzerland	39.2	2.3	17
United	72.0	2.1	34
United States	155.0	5.0	31

Table 2 shows estimates of fatalities of MTW, TWT and car occupants per billion vehicle km for selected Indian cities (Goel, Guttikunda, Mohan, & Tiwari, 2015; Mohan, Goel, Guttikunda, & Tiwari, 2014; Mohan, Tiwari, & Mukherjee, 2016). These data are not available at the country level. Vehicle mileage data for Delhi and Vishakhapatnam were obtained from special surveys (Mohan et al., 2014). Vishakhapatnam vehicle-use data were used for other cities as they are similar in size. TWTs are para transit

[2] The high U.S. rate for motorcycles is due to their unique exposure. They have almost never been used for transportation per se, instead over 80% of their use is recreational.

vehicles used as taxis and an example is shown in Figure 7. Helmet use is compulsory for all MTW riders by law in India (Ministry of Road Transport and Highways, 1988) but out of the six cities included in Table 2 the law was being enforced only in Delhi, which may explain the relatively low fatality rate in Delhi. Agra has the highest fatality rates for the three categories of vehicles compared to the other cities. The reasons for this are not known. The fatality rates per billion vehicle km for each category of vehicles differ by more than a factor of 5. The differences among these cities are similar in magnitude as those observed for OECD countries. Detailed epidemiological data are not available at present to account for these differences. It would be very useful if data are obtained to understand the reasons for the differences between high and low-rate cities for each category of vehicles.

Table 2. MTW, TST and car occupant fatalities per billion vehicle km in selected Indian cities (Data source: Mohan, Goel, Guttikunda, & Tiwari, 2014; Mohan, Tiwari, & Mukherjee, 2016)

Indian city	Fatalities/billion vehicle km			MTW/ Car Ratio	TWT/ Car Ratio
	MTW	TWT	CAR		
Delhi	16.5	-	3.8	4.3	-
Agra	70.7	45.3	25.2	2.8	1.8
Bhopal	31.8	11.1	7.3	4.4	1.5
Ludhiana	12.8	12.8	5.0	2.6	2.6
Vadodara	27.6	3.8	11.8	2.3	0.3
Vishakhapatnam	51.0	27.4	21.4	2.4	1.3

In OECD countries, all cars are required to conform to crashworthiness standards and seat belt wearing rates in a majority of the countries are more than 80%. In contrast, in cars in Indian cities did not have to conform to crashworthiness standards before 2017 (Mohan et al., 2015) and seatbelt use is likely less than 20% overall as the law is applicable only to front seat passengers and not enforced strictly except in Delhi during daytime (Mohan, 2009). Use of seat belts by drivers, front seat passengers and rear seat passengers is expected to reduce fatalities by 50%, 45% and 25%, respectively (Elvik & Vaa, 2004). According to Farmer and Lund (2015), between the years 1984 and 2009 the risk of driver death declined by an estimated 42% in cars, 44% in pickups, and 75% in SUVs in the US. Therefore, we should expect fatality rates of car occupants in Indian cities to be about double those in the OECD countries with better safety records.

Figure 7. Example of a three-wheeled scooter taxi (TWT)

Average country fatality rates for vehicles can be higher than city rates due to lower speeds in cities, therefore it is probable that some car occupant fatality rates per billion vehicle km in Table 1 are higher than the average city rates in Table 2. However, the highest and lowest fatality rates for cars on an average in India are about double those in the OECD countries. If all cars in India passed NCAP crashworthiness norms we could expect a reduction in car fatalities by more than 50%. It is estimated that car occupant fatalities in India are about 10,000-13,000 (7%-9%) of the total 141,526 fatalities. Therefore, if all cars in India were similar to those in OECD countries in 2014 and seat belt laws were being enforced we would have saved about 5,000-6,000 (~4%) lives annually. At present growth rates, it will take about 15 years for 90% of the car fleet to be replaced in India.

5 SAFETY STANDARDS FOR VEHICLES OTHER THAN CARS (NOT COVERED BY NCAP AT PRESENT)

5.1 Safety of para-transit vehicles (three-wheeled scooter taxis)

Given the present trip lengths for each vehicle type, MTW riders are 3–6 times more at risk than car occupants.

The fatality rates of TWT occupants per billion vehicle km range from 0.3 times to 2.6 times that for car occupants. The average occupancy of cars ranges from 1.8 to 2 and that of TWTs from 3-8 (Arora & Jawed, 2011; Chanchani & Rajkotia, 2012; Gadapalli, 2016; Mohan et al., 2016). Since the average occupancy of TWTs can be more than 2 times that of cars and the fatality rate per billion km is half that of cars, the risk of fatality per passenger for the two vehicles could be similar. This is a very surprising finding because TWTs weigh less than a third of cars, have no surrounding steel shell and have to subscribe to only minimal safety standards.

At an individual level, risk per trip seems to be the lowest for TWT occupants in all the cities under the assumed occupancy rates and number of trips per day.

Studies comparing safety of large cars with small cars have consistently found that larger cars provide better protection than small cars (Broughton, 2008; Buzeman, Viano, & Lovsund, 1998; Wood, 1997). All these studies have been done in HICs where cars of all sizes are capable of the same driving speeds.

Small lightweight vehicles with limited speed capabilities operating in the urban environment can result in low occupant fatality rates.

Personal fatality risk for various vehicles in four Indian cities has been calculated by dividing vehicle-specific occupant fatality rates by estimates of the average daily occupancy of each vehicle. The occupancy rates for MTW, car and TWT were estimated to be 4, 7 and 60 persons respectively per day (Chanchani & Rajkotia, 2012; Mohan & Roy, 2003; Wilbur Smith Associates, 2008). The results of these calculations are shown in Figure 8 (Mohan et al., 2016). Given the present trip lengths for each vehicle type, MTW riders are 3–6 times more at risk than car occupants. The MTW

Very different crashworthiness standards (than current NCAP) need to be developed for low mass vehicles incapable of operating speeds greater than 50 km/h. Such vehicles may be optimal for urban use and could be prohibited for roads with speed limits greater than 50 km/h

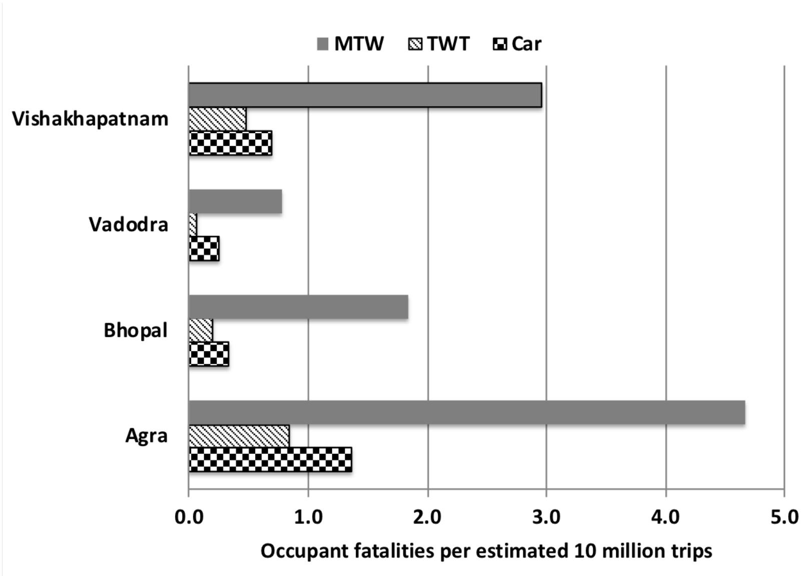

Figure 8. Personal fatality risk per 10million trips for occupants of motorised two-wheelers, TWT, and cars in four Indian cities (Source: Mohan et al., 2016).

fatality rates per trip in Agra and Vishakhapatnam are much higher than those in the other three cities. The reasons for this are not known at present. At an individual level, risk per trip seems to be the lowest for TWT occupants in all the cities under the assumed occupancy rates and number of trips per day.

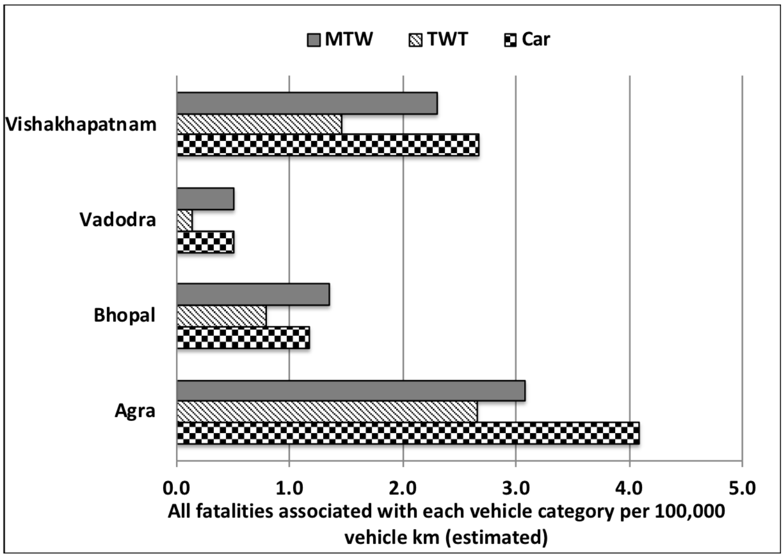

Figure 9. All fatalities associated with each vehicle category per 100,000 vehicle km (estimated) in four Indian cities. Source: Mohan et al., 2016.

Fig. 9 shows all the fatalities associated with each vehicle type per 100,000-vehicle km per day. We assumed the following daily travel distance values for the different vehicle types: Bus-150 km, Car-50 km, TWT-150 km, MTW-25 km. The data include fatalities of occupants and road users other than vehicle occupants. For example, if a motorcycle hits a pedestrian and the pedestrian dies, the pedestrian death is also associated with the motorcycle. This index gives a rough idea of the total number of fatalities one might associate for each vehicle type given the present traffic conditions and mode shares. Essentially, the figures indicate that the low rate for TWT relative to cars is due to the higher number of passengers carried TWT per day. These indices appear to suggest that, on a travel distance basis, TWT, MTW, and cars may pose roughly similar level of danger to society under the present conditions. Safer design is a pressing concern for TWT, which are threats to both their occupants and the VRU that they impact.

No previous studies are available on safety records of motor vehicles that are not capable of high speeds operating in mixed traffic in urban areas. TWT operating in Indian cities have engines smaller in size than 175 cc and generally cannot exceed velocities greater than 50 km/h. The experience of TWT in Indian cities suggests that small lightweight vehicles with limited speed capabilities operating in the urban environment can result in low occupant fatality rates. The lower operating speed of TWT also implies that they pose a much lower risk to pedestrians, bicyclists, and other road-users.

This issue needs to be studied in greater detail, and if found true, it may suggest that there very different crashworthiness standards or NCAP tests need to be developed for low mass vehicles incapable of operating speeds greater than 50 km/h. Such vehicles may be optimal for urban use and could be prohibited for roads with speed limits greater than 50 km/h.

5.2 Buses, trucks and VRU safety

While it is true that eventually cars designed in the HICs with pedestrian friendly front designs will become available in LMICs, the impact on injury reduction from such measures is expected to be less than in HICs because of the lower rate involvement of passenger cars in VRU crashes. In Delhi, India, for instance, 112 of the 367 pedestrians killed in 2014 were struck by a passenger car where details were known. In comparison, buses and trucks accounted for 174 of these fatalities. But, safer bus or truck fronts are not included in the legislation currently being considered in India or internationally.

Studies over the past decade (mainly modelling and laboratory tests) suggest that it is possible to design truck and bus fronts such that the risk of fatal pedestrian injuries can be reduced significantly (Bovenkerk & Fassbender, 2006; Chawla, Mohan, Sharma, & Kajzer, 2000; Nooij et al., 2009; SP3, 2006). Some of the issues identified include:

Studies over the past decade (mainly modelling and laboratory tests) suggest that it is possible to design truck and bus fronts such that the risk of fatal injuries is reduced significantly in pedestrian impacts.

- Lower impact velocity range: Enhanced field of view will reduce accidents with vulnerable road users (Talbot, Reed, Christie, Barnes, & Thomas, 2017).
- Middle impact velocity range: At impact velocities below 30km/h, approximately 80% of the vulnerable road users end up under the heavy goods vehicle. Deflecting the pedestrian to the side prevents run-over. The nose-cone concept is a promising concept reducing fatalities due to run-over. Numerical simulations indicated also a less severe secondary contact with the road, when hit by a nose-cone goods vehicle.
- Upper impact velocity range: At impact velocities exceeding 30km/h, the severity of the primary impact needs to be reduced. The safety bar will reduce the load on the vulnerable road user during impacts with the cabin. This results in a reduced injury risk to the head and to other body regions.

In more recent years the lower costs of electronics and computing power has made possible important advances in crash avoidance features. These features promise significant reductions in both deaths to occupants and vulnerable road users. However, there will also be important issues related to how drivers interact with some of these technologies.

The modelling exercises have demonstrated that it is possible to reduce impact forces experienced by various body segments by modifying the bus front shape and front surface properties. The items that have significant influence are:

- Height and width of the bumper
- The offset distance between the bumper surface and the front panel surface of the bus front.
- The incline of the front surface with respect to the vertical.
- The height of the bottom edge of the windshield determines the onset of the stiff region. This might be an important consideration in future designs.

A great deal of extra research and testing is necessary before pedestrian safety standards can be mandated for buses and trucks. In the meantime, existing guidelines regarding enhanced driver view mechanisms, underride guards for bicycles and less aggressive fronts can certainly be implemented. These will have a significant impact in reducing VRU injuries in LMICs.

The fact that drivers sometimes to change their behaviour in response to changes in the driving task has implications for some of the advanced electronic systems that have been, or are being developed for modern cars.

6 CRASH AVOIDANCE AND ELECTRONICS

As noted in section 2.1 Role of the “safer” automobile, most of the vehicle safety improvements that began to appear in vehicles after 1970 were to crashworthiness. These were first driven by government regulations and later by a variety of New Car Assessment Programs (NCAPS). However, in more recent years the lower costs of electronics and computing power has made possible important advances in crash avoidance features. These features promise significant reductions in both deaths to occupants and vulnerable road users. However, there will also be important issues related to how drivers interact with some of these technologies.

6.1 Risk compensation, driver adaptation, and inattentiveness

When crashworthiness improvements were first mandated in the 1970s there were claims that if drivers were "forced" by regulations to drive more crashworthy vehicles, and as a result have reduced injury risks, they would adjust their driving and take more risks to "compensate" for their increased safety. As a result there would be increases in the deaths of vulnerable road users. The same arguments were extended to safety belt use laws. It was clear at the time that these arguments were driven by ideological opponents of government regulations.

When the studies that purported to support these claims were carefully evaluated they were shown to be invalid and there was no evidence to support the claims that people had a "fixed demand" for injury risk, and as a result would compensate with more risky driving (Hedlund, 2000; Pless, 2016). In some circumstances, however, when vehicle features change the driving task in very noticeable ways some drivers do "adapt" their behaviour. The best example of this is in the finding that drivers with studded tires drive faster around curves with icy surfaces than drivers with regular tires. In this case, however, it is more likely that both groups of drivers were more concerned with avoiding any kind of crash, including minor ones, rather than thinking about injuries per se.

The fact that drivers sometimes do change their behaviour in response to noticeable changes in the driving task has implications for some of the advanced electronic systems that have been or are being developed for modern cars. But there is no evidence of drivers changing behaviour if automatic interventions are rare, thus for example, it has been suggested that, despite the overwhelming evidence of its effectiveness, the ESC systems could encourage some drivers to become "more careless". But ESC fails the tests outlined by Hedlund (2000) to determine whether drive adaptation is likely. ESC does not change the driving task at all, only in the relatively rare circumstances when a driver is about to lose control does the system automatically intervene, and even then the intervention is not especially noticeable. Furthermore, drivers typically are not aware that their vehicles have ESC or what it does.

6.2 Distracted driving

In-car electronics, such as touch screens and navigation systems, together with cell-phone conversations and text messaging, are potential sources of distractions that can result in drivers paying insufficient attention to the driving task. It has been claimed that cell-phone conversations result in risks comparable to alcohol-impaired, however, despite the huge increase in the use of cell-phones (and text messaging) in cars in the U.S. in recent years, there has been no noticeable surge in crashes. It may be that there have always been driver distractions, for example, radios, tape and CD players, which have been replaced by newer ones. However, because of the proliferation of electronics in occupant compartments the potential for driver distractions is clearly increasing, which cannot be a good thing for safety, especially in traffic environments with many vulnerable road users.

6.3 Autonomous driving

Some of the new electronic technologies being developed (and in some cases, being introduced) may pose some increased risks because they can lead to adverse driver behaviour changes. For example, in 2016 n the U.S. the driver of a Tesla was killed while using the semi-autonomous "Autopilot" feature in the vehicle. The crash occurred because the vehicle's forward sensors failed to detect a tractor-trailer that was crossing its path and no braking occurred prior to the impact. The Tesla Autopilot system can steer itself by following lane delineations, drivers using this system, however, are instructed to keep their hand on the wheel. The driver in this crash had his hands on the wheel "for only 25 seconds of an extended 37-minute period" despite there being multiple visual and audible warnings that "Hands Required Not Detected".[3] At the time of this crash there were reports of multiple videos on the internet of Tesla drivers showing how they

[3] https://jalopnik.com/tesla-driver-in-fatal-florida-crash-got-numerous-warnin-1796226021)

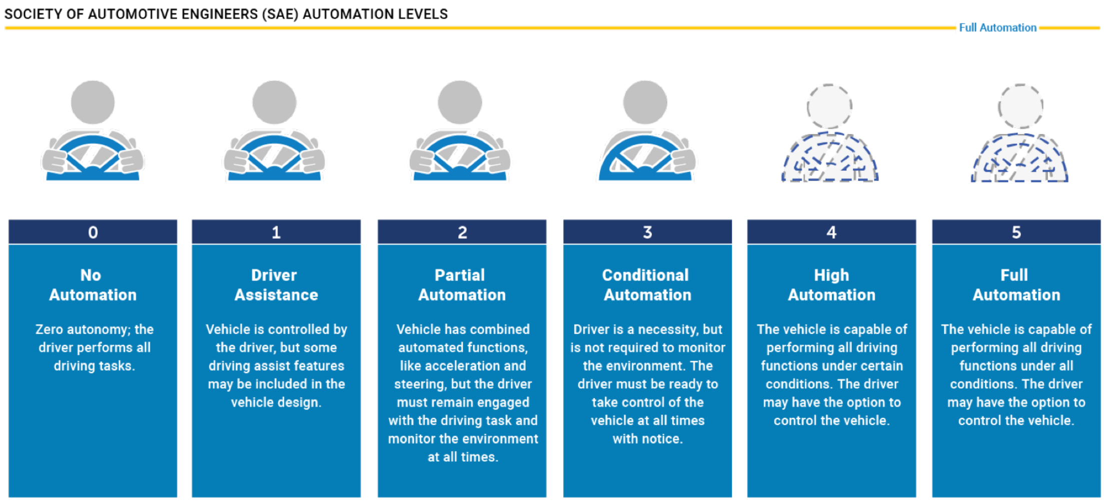

Figure 10. Taxonomy for the various levels of autonomous driving.

Because of the proliferation of electronics in occupant compartments the potential for driver distractions is clearly increasing, which cannot be a good thing for safety, especially in traffic environments with many vulnerable road users.

'Alcholock', if successful may have great potential in reducing pedestrian deaths and injuries.

were being driven without their hands on the wheel. Another fatal crash in China may also have involved a car driving semi-autonomously.[4] Some Mercedes models also include semi-autonomous steering capabilities but require drivers to be holding the steering wheels. Unlike ESC these kinds of partial autonomous driving are changing the driving task in a very noticeable way, these systems can actually steer the vehicles on some roads.

As Tesla and Mercedes models illustrates some forms of autonomous driving are already beginning to show up in HICs. The Society of Automotive Engineers (SAE) has developed a taxonomy for the various levels of autonomous driving ranging from level 0 "No automation" to level 5 "Full Automation" (Figure 10), This approach has been adopted by the U.S NHTSA as it seeks to ensure that there are no regulatory impediments to the safe implementation of the technology.

In the U.S many vehicles have level 2 systems (partial automation) with features such as adaptive cruise controls which maintain speed and separation with no input from drivers. Level 3 systems (conditional automation) are technically close with systems such as the Tesla Autopilot discussed above and active lane keep assist available on Mercedes models. However, as the Tesla crash illustrates, ensuring a timely and effective handoff of control to the driver when an emergency is imminent is a huge challenge. NHTSA, perhaps somewhat optimistically, anticipates level 5 systems (Full Automation) could be available as early as 2025.[5]

Many other advanced crash avoidance features, such as lane departure warnings, automatic emergency braking (AEB), which will be essential features for autonomous driving are being rapidly

[4] https://jalopnik.com/the-first-fatal-tesla-autopilot-crash-may-have-happened-178662698

[5] https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

introduced in new cars in the U.S. For example, there is a voluntary agreement between 20 car makers, IIHS, and NHTSA, that by 2022 all new cars will have AEB as standard equipment. Some manufacturers are significantly ahead of this deadline, thus every 2018 Toyota model sold in the U.S. will have AEB (almost certainly with pedestrian detection) as standard equipment.[6]

6.4 Crash avoidance features and New Car Assessment Programs (NCAP)

In recent years various NCAP programs have begun including crash avoidance features in their safety ratings. Starting in 2010 NHTSA began including "recommended safety features" and these now include forward collision warning, lane departure warning, rear-view video, and automatic emergency braking. IIHS vehicle ratings, in addition to multiple crash tests, now include ratings for forward crash protection (none, advanced, or superior) plus headlight ratings. EuroNCAP includes assessments of speed assist systems and autonomous emergency braking systems designed for urban roads and highways.

6.5 European approaches

A recent European report classified the new systems as follows (International Road Safety & Connected Mobility Task Force, 2014):

Over-Vision Systems: These systems operate mainly at night. Basic ideas are to enlarge lit zones, illuminate appropriately zones that must be lit, and avoid glare in rural areas where drivers have to switch between high beams and low beams depending on the traffic ahead.

Co-Pilot Systems: The generic term Intelligent Speed Adaptation (ISA) encompasses a wide range of different technologies aimed at improving road safety by reducing traffic speed and homogenizing traffic flow, within the limit of posted speed limits.

Angel-Guard Systems: There are several technologies under this denomination, here we only consider the ones relevant to pedestrian safety. Advanced Emergency Braking (Collision Imminent Braking) Systems allow an automatic braking in follow-up driving situations when they detect that an impact is imminent. Some current systems can also detect pedestrians at and prevent crashes completely at speeds less than 40 km/h and reduce impact severities at higher speeds.

Driver behaviour control: Technologies to detect drowsiness and drivers under the influence of alcohol. The latter, generally clubbed under the term 'alcholock', if successful may have great potential in reducing pedestrian deaths and injuries. Advanced alcohol interlocks, in theory, could prevent huge numbers of crashes, but could be strong political opposition to making such systems mandatory in many jurisdictions.

In late 2016 the European Commission published a Report from the Commission to The European Parliament and the Council titled *Saving Lives: Boosting Car Safety in the EU (EC, 2016)*. The report features 19 specific vehicle safety measures, that could be considered when reviewing and updating the General Safety Regulation and the Pedestrian Safety Regulation. They suggest that these measures should become mandatory to increase safety on the roads. Some of the new ITS features already available are listed below.[7]

[6] http://www.iihs.org/iihs/news/desktopnews/manufacturers-make-progress-on-voluntary-commitment-to-include-automatic-emergency-braking-on-all-new-vehicles.

[7] Most information from European Commission, Mobility and Transport, Road Safety, https://ec.europa.eu/transport/road_safety/specialist/knowledge/esave/esafety_measures_known_safety_effects/electronic_stability_control_en, and, Hynd et al., 2015.

1. Main benefit for vehicle occupants

o *Seat belt reminders* are already mandatory on driver seats and the Commission is considering whether they should be mandatory for all seats.[8]

Many countries including the US, S. Korea and others will require automated emergency braking systems (AEBS) to be fitted in all new models 2022 onward. Effectiveness and acceptability of these systems in LMICs is not known

o *Intelligent Speed Assistance* (ISA) is already available as standard on some of the high-end cars. It is an over ridable system that communicates the speed limit to the driver using digital maps and helps drivers maintain the correct speed (the effectiveness of this system is not known).

o *Electronic stability control (ESC)*. aims to stabilise the vehicle and prevent skidding under all driving conditions and situations, within physical limits. It does so by identifying a critical driving situation and applying specific brake pressure on one or more wheels, as required.

o *Lane departure warning system* (LDWS) is an in-vehicle system that provides a warning to the driver of an unintended lane departure. LDWS is currently fitted to higher specification cars and increasingly on more mainstream models. LDWS rely to a large extent on the presence of road markings. LDWS are generally optional systems and are typically packaged with other related systems.

The research needed for AEB in LMICs is the extent to which the different traffic environments produce too many false positives. It is entirely possible that AEB pedestrian protection should be deactivated for relatively low speeds, where false positives may be most common.

2. Benefits for vehicle occupants and VRU

o *Driver distraction and drowsiness technologies*. Low presence in the current literature with poor evidence of effectiveness for drowsiness detection. Effectiveness is not known.

o *Automated emergency braking systems (AEBS).* Combine sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid an accident. First generation AEBS are in production on a number of current vehicles and are capable of automatically mitigating the severity of two-vehicle, front to rear shunt accidents (on straight roads and curves dependent on sensor line of sight and environment "clutter") as well as some collisions with fixed objects and motorcycles (Hynd et al., 2015). AEBS are voluntary on M1 and N1 vehicles, although fitment is incentivised via Euro NCAP. AEBS is fitted by over a dozen manufacturers in Europe, with few offering it as standard on at least one model. Current fitment in the EU fleet is still low, probably less than 5 per cent. Current consumer costs for 'city safety' AEBS are as low as Euro ~200 (Ford, VW). Some manufacturers package this with other functions where the option pack can be as high as Euro 3,000. Many countries including the US, S. Korea and others will require these systems to be fitted in all new models 2022 onward. Effectiveness and acceptability of these systems in LMICs is not known.

It appears Driver Alcohol Detection System for Safety may be available commercially within a few years. If the costs can be brought down a reasonable level, these technologies may be very suitable for LMICs as they may prove to be less cost intensive than intensive road checks to detect erring drivers.

The research needed for AEB in LMICs is the extent to which the different traffic environments produce too many false positives. It

[8] Front seats in the US

is entirely possible that AEB pedestrian protection should be deactivated for relatively low speeds, where false positives may be most common.

- *Alcohol interlock devices* prevent the vehicle ignition from operating if alcohol above a pre-defined threshold is detected. Application of this measure is intended to reduce collision risk by restricting the opportunity for drivers to operate vehicles when under the influence of alcohol. While breath-based devices require the driver to exhale into a specific device, other less invasive techniques are under development to detect a driver's alcohol level. (a) Tissue spectroscopy uses the changes in light absorption of skin tissues caused by the presence of alcohol to produce an estimate of blood alcohol concentration; (b) distance spectroscopy uses an unobtrusive 'sniffer' to detect alcohol in the vehicle. Multiple sensors can be placed within the vehicle (e.g. steering wheel, A-pillar etc.) to identify and quantify the alcohol concentration in exhaled breath as detected within the vehicle cabin; (c) Transdermal (skin-contact) systems determine alcohol in perspiration through contact with the skin.

Driver Alcohol Detection System for Safety (DADSS) Program in the US, is exploring the feasibility, the potential benefits of, and the public policy challenges associated with a more widespread use these technologies to prevent alcohol-impaired driving (Zaouk, Willis, Traube, & Strassburger, 2015). Significant progress has been made to identify DADSS technologies that have the potential to be used on a more widespread basis in passenger vehicles. Prototype testing has indicated that there are potential technologies that ultimately could function non-invasively in a vehicle environment to measure a driver's BAC.

It appears that these technologies may be available commercially within a few years. If the costs can be brought down a reasonable level, these technologies may be very suitable for LMICs as they may prove to be less cost intensive than intensive road checks to detect erring drivers.

6.6 Summary

Of all the technologies available, the following can be selected for evaluation and further research and evaluation in LMICs:

- Speed adaptation/speed control.
- Automatic Emergency Braking with pedestrian detection.
- Efficient light systems.
- Alcohol interlocks.

7 CONCLUSIONS

1. New data suggest that the earlier understanding of the relationship between national income and RTI fatality rates (initial increase in deaths with increasing incomes and a subsequent decrease) may not be entirely correct.
2. There is a large variation in road safety performance of countries at the same income level. This is true for countries at all income levels. The reasons for such variation are poorly understood but are likely due to a wide range of structural factors that affect road safety outcomes.
3. Different patterns of built environment, settlement patterns and commuting modes and distances play a very significant role in RTI fatality rates in addition to vehicle and road design issues.
4. When vehicle occupant deaths contributed only 20% in a country instead of >50% of the total count, then it is possible that reduction in deaths due to automobile safety standards would be less than 15%.
5. While it is important to establish the latest vehicle safety standards worldwide, it should be noted that this alone will not reduce overall death rates in LMICs as the HICs experience indicates.

6. Recent findings indicate that significant gains in traffic safety in HICs are partly due to reducing exposure of VRU and not only due to effect of safety policies.
7. It may not be possible for LMICs to reduce fatality rates below ~7 per 100,000 population along with high exposure of VRUs unless there are innovative developments in road design and vehicle safety standards including all vehicle types with special emphasis on VRU protection.
8. There are no clear explanations available why car occupant risk rates differ by a factor of five and MTW rates by a factor of six in OECD countries.
9. Detailed epidemiological data are not available at present to account for these differences. It would be very useful if data are obtained to understand the reasons for the differences between high rate and low rate cities for each category of vehicles.
10. If all cars in India were similar to those in OECD countries in 2014 and seat belt laws were being enforced we would have saved about 5,000-6,000 (~4%) lives annually.
11. Small lightweight vehicles with limited speed capabilities operating in the urban environment can result in low occupant fatality rates.
12. Very different crashworthiness standards (than current NCAP) need to be developed for low mass vehicles incapable of operating speeds greater than 50 km/h. Such vehicles may be optimal for urban use and could be prohibited for roads with speed limits greater than 50 km/h
13. Studies over the past decade (mainly modelling and laboratory tests) suggest that it is possible to design truck and bus fronts such that the risk of fatal injuries is reduced significantly in pedestrian impacts.
14. VRU protection technologies of concern have largely been limited to cars. In the LMICs context, it is necessary that we focus on future design specification for all motor vehicles. These would include:
    - Trucks and buses
    - Cars
    - Intermediate public transport (three wheelers, e-rickshas, etc)
    - Motorised two-wheelers
15. Desirable safety standards for trucks and buses:
    - Specifications for pedestrian impact standards
    - Automatic Emergency Braking with pedestrian detection.
16. Desirable safety standards for cars:
    - Development of advanced pedestrian impact standards, especially for small cars.
    - Evaluation and development of following technologies: Speed adaptation/speed control, Emergency braking, and brake assist, pedestrian detection and efficient light systems, alcohol locks.
    - Development of new standards for low mass vehicles with speeds restricted to 50 km/h
17. Desirable safety standards for Intermediate public transport (three wheelers, e-rickshas, etc).
    - Development of regulations to make fronts of all vehicles less aggressive (removal of sharp and pointed objects and elimination of rigid objects that are not necessary).
    - Development of guidelines for pedestrian impact standards.
18. Desirable safety standards for motorised two-wheelers.
    - Assessment and study of MTW components associated with pedestrian injuries.
    - Development of guidelines for MTW design modification on the basis of above analysis.

- Mandatory ABS (combined braking system for vehicles < 90cc) and DRL. Study to evaluate effect of DRL, ABS and combined braking system equipped MTW on pedestrian fatalities and injuries.

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