Preventing motor vehicle crash injuries and deaths: Science vs. folklore
Part 2: Lessons from history - 1970 to today

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1 INTRODUCTION

In the late 1960s and early 70s there was a significant paradigm shift in the development of countermeasures to reduce motor vehicle crash injuries and deaths. Prior to this time countermeasures were largely based on folklore and were not evaluated, the new paradigm envisaged a much broader range of countermeasures and emphasized the importance of evaluating them. This is the second of two papers summarizing the history of efforts to prevent motor vehicle crash deaths and injuries, and it focusses on countermeasures adopted since this paradigm shift in high income countries (HICs), and also efforts to implement some of them in low-and middle-income countries (LMICs).

The first part of the history noted that the exclusive focus for 50+ years was on preventing crashes by changing road user behaviour. In 1968 William Haddon Jr. helped to initiate the paradigm shift by formalizing a concept for a comprehensive set of countermeasure possibilities in which the vehicle, human, and environmental factors involved in crashes were separated into pre-crash, crash, and post-crash phases to create a matrix that illustrates the wide range of countermeasure possibilities. This became known the Haddon matrix, and is shown in Table 1 with examples of issues than can be addressed in each of the cells (Haddon, 1968). This matrix has been the basis for efforts to combat motor vehicle crash deaths since about 1970.

Table 1. The Haddon Matrix

Phase	Human Factors	Vehicle and Equipment Factors	Environmental Factors
Pre-crash	Road user attitudes Impairment by alcohol Law enforcement	Brakes Lights Tires	Road design Traffic safety laws Separation of road users
Crash	Restraint use Helmet use Injury tolerance	Structural designs Crush zones Restraint systems	Roadside hazards Guard rail designs
Post-crash	Number of injured body regions Body regions injured	Fuel leakage Ease of access to compartment	Emergency response time Medical treatment Traffic congestion

2 VEHICLE FACTORS – CRASHWORTHINESS AND CRASH AVOIDANCE IMPROVEMENTS

Probably the biggest change that resulted from the paradigm shift was the introduction of safety standards for motor vehicles, especially those that addressed the performance of improvements to motor vehicles to protect occupants in crashes. Although several individuals had advocated that seat belts and other improvements to motor vehicles to protect occupants in crashes be introduced as early as the 1920s, it wasn't until the 1960s that seat belts started to become standard equipment on new vehicles. Many other safety features were mandated for new vehicles starting in 1967 in response to the first U.S. federal motor vehicle safety standards. A few years later similar standards were issued in Australia and Europe. These standards were the starting point for the many vehicle safety improvements that followed.

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2.1 Crashworthiness

The initial U.S. federal safety standards required automakers to install lap and shoulder belts, padded dashboards, energy-absorbing steering columns, high-penetration-resistant windshields, head restraints, etc. These crashworthiness standards were specified in performance terms, including for the first-time mandatory crash tests at 30 mph (48 km/h) into a rigid flat barrier. The legislation authorizing these initial standards required that they be based on existing standards (usually from the Society of Automotive Engineers) and did not require manufacturers to develop any new technologies. At that time, it was an open question as to whether future standards could specify levels of performance that would require new technologies.

Probably the biggest change that resulted from the paradigm shift was the introduction of safety standards for motor vehicles, especially those that addressed the performance of vehicles in crashes.

This issue was tested in US courts in the 1970s when the National Highway Traffic Safety Administration (NHTSA) issued a proposal for a new regulation that would have required automakers to install airbags in future models. At the time of this proposal one supplier had done some development work on the concept of airbags, but additional development would have been needed before they could be installed in large numbers of cars. The automakers strongly resisted this proposal, and in a lawsuit argued that the statute under which safety standards were issued could not force the development of new technology such as airbags. The automakers lost this argument as the court ruled that NHTSA could require new technology, however, automakers were able to utilize other regulatory delaying tactics to block requirements for airbags for almost 20 years. Thus, although government rules can improve vehicle safety, typically it has been a very slow process.

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In 1978 NHTSA changed the paradigm for producing crashworthiness improvements when it started a New Car Assessment Program (NCAP), in which cars were tested in full-width flat barrier tests at 35 mph (56 km/h) with instrumented crash test dummies. The test speed was 5 mph (8 km/h) higher

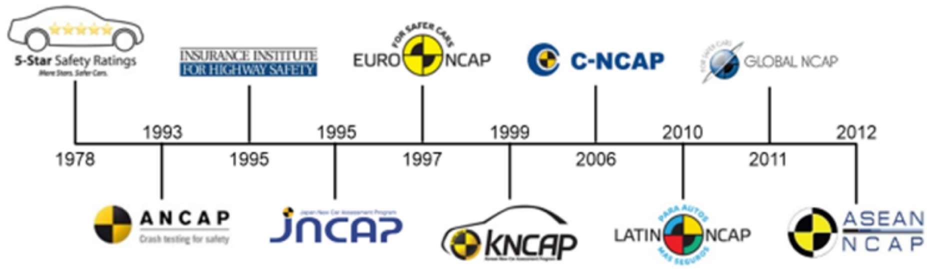

Figure 1. Various New Car Assessment Programmes (NCAP) that have produced major improvements in vehicle crashworthiness much faster than by government regulations.

than the corresponding test mandated in the frontal crash test standard.[1] Injury measures from the test dummy are used to assess the vehicle's performance which is reported using star ratings from one to five. The underlying idea was that well publicized differences in ratings would encourage automakers to compete on safety, and although automakers opposed this program, they could not ignore it and were soon working to improve their vehicles' NCAP ratings.

A few years later in 1993 a similar Australian program (ANCAP) was started, but with a 56 km/h offset frontal crash test. The Insurance Institute for Highway Safety (IIHS) began its Crashworthiness Assessment program in 1995 with a 40 mph (64 km/h) offset crash test. Today there are multiple programs of this type around the world and they have produced major improvements in vehicle crashworthiness much faster than by government regulations (Figure 1).

For example, in addition to injury measures from crash test dummies, the IIHS crashworthiness evaluations also emphasized that occupant compartments should not collapse, so that the restraint systems could be as effective as possible. At the start of the IIHS program, occupant compartment collapse in the 64 km/h offset crash test was common, as illustrated by the 1995 Saab 900 post-crash picture shown in Figure 2.

Despite this compartment collapse this model met all of the applicable U.S. federal motor safety standards, however, within a few years Saab re-engineered the front-end crush zone and the occupant compartment. A redesigned 2011 model, designated as the Saab 9-3, when retested illustrated optimum structural performance, with damage confined to the crush zone and the compartment was essentially undamaged.

Figure 2. Occupant compartment collapse in the 64 km/h offset crash test, 1995 Saab 900 (top). Redesigned Saab 9-3, with occupant compartment essentially undamaged (bottom).

[1] Although 5 mph (8 km/h) may not seem like a large increase in speed the kinetic energy increases by 36%.

Today, all car models in the U.S. have structural performance comparable to that illustrated by the Saab 9-3, and this has been accomplished without any government regulations.

There is no question that the various NCAP type programs around the world have accelerated improvement in vehicle crashworthiness.

As another example, in 2003 IIHS introduced a side impact consumer test that simulated a side impact by a striking SUV, which because of their high front-ends put the heads of car occupants at high risk. Since that time, side airbags with head protection and side structural improvements have been implemented across the fleet and the proportion of vehicles rated good (the IIHS top rating) has increased to 93% of 2012–2014 model year vehicles. Drivers of vehicles that IIHS rated as good in side-impact protection are 70% less likely to die in a left-side crash than drivers of poor-rated vehicles (Brumbelow, Mueller, & Arbelaez, 2015). The improvements driven by this test program, especially the introduction of side-impact airbags, were introduced by automakers much earlier than specified by the federal standard mandating this technology.

There have been many attempts to understand why the performance of ABS on test tracks did not translate into fewer fatal crashes in the real-world, but no definitive conclusions have been determined.

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2.1.1 Pedestrian protection requirements

The European Experimental Vehicles Committee of the United Nations Economic Commission for Europe submitted a report on pedestrian injury accidents at the 9th ESV Conference, Kyoto, in November 1982 (European Experimental Vehicle Committee: Working Group 7, 1982). Partly in response to this and rising concerns for pedestrian safety prompted the UNECE Sustainable Transport Division's World Forum for Harmonization of Vehicle Regulations (WP.29) to initiate moves for pedestrian safety standards. After many delays, in 2008 ECE established a Global Technical Regulation No. 9 on Pedestrian Safety.[2]

Unlike passenger vehicles, research shows that the rate of fatal motorcycle crashes in the U.S. is 31% lower for motorcycles equipped with optional ABS compared to the same models without them.

EuroNCAP incorporated these tests into its crashworthiness rating system in 2009. In the U.S. NHTSA considered such a regulation but concluded that the projected benefits would not justify the costs.

Strandroth et al. (2014) compared EuroNCAP pedestrian scoring with real-life injury outcomes in car-to-pedestrian and car-to-bicyclist crashes occurring in Sweden and they found significant injury reductions to both pedestrians and bicyclists between low and high performing cars. Further improvements in these designs are being explored.

ESC has been on all new cars in the U.S. since 2012 and is one of the most effective technologies yet developed for preventing serious crashes

Automatic emergency braking systems will offer additional protection to pedestrians in a wider range of crashes (see section 2.2.5 below).

2.2 Crash avoidance

The initial U.S. federal safety standards included specifications for brakes, lights, turn signals, etc., that were intended to help drivers

[2] https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29wgs/wp29gen/wp29registry/ECE-TRANS-180a9e.pdf)

avoid crashes, but these initial standards did little more than codify existing designs. But as vehicle designs have incorporated more and more electronics this has opened up the possibilities for advanced crash avoidance systems such as antilock brakes, electronic stability control, blind spot detection, "smart" cruise control, and automatic emergency braking systems, etc., and, at some point in the future, autonomous driving. The various NCAP programs around the world have begun to expand beyond crashworthiness to incorporate many of these new crash avoidance systems in their ratings, and this is accelerating their introduction into new vehicles.

2.2.1 Antilock brakes for passenger vehicles

Drivers can lose control of their vehicles when one or more of the wheels lockup during braking, antilock braking systems (ABS) can prevent this by releasing the brake pressure on individual wheels that are about to lockup and then reapplying the pressure in rapid cycles. In 1971 the Chrysler Imperial was the first passenger vehicle to be sold with ABS brakes, and tests on this car demonstrated that the ABS system could significantly reduce stopping distances on wet surfaces, but had slightly longer stopping distances on dry surfaces. Another advantage of ABS is that on slippery surfaces it allows drivers to maintain steering control during hard braking.

In the U.S. ABS became widely available in the 1990s, although it was offered on a number of sports and luxury cars in the mid-1980s. Antilock brakes were made mandatory in Europe for all passenger cars sold after 2004. There was no comparable regulation in the U.S.[3]

The real-world effectiveness of ABS was evaluated in a number of studies by General Motors, NHTSA, and IIHS and their conclusions were very similar. Their net effect on fatal crashes was close to zero, but there were some reductions in nonfatal crashes (Evans & Gerrish, 1996; Charles M. Farmer, 2001; Kahane & Dang, 2009). There have been many attempts to understand why the performance of ABS on test tracks did not translate into fewer fatal crashes in the real-world, but no definitive conclusions have been determined.

2.2.2 Antilock brakes for motorcycles

Riding a motorcycle is inherently riskier than driving a car, in part because it is harder to maintain control on two wheels than four. As noted above ABS prevents wheels from locking up and this is extremely important for two-wheeled vehicles. Unlike passenger vehicles, research shows that the rate of fatal motorcycle crashes in the U.S. is 31% lower for motorcycles equipped with optional ABS compared to the same models without them (Teoh, 2013).

2.2.3 Antilock brakes for tractors and trailers

In the U.S. ABS was originally mandated for tractor-trailers in 1975, but the industry fought this regulation in court and it was overturned on the grounds that the technology at that time was not reliable. Some years later, after ABS had been in cars for any years, a new ABS regulation took effect in 1997 for tractors and one year later for trailers. A 2010 NHTSA evaluation on the effectiveness of this regulation concluded that there was a 6% reduction in crashes where ABS was assumed to be relevant. Among the crash types with large reductions were "jack-knives", off-road overturns, and at-fault collisions with other vehicles (except front-to rear collisions) (Allen, 2010).

2.2.4 Electronic stability control systems (ESC)

Drivers on test tracks demonstrating the potential benefit of ABS had to brake differently than they would have with conventional brakes, instead of pumping the brakes to avoid wheel lockup they had to brake as hard as possible to activate the ABS. Also, the ability to steer during emergency braking is relatively easy on a test track, but in real-world emergencies many drivers may not try to steer. ESC is an extension of ABS technology that automatically helps drivers

[3] Electronic Stability Control (ESC), which is based on ABS (see section 3.2.4), was mandated for new passenger vehicles in the U.S. beginning in 2007. The requirement was phased in over several years and applies to all new light vehicles manufactured on or after September 1, 2011.

maintain control of their vehicles on curves and slippery roads by selectively braking individual wheels so that the vehicle goes where the driver is steering. This technology has been on all new cars in the U.S. since 2012 and is one of the most effective technologies yet developed for preventing serious crashes. In a study of all fatal crashes in the U.S. during the 10 years from 1999 to 2008, ESC was found to have reduced fatal crash involvement risk by 33%; 20% for multiple-vehicle crashes, 49% for single-vehicle crashes, and 73% for single-vehicle fatal rollover crashes (Charles M. Farmer, 2010). In a 2016 NHTSA study, ESC was estimated to have saved 1,580 lives of passenger vehicle occupants in calendar year 2014, when 39% of the passenger vehicle fleet had ESC as standard equipment (Webb, 2016).

The newer AEB systems also include pedestrian detection which has the potential to prevent some pedestrian deaths and injuries entirely.

2.2.5 Automatic emergency braking

Automatic emergency braking (AEB) is a relatively new technology that helps prevent crashes or reduce their severity by applying a vehicle's brakes automatically when it senses that a crash will occur if there is no braking. These systems use on-board sensors such as radar, cameras or lasers to detect an imminent crash, sometimes warning the driver, and applying the brakes or increase the braking effort if the driver does not take sufficient action. Some systems have a forward collision warning (FCW) system to alert drivers prior to automatically braking and others do not. The newer AEB systems also include pedestrian detection which prevent prevent some pedestrian deaths and injuries. It also should reduce the severities of impacts in which automatic braking occurred but was insufficient to prevent the crashes, and a number of these reduced severity pedestrian impacts should then be in the speed ranges where the ECE Global Technical Regulation No. 9 on Pedestrian Safety is effective (ECE, 2009).

It is important to find effective ways to change behaviours. However, as with all countermeasures, those aimed at changing road user behaviour should be evaluated for their effectiveness.

Recent research on the effectiveness of different AEB systems in reducing front-to-rear crashes and injuries compared a low-speed AEB system operational at speeds up to 19 mph (30 km/h) that does not warn the driver prior to braking and an AEB system that operates at higher speeds. The low-speed AEB, FCW alone, and FCW with AEB reduced rear-end striking crash involvement rates by 27, 43, and 50%, respectively. Rates of rear-end striking crash involvements with injuries were reduced by 20, and 56%, respectively, by FCW alone, low-speed AEB, and FCW with AEB (Cicchino, 2017).

A 2012 study included a comprehensive international literature review of effectiveness studies of standard driver education programs and reported: "These reviews are uniform in failing to identify a crash reduction benefit for standard driver education programs."

In March 2016 NHTSA and IIHS announced a commitment by 20 automakers representing more than 99% of the U.S. auto market to make AEB a standard feature on virtually all new cars no later than September 2022. IIHS now includes AEB in its car safety rating, and NHTSA will rate AEB systems and other advanced technologies under its 5-Star NCAP Safety Ratings beginning in model year 2018.

2.2.6 Other advanced crash avoidance features

Other advanced technologies include lane departure warning and blind spot detection, research has shown that these have reduced police-reported crashes relevant to those technologies.[4] Advances also are being made in intelligent transportation systems that allow vehicles to communicate with one another or with road infrastructure to help avoid crashes.

3 HUMAN FACTORS - CHANGING ROAD USER BEHAVIOUR

The fact that with the paradigm shift there has been a broader range of countermeasure opportunities doesn't mean that changing road user behaviour is not important, it is. Thus, for example, it has long been recognized that motorists who have consumed alcohol, or who exceed speed limits have increased crash risks, as do those who violate other traffic laws such as running red lights. It is important to find effective ways to change these behaviours. However, as with all countermeasures, those aimed at changing road user behaviour should be evaluated for their effectiveness.

3.1 Driver education

As part 1 of this history documented, educating drivers was the central focus of highway safety countermeasures for 60 plus years, even though its effectiveness had not been scientifically evaluated. It was not until after the paradigm shift in the 1970s and later that evaluations, including random assignments of students, were undertaken.

3.1.1 High school driver education

By the late 1960s high school driver education had been one of the principal highway safety countermeasures in the U.S. for decades. Even though there was no evidence that such programs were effective, the 1966 U.S. Highway Safety Act specified that standards should be set for driver education courses, and implicitly endorsed this as a key approach to changing driver behaviour, so folklore was not entirely defeated.

There were repeated claims through the years that beginning drivers who took driver education courses had fewer crashes than people who learned to drive by other means. In addition, in the 1960s and 70s, some U.S. insurers offered discounts for teen drivers who had completed a high school driver education course. There was, however, a fundamental flaw in all of these early comparisons of the driving records of students who completed the courses vs. those that did not. The flaw was that students who chose to take the courses were different than those who did not. These differences were identified by comparisons of students who wanted to take a driver education course (but for various reasons were unable to) and those who chose not to take a course. The students who wanted to take a course (but were unable to) had fewer crashes than those who didn't try to take a course. This "volunteer effect" has been repeatedly demonstrated in studies of a wide range of driver education/improvement courses indicating the need for studies with random assignment of students to the different treatment groups.

One of the earliest scientific studies on beginning driver education was conducted in England (Shaoul, 1975). This study reported that the education had no effect on individual risk, but that it increased the overall risk because it promoted earlier driving by the teenage population, a group with very high crash risks. This latter finding that beginning driver education increased crashes because it increased the exposure of teenage drivers was also reported in research in the U.S. (Robertson & Zador, 1978).

In the 1980s NHTSA funded the largest experimental study with random assignment to evaluate high school driver education (Stock, Weaver, Ray, Brink, & Sadof, 1983). This study (referred to as the DeKalb county study) randomly assigned 16,000 U.S. high school volunteers to three groups – intensive training, minimal training, or no formal education. The results failed to show any significant benefits from the driver education courses.

[4] http://www.iihs.org/iihs/topics/t/automation-and-crash-avoidance/hldi-research

These reviews are uniform in failing to identify a crash reduction benefit for standard driver education programs.

It is not clear if training (or what type) reduces the risk of crashes, injuries or offences in motorcyclists, and a best rider training practice can therefore not be recommended.

"Advanced" driver training programs that have included driving on skid pads, etc., have been shown to increase the crash risks of the students, and this is presumed to be due to the courses making the drivers overconfident of their abilities.

Today there is abundant research evidence that education, advertising, advanced skill training, etc., do not result in fewer crashes or increases in the use of safety equipment such as motorcycle helmets or safety belts. What does change road user behaviour, however, are traffic laws that road users believe will be enforced resulting in penalties.

The conclusions of the DeKalb county study have been challenged and the data reanalysed, and there have even been claims that some benefits in terms of reduced crashes began to occur 18 months or more after completion of the courses, which is a finding that is hard to justify. A relatively recent review of the world-wide literature on the evaluations of driver education courses concluded that "Past studies have demonstrated that common-sense assumptions about what is effective in reducing young driver risk are not always well founded. Reviewers of the evaluation literature have typically concluded that beginning driver education has yet to demonstrate clear success in improving the safety of new drivers" (Lonero & Mayhew, 2010).

A 2012 study included a comprehensive international literature review of effectiveness studies of standard driver education programs and reported: "These reviews are uniform in failing to identify a crash reduction benefit for standard driver education programs" (Thomas, Blomberg, & Fisher, 2012).

3.1.2 Motorcycle rider training and education

Riding a motorcycle requires different skills than driving a car, and rider education courses can teach novice motorcyclists basic operating skills and help experienced motorcyclists refresh their skills. However, despite claims to the contrary, there is no convincing evidence that they reduce the risks of motorcycle crashes.

A 1996 review of the effects of motorcycle rider training in the United States, Canada and Europe on crash risk concluded that there is "no compelling evidence that rider training is associated with reductions in collisions" (Mayhew & Simpson, 1996). The New York Department of Motor Vehicles conducted a large-scale analysis of motorcycle rider training between 1981 and 1985 in which motorcycle operators' license applicants were randomly assigned to one of four groups. One group took the state's existing knowledge and driving test and another took a skills test developed by NHTSA. The two remaining groups were assigned to rider training courses, plus the skills test. Riders who took the state's standard knowledge and driving test had fewer motorcycle crashes in the subsequent two years than riders in the three experimental groups

A Cochrane review of 23 selected studies of pre-license training of motorcycle riders concluded that "mandatory pre-license training may be an impediment to completing a motorcycle licensing process, possibly indirectly reducing crashes through a reduction in exposure. It is not clear if training (or what type) reduces the risk of crashes, injuries or offences in motorcyclists, and a best rider training practice can therefore not be recommended." (Kardamanidis, Martiniuk, Ivers, Stevenson, & Thistlethwaite, 2010).

3.2 Driver skills vs. attitudes

The fundamental assumption of driver education is that imparting knowledge and improving the skills of drivers will result in fewer crashes, however, there is substantial evidence that this assumption is not correct. More knowledge does not automatically change behaviour, and more skilful drivers do not necessarily crash less, in fact some of them have elevated crash risks (Appleyard, Gerson, & Lintell, 1981; Lonero & Mayhew, 2010; Williams & O'Neill, 1974; Williams, Preusser, & Ledingham, 2009). This is most likely because the attitudes of drivers have a very strong influence on the way they drive. Thus, most drivers who have consumed significant amounts of alcohol are aware that their risks of a crash are increased, but they decide to do it anyway. Similarly, teenagers in the U.S. drive differently when there are adults in the vehicle with them, compared to when their passengers are other teens, and as a result their crash risks are much higher with teen passengers (Williams, Ferguson, & McCartt, 2007).

Similarly, "advanced" driver training programs that have included driving on skid pads, etc., have been shown to increase the crash risks of the students, and this is presumed to be due to the courses making the drivers overconfident of their abilities (C. M. Farmer & Wells, 2015; Hirsch, Maag, & Laberge-Nadeau, 2006; Katila, Keskinen, Hatakka, & Laapotti, 2004; Ker et al., 2005; Sumer, Ozkan, & Lajunen, 2006).

A big impediment to changing driver behaviour through education is that a large majority of drivers around the world believe that their driving ability is average or better than average with almost none believing that they are worse than average. Thus, a 2003 paper reporting on a random sample of U.S. drivers found that 17% rated their driving skills as "Much better than average", 57% rated their skill as "Average", and only 1% rated their skill as "Worse than average" (Williams, 2003). This is probably the principal reason that efforts to change driver behaviour have support among laypersons and why, at the same time, such efforts fail. Virtually all drivers believe that there are many "bad" drivers who need to be improved, but do not accept that they themselves are often part of the problem.

3.3 Driver training and education today

Despite the lack of evidence on effectiveness of driver and rider education and training, significant resources continue to be invested in these kinds of programs. Thus, for example, despite the evidence of adverse effects from training drivers on skid pads, such courses are widely available in the U.S., and a number of them are promoted by car companies such as Mercedes and BMW.

Educational approaches continue to have strong support, especially among laypersons. Thus, for example, in 2014 a Florida newspaper headlined an article: "Drivers ed helps teens stay safe, but is not offered in all schools", even though all of the available evidence is that such courses increase the crash risks for teenagers. There continue to be efforts to develop "new" educational messages, when perhaps the simplest one would be "obey all traffic laws," However, as the following section documents, such a message is only likely to be followed if motorists believe the laws will be enforced.

3.4 Traffic safety laws can change road user behaviour

Today there is abundant research evidence that education, advertising, advanced skill training, etc., do not result in fewer crashes or increases in the use of safety equipment such as motorcycle helmets or safety belts. What does change road user behaviour, however, are traffic laws that road users believe will be enforced resulting in penalties. In some cases, for example, laws aimed at reducing alcohol-impaired driving require intensive enforcement together with associated publicity, whereas others, for example, motorcycle helmet use laws, generally do not require intensive enforcement.

3.4.1 Alcohol-impaired driving laws

Today laws defining the offense of alcohol-impaired driving in virtually all jurisdictions are specified by BACs thresholds, commonly 0.03, 0.05 or 0.08%. Despite these laws, however, alcohol-impaired driving is a leading cause of crash deaths in many countries, and there is abundant evidence that vigorous enforcement of these laws together with related publicity is needed to reduce this problem (Erke, Goldenbeld, & Vaa, 2009).

Research in the 1970s clearly documented that deterrence is created in the minds of motorists by their beliefs in the risk of apprehension and certain punishment if they violate the law, and that the severity of the punishment has little effect on driver behaviour.

For a long time, it was assumed that the success of these laws could be assessed by counts of arrests and convictions, and police authorities, in particular, were sceptical of any enforcement activities that did not result in arrests. However, research in the 1970s clearly documented that deterrence is created in the minds of motorists when they believe there is a risk of apprehension and punishment if they violate the law. The severity of the punishment has little effect on driver behaviour (Ross, 1982). This has led to the adoption of highly visible sobriety checkpoints, where large numbers of motorists are randomly stopped and assessed for impairment. Even though typically this approach does not result in many arrests (to the frustration of police initially) it creates deterrence which is necessary to reduce the magnitude of the problem.

The state of Victoria, Australia has demonstrated how effective driving-while-impaired (DWI) laws can be when they are rigorously enforced with highly visible random breath testing, but no other jurisdictions have conducted programs with the levels of enforcement as Victoria. In 2016, in that state there were approximately 4 million random breath tests conducted in a population with about 4.5 million licensed drivers. The proportion of motorists killed with blood alcohol concentrations (BACs) above 0.05% dropped from 49% in 1977 to 15% in 2014 (Donellan 2017). In contrast, in the U.S. which has reasonably strong laws aimed at alcohol-impaired driving but relatively weak enforcement, the proportion of fatally injured drivers with BACs greater than or equal to 0.08% in 2014 was 31%, more than double the rate in Victoria.[5] The intense enforcement of the Victoria law is probably the most effective countermeasure aimed at alcohol-impaired driving anywhere in the world, with thousands of lives saved since it was first implemented in 1976.

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3.4.2 Speed limits

Higher vehicle speeds increase the likelihood of crashes and the severities of those that occur. Speed limits have been the principal approach to address this problem since the beginning of motorization. Today speed limits vary widely ranging from relatively low limits in urban areas to high limits (including some sections of the German autobahns which have no limits) on rural limited access highways.

The enforcement of speed limits by traffic police and automated cameras are the most common approaches. Speed limiting devices on some vehicle types such a trucks and buses, and modifications to urban traffic environments are also used (see section 4.2, Traffic calming).

Speed limits are similar to most other traffic laws in that there needs to be sufficient enforcement of these laws to create the perception among motorists that violators will be apprehended

Speed limits are similar to most other traffic laws in that there needs to be sufficient enforcement of these laws to create the perception among motorists that violators will be apprehended and punished.

[5] http://www.iihs.org/iihs/topics/t/impaired-driving/fatalityfacts/impaired-driving

and punished. Unlike most traffic safety laws, the enforcement of speed limits is often controversial, with claims that it is more about raising revenue than promoting safety, and this is especially the case for automated speed enforcement with cameras (see section 4.4, Automated enforcement).

Speed limit enforcement is most commonly undertaken by traffic police using speed detection devices using laser or radar technology. Given the wide diversity of police departments in different countries it is difficult to generalize on the effectiveness of police speed enforcement. However, since 1974 multiple changes in speed limits on Interstate highways in the U.S. have resulted in a series of natural experiments that provide useful information on motorists' reactions to the control of speeds on high speed roads

In the U.S. speed limits are set at the state level, however, in 1974 in response to an oil embargo by OPEC countries the U.S. congress passed legislation that required all states to enact a maximum speed limit of 55 mph (88 km/h) to save fuel or face the loss of federal highway construction funds. This coercion worked and all 50 states soon had this maximum speed limit. In 1974, because of the fuel shortage road travel decreased, and so did travel speeds on interstate highways. Motor vehicle crash deaths dropped 16% (54,052 vs. 45,196) in 1974 compared to 1973, in a subsequent study the Transportation Research Board estimated that about 4,000 of this reduction in deaths could be attributed to the decreased speeds (Transportation Research Board, 1984).

As the fuel shortages ended opposition to the 55 mph limits began to grow, with organized groups lobbying for repeal of the federal legislation and compliance with the limits eroding. As a result, in 1987 the federal requirements for the rural sections of the highways were repealed, and they were completely repealed in 1995. Most states increased their speed limits after these repeals, and these higher limits were associated with immediate increases in travel speeds. Thus, for example, within one year after speed limits were raised from 55 mph (88 km/h) to 70 mph (112 km/h) on three urban freeways in Texas, the percent of passenger vehicles travelling faster than 70 mph increased from 15 to 50%, and the percent exceeding 75 mph (120 km/h) increased from 4 to 17% (Richard A. Retting & Greene, 1997).

It has often been claimed that motorists will choose speeds that they believe to be "safe", however, observations of travel speeds on U.S. interstate highways since the 1995 repeal of 55 mph limits show that the speeds of many motorists are influenced by the speed limits. Typically, they do not strictly observe the limits but instead choose somewhat higher speeds because of the widespread belief that U.S. traffic police have tolerance levels of 8 to 10 mph above the posted limits before they will stop and ticket offenders. This behaviour is illustrated by motorists' responses to state speed limits that were increased more than once. The second and sometimes third speed limit increases were usually in response to observations that many motorists were violating the new limits, however, soon after the new higher limits were in effect speeds increased again. This has been a consistent finding, higher speed limits typically do not result in significantly more motorists observing the new limits, instead travel speeds increase.

Many studies have reported that deaths on U.S. interstate highways increased as a result of the higher speed limits since 1987. One study of the long-term effects of raising speed limits in 41 states during 1993 to 2013 estimated that there were 33,000 additional deaths in these years than would have been expected if the 1993 maximum limits had stayed in place (Charles M. Farmer, 2017).

Currently in the U.S. maximum speed limits typically are 70 or 75 mph, a few states have 80 mph (128 km/h), and one section of a Texas highway has an 85 mph (136 km/h) limit.

3.4.3 Motorcycle helmet laws and helmet use

Laws requiring motorcyclists to wear certified helmets predate belt use laws, the first such law took effect in Victoria, Australia in 1961. A little later in 1967, the U.S. federal government issued regulations under the Highway Safety Act which included requirement that all states enact helmet use laws or risk losing federal highway construction funds. This federal incentive worked, and in the early 1970s, 47 states had universal motorcycle helmet laws. At about the same time, however, some motorcyclists started an organization called ABATE (A Brotherhood Against Totalitarian Enactments) to lobby against the federal mandate for helmet use laws. In 1976, this group and politicians from the states without helmet laws successfully lobbied Congress to prevent the federal government from assessing penalties for failure to pass these laws. This quickly resulted in many states repealing or weakening (for example, making them apply only to riders under 21) such laws.

The basic findings are that laws requiring all riders to wear helmets resulted in close to 100% use, but when repealed or weakened usage dropped to about 50%, and when some laws were reinstated usage went back up to close to 100% again.

At around the same time that organized opposition to helmet laws was growing in the U.S. these laws were beginning to be passed in Europe with little opposition. For example, the first motorcycle helmet use law in the U.K. took effect in 1973.

The changes in U.S. state motorcycle helmet use laws have provided a number of natural experiments that allow good assessments of the effects of the changes. The basic findings are that laws requiring all riders to wear helmets resulted in close to 100% use, but when repealed or weakened usage dropped to about 50%, and when some laws were reinstated usage went back up to close to 100% again. As expected the motorcyclist death rates went up or down with the helmet use changes (Carter et al., 2017; Kraus, Peek, McArthur, & Williams, 1994; Kyrychenko & McCartt, 2006; Mounce, Brackett, Hinshaw, Lund, & Wells, 1992).

A large number of studies continue to be done around the world documenting reasons why motorcyclists do not wear helmets, however, the evidence suggests that all over the world helmet use remains low when there is no enforcement of a helmet law and increases to 80% to 90+% when laws are introduced and enforced.

Currently only 19 U.S. states have laws requiring all motorcyclists to wear a helmet, known as universal helmet laws. Laws requiring only some motorcyclists to wear a helmet are in place in 28 states. There is no motorcycle helmet use law in three states (Illinois, Iowa and New Hampshire).

3.4.3.1 <u>*Motorcycle helmet laws and helmet use in LMICs*</u>

In many LMICs motorcycles are the only motorized vehicles that some families own, and as a consequence they are often used for family transportation. This practice raises some special safety issues, in particular, the lack of helmet use by children.

In 2001, wearing a helmet became mandatory in Vietnam for all motorcycle drivers and passengers on certain roads, however, there was limited enforcement and helmet use was estimated to be only about 30% on average and it varied greatly by time of day and type of road.

It should not be assumed that passing a law is, by itself, sufficient. In many instances, some levels of enforcement have been necessary to achieve and maintain high levels of belt use.

Toward the end of 2007 this law was extended to riders on all roads (Figure 3). Random observational helmet use surveys were conducted in 2008, the results showed a substantial increase in the use of helmets, but only among adults (90 to 99%); the wearing of helmets among children was much lower (53% among children younger than 8, and 38 to 53% among children from 8 to 14) (Pervin et al., 2009).

In LMICs helmet use in the daytime is usually greater than 70% where the law is enforced. Helmet wearing rates exceeds 88% in Delhi where the law is enforced compared to less than 20% in other Indian cities where the law is not enforced (D. Mohan, 2016). In Karachi, where the law is not enforced, only 7% of crash involved motorcyclists were reported to be wearing helmets (Shamim, Razzak, Jooma, & Khan, 2011).

A report from South America (29 cities in 6 countries) documents helmet use of more than 80% of the riders where the laws are enforced and typically less than 30% where the laws are not enforced (Lambrosquini et al., 2017). A study from Africa found a large difference in the use of helmets in two neighbouring countries – 97% in Kigali, Rwanda, compared to only 9% in Kampala, Uganda (Haglund & Tibaleka, 2012).

Figure 3. Motorcycle traffic in Vietnam.

A large number of studies continue to be done around the world documenting reasons why motorcyclists do not wear helmets, however, the evidence suggests that all over the world helmet use remains low when there is no enforcement of a helmet law and increases to greater than 80% when laws are introduced and enforced.

3.4.4 Seat belt laws and belt use

Seat belt use laws spread rapidly after the first and successful introduction of such a law in Victoria, Australia in 1970 (Table 2).

Seat belt use laws are now widespread around the world, but when first introduced they have not always produced high levels of use. In many jurisdictions, notably Canada and the United States, focused enforcement efforts over many years were needed before high belt use rates were achieved (Williams, Wells, McCartt, & Preusser, 2001). In contrast, in West Germany where the initial seat belt use law had no fine or penalty, this law caused belt use to increase almost immediately to about 50%. The German law was subsequently amended to include a fine for non-compliance and belt use almost immediately jumped to about 90%, even though there was little enforcement.

In many jurisdictions, surveys of belt use were conducted soon after the laws took effect, but it appears that few of these surveys are continuing today. This is unfortunate because it should not be assumed that passing a law is, by itself, sufficient. In many instances, some levels of enforcement have been necessary to achieve and maintain high levels of belt use. This means that surveys of belt use should be conducted periodically.

In the U.S., the NHTSA annually conducts a National Occupant Protection Use Survey (NOPUS),

Table 2. Seat Belt Laws - Dates first implemented by country.

Country	Year	Country	Year
Australia (Victoria)[1]	1970	United Kingdom	1983
New Zealand	1972	USA (New York) [1]	1984
Singapore	1973	Japan	1985
Spain	1975	Italy	1989
Sweden	1975	European Union[2]	1993
Canada	1976	Argentina	1994
Czech Republic	1976	Thailand	1996
Germany	1976	India	1999
Hungary	1976	Philippines	2000
Netherlands	1976	Egypt	2000
France	1979	China	2003
Ireland	1970	Vietnam	2008
Finland	1982	Indonesia	2009
Hong Kong	1983	Sri Lanka	2011

[1]Other states adopted laws soon after

[2]Directive issued by EU in 1991

Source: https://en.wikipedia.org/wiki/Seat_belt_legislation which provides nationwide probability-based observed data on seat belt use in the United States (Pickrell & Li, 2016). This continuing survey reported that daytime belt use was 60% in 1995, and this rate has steadily increased since that time, with the latest use rate for 2016 being 90%.

Japan also has a continuing survey of belt use and it shows belt use increasing from 80% in 2005 to 95% in 2015.[6]

The evidence available from LMICs suggests that their experience is similar to that of the HICs. Belt use increases only when a comprehensive law is enacted and enforced and studies from LMICs show that it is possible to achieve high belt use rates when there is regular enforcement to ensure use.

The WHO Global status report on road safety includes belt use rates for many countries, but most of the results are not likely to be reliable because there is no way to distinguish between rates that are based on actual observations and those that are consensus estimates of local experts, which are basically guesses. There is no adequate substitute for surveys that observe belt use, and even these have limitations in that they are almost always conducted in daytime. Little is known about belt use at night, however, the few attempts to get night time belt use rates have reported results that are typically lower than during the daytime.

It is important to recognize that not all HICs have achieved high belt use rates. Thus, for example, many European countries have reported high rates of belt use (90% and higher), but Greece has a reported use rate of only 75% for drivers and much lower rates for rear seat passengers.[7]

3.4.4.1 Seat belt laws and belt use in LMICs

The principle that there should not be features at the sides of high speed roads that would be hazardous if struck by vehicles that leave the roadways at speed was established in the late 1960s. Such features include signs with rigid supports, bridge abutments, telephone poles, trees, concrete pillars, etc.

The WHO Global status report on road safety states that "While 161 countries have national seat-belt laws, only 105 countries, representing 4.8 billion people, meet best practice by including rear-seat occupants as well as front-seat occupant. Other countries have seat-belt laws that, while they might apply to all passengers, have exclusions that weaken the law: for example, some countries apply a seat-belt law only on roads where vehicles may be driven at a speed higher than the normal limit, and others require seat-belt use only inside or outside cities" (WHO, 2015). This would suggest that a majority of the LMICs already have laws requiring all cars to be equipped with seat belts and all passengers to use them. However, this may not be entirely correct as the report includes data reported by official country committees without actual checks on the data provided. Further, very few LMICs have time series data on actual belt use based on representative road side observations.

Vecino-Ortiz et al. (2014) observed seat belt use in 2010 in eight major cities in Egypt, Mexico, Russia and Turkey and found that that the rates for drivers in Turkey and Egypt were less than 25% and in the other countries generally less than 55%. For front seat passengers, the rates were less than 32% except in Ivanovo (Russia) where it was 50%.

6 Japan reference, "シートベルト着用状況全国調査 (2015)" (PDF). Japan Automobile Federation and National Police Agency. Retrieved 2016-07-13. Data taken 2015-10.

7 https://www.nrso.ntua.gr/seat-belt-use-rate-greece-2009/

In India, all cars manufactured after March 25, 1994 were equipped with front seat belts and the rule was extended for rear seats in 2002. Belt use by front seat occupants was made mandatory in 2002 but not for the rear seat. Enforcement of traffic regulations done by the states in India and most states did not enforce the laws immediately. In 2002 Delhi, the capital city of India, started enforcing the belt law for front seat occupants. One year before the law took effect and for the first four years the law was in in effect, seat belt use was monitored by roadside observations. Seat belt use rates for front seat occupants increased from 12% before the law, to over 70% (in the daytime) for the first 4 years the law was in effect. In 2014 the daytime rates for drivers, front seat passengers and rear seat passengers were 92%, 76%, and 6% respectively (D. Mohan, 2009, 2016). Anecdotal and newspaper reports suggest that the overall seat belt use in India may be less than 25% for front seat occupants and less than 5% for rear seat occupants.[8]

Seat belt use surveys have been conducted in many LMICs mostly in urban areas in the past five years and most of them find relatively low use rates in the absence of active enforcement by police officials. Roadside driver observations made at 48 sites on intercity roads, main streets, and side streets, in 3 cities in Iran found the average rate to be 58% (Torkamannejad Sabzevari, Khanjani, Molaei Tajkooh, Nabipour, & Sullman, 2016). A study of driver seatbelt use in Enugu, Nigeria by gender, vehicle type/use and time of day showed that average compliance was 38%, for males 85%, females 15%, 75% in the day and 0.3% at night (Agu, Enemuo, Okoye, & Onwuasoigwe, 2017). In 2013 a national survey was conducted for the systematic recording of seat belt use rates among Pakistani drivers and front passengers on 5 different kinds of roads and reported that average seat belt use rates were 20% with the highest on motorways (53%) and the lowest on rural roads (5%), and in the city of Lahore only 8% drivers were wearing a seat belt (Klair & Arfan, 2014). Laws regulating the use of seatbelts by both passengers and drivers were in place in 74% of the Latin American countries by 2012 but an average of 59% of drivers used their seatbelts (Perez & Nazif, 2015).

The evidence available from LMICs suggests that their experience is similar to that of the HICs. Belt use increases only when a comprehensive law is enacted and enforced and studies from LMICs show that it is possible to achieve high belt use rates when there is regular enforcement to ensure use.

4 ENVIRONMENTAL FACTORS - ROADS AND TRAFFIC ENGINEERING

4.1 Roadside hazards on high speed roads

The principle that there should not be features at the sides of high speed roads that would be hazardous if struck by vehicles that leave the roadways at speed was established in the late 1960s. Such features include signs with rigid supports, bridge abutments, telephone poles, trees, concrete pillars, etc.

The high-speed crash into the massive concrete support pillar (Figure 4), could have been prevented if there had been guard rails installed to prevent vehicles that left the roadway from ever reaching the pillar. Haddon pointed out in the late 1960s, that if rigid objects and

Figure 4. High speed crash into a concrete support pillar.

[8] Only 25% of drivers fasten seat belts in India: Study. The Times of India, 5 November 2017, https://timesofindia.indiatimes.com/india/only-25-of-drivers-fasten-seat-belts-in-india-study/articleshow/61513168.cms

structures lined the sides of airport runways there would be outrage, but they can still be found at the sides of many high-speed roads around the world.

Before this awareness, it was not uncommon to have guard rails that guided vehicles directly into bridge abutments, guard rail ends that acted as spears that penetrated occupant compartments, and if a telephone pole was broken or knocked down by a vehicle the replacement would typically be made stronger!

In Holland, where many old towns had narrow streets and little space for the separation of road users, the residents of Delft and the town planner refigured the narrow streets to integrate vehicles and pedestrians.

Modern roads should be built without these kinds of roadside hazards, and there should be systematic programs to eliminate the worst of these hazards on older roads. Where roadside signs are needed they should have “slip” bases that break away when struck. Guard rails should also be used to guide errant vehicles away from potential hazards. Although there was some early resistance to these ideas when they were first introduced in the late 1960s, not long after the U.S. FHWA began to establish standards for this aspect of road design for new roads that used federal funds, and it also required that when federal funds were used to rehabilitate and restore older roads the existing roadside hazards should be eliminated.

The slow speeds were accomplished with humps, staggered and narrow traffic lanes. This was known as the “Woonerf design” and was the first traffic calming initiative.

Figure 5. Section of the tunnel where Princess Diana and two others died in a road crash.

Converting intersections with stop signs or traffic signals to modern roundabouts is associated with substantial reductions in motor vehicle crashes.

Perhaps the most famous fatal roadside hazard fatal crash was in 1997 in a Paris road tunnel which killed Princess Diana and two others. Figure 5 shows the section of the tunnel where the crash took place, the car impacted the 13th pillar head-on at an estimated speed of 105 km/h (65 mph). Despite the high speed of the impact, if there had been guard rails appropriately attached along the pillars or some other feature to redirect errant vehicles, instead of a head-on impact into a rigid pillar there would have been a glancing blow. The crash would probably still have been significant but almost certainly would not have been fatal. A French judicial investigation in 1999 found that the crash was caused by the driver, who lost control of the Mercedes at high speed while impaired by alcohol. As far as I can determine there was little or no recognition of the role played by the poor design of the tunnel, even though the risks these kinds of designs pose to motorists had been identified almost 30 years earlier.

4.2 Traffic calming

Traffic calming is an approach to reduce vehicle speeds in urban areas that was first developed in Holland in the late 1960s (Ewing, 1999; Kjemtrup & Herrstedt, 1992). The numbers of motor vehicles in use in Europe started to grow rapidly in the 1950s and soon this led to traffic congestion and safety issues, especially for pedestrians, in many urban areas that had not been designed for the motor vehicle. The early attempts to solve this problem often involved adding more traffic lanes, and safety issues were addressed by separating fast moving vehicles from pedestrians and other vulnerable road users. This approach, however, although viable for new developments, had only limited applicability in many cities and towns, and protests against new urban traffic arteries began to develop.

In Holland, where many old towns had narrow streets and little space for the separation of road users, the residents of Delft and the town planner refigured the narrow streets to integrate vehicles and pedestrians. This was accomplished by designing local roads as leisure areas with tables, benches, and sand boxes, and leaving space for relatively slow-moving motor vehicles. The slow speeds were accomplished with humps, staggered and narrow traffic lanes. This was known as the "Woonerf design" and was the first traffic calming initiative (Figure 6).

Figure 6. The woonerf, an example of traffic calming.

This idea spread across much of Europe from the mid-1970s, and formal guidelines for this design approach were developed in Holland and officially legalized eight years after the first implementations in Delft. Formal guidelines for traffic calming were also developed in many other European countries. Many studies of this traffic calming approach in Europe have reported significant declines in accidents and injuries (Kiemtrup, K. and Herrstedt, L. 1992).

4.3 Modern roundabouts

Circular road intersections have existed for a long time, for example, the 1907 Place de l'Étoile around the Arc de Triomphe in Paris. However, the operating and entry characteristics of these circles differ considerably from modern roundabouts which are becoming common in many countries. Modern roundabouts began in the UK 1960s when the UK Transport Research Laboratory redesigned circular intersections to improve safety and capacity benefits.

A typical modern roundabout is shown in Figure 7, vehicles entering the roundabout must yield to those already in the circle. The curvature of the circle forces all vehicle to slow down, as a result high speed front-to side crashes are essentially eliminated. The pedestrian crossings are outside of the roundabout so there is only one traffic direction for them to be concerned about.

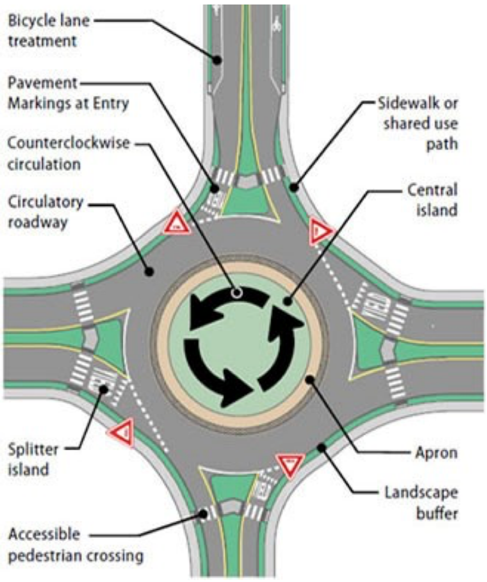

Figure 7. Principles of modern roundabout design.

Converting intersections with stop signs or traffic signals to modern roundabouts is associated with substantial reductions in motor vehicle crashes. A study of the conversion of 181 Dutch intersections with traffic signals or stop signs to modern roundabouts reported that crashes and injuries were reduced by 47% and 71%, respectively, and crashes resulting in more severe injuries (requiring hospital admissions) were reduced by 81% (Schoon & van Minnen, 1994). A study in Victoria, Australia reported a 74% reduction in the rate of crashes involving injuries following conversion of 73 intersections to roundabouts. In the U.S., a study of the conversion of 24 intersections from stop sign and traffic signal control to roundabouts reported reductions of 38% for all crash severities combined and of 76% for all injury crashes (R. A. Retting, Persaud, Garder, & Lord, 2001).

Modern roundabouts also improve traffic flow and are better for the environment. Research shows that traffic flow improves following conversion of traditional intersections to roundabouts. Less idling, which in turn, reduces vehicle emissions and fuel consumption.

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There are a number of roundabout design variations, including mini roundabouts, turbo roundabouts, and “magic” roundabouts, and these are usually used for more complex intersections.[9]

4.4 Automated enforcement

A 2005 Cochrane Injuries Group review of red light camera research identified “five studies in Australia, Singapore and the USA all of which found that use of red-light cameras cut the number of crashes in which there were injuries. In the best conducted of these studies, the reduction was nearly 30%.

Cameras can be used to photograph the license plates of vehicles running red lights or exceeding speed limits and then citations for the law violations are mailed to the vehicle owners. In some jurisdictions, the relevant laws are modified so that vehicle owners can be held legally responsible for offenses identified by cameras regardless of who was driving, these offenses are considered less serious than the same ones identified by traffic police. In other jurisdictions vehicle owners can be required by law to identify the drivers who committed the offenses. These legal changes are needed because, although it is feasible to photograph drivers, it is not done for privacy reasons in many locations.

As with all traffic law enforcement, it is important that motorists are aware that there is enforcement, and this is especially true for camera enforcement, which is not as visible as traditional police enforcement, and so these programs should be publicized to enhance their effectiveness.

As with all traffic law enforcement, it is important that motorists are aware that there is enforcement, and this is especially true for camera enforcement, which is not as visible as traditional police enforcement, and so these programs should be publicized to enhance their effectiveness.

Although automated enforcement has been shown to be effective it is often controversial. This is sometimes due to arrangements between some jurisdictions and the camera system vendors, in which the vendors agree to install and operate the systems in return for a percentage of the revenue from the fines. Since the principal purpose of all traffic law enforcement should be to deter potential offenders, business models that anticipate continuing revenue from violations can become difficult to defend.

[9] https://en.wikipedia.org/wiki/Roundabout

4.4.1 Red light cameras

Red light running is an offense that is especially suited for automatic camera enforcement because it is difficult for traffic police to observe the offenses and then apprehend violators without also running through the red lights. Prior to the implementation of any red-light camera programme it is important that the signal timing settings, in particular the yellow (caution) time, be set according to the appropriate traffic engineering guide lines.

Recent research has estimated that red light camera programs in 79 large U.S. cities saved nearly 1,300 lives through 2014 (Hu & Cicchino, 2017). However, even though surveys have found strong support for red light cameras in the U.S. communities that have them, opposition from a vocal minority has led some jurisdictions to shut off their cameras, and the total number with red light cameras fell to 467 in 2015 from a peak of 533 in 2012. The researchers controlled for various external factors, and concluded that the rates of fatal red light running crashes in 14 cities that terminated cameras programs during 2010-14 were 30% higher after the cameras were turned off than would have been expected had cameras remained.

A 2005 Cochrane Injuries Group review of red light camera research identified "five studies in Australia, Singapore and the USA all of which found that use of red-light cameras cut the number of crashes in which there were injuries. In the best conducted of these studies, the reduction was nearly 30%. More research is needed to determine best practice for red-light camera programmes, including how camera sites are selected, signing policies, publicity programmes and penalties" (Aeron-Thomas & Hess, 2005).

4.4.2 Speed cameras

A 2010 Cochrane review identified 35 studies that met its inclusion criteria and reported that: "Compared with controls, the relative reduction in average speed ranged from 1% to 15% and the reduction in proportion of vehicles speeding ranged from 14% to 65%. In the vicinity of camera sites, the pre/post reductions ranged from 8% to 49% for all crashes and 11% to 44% for fatal and serious injury crashes. Compared with controls, the relative improvement in pre/post injury crash proportions ranged from 8% to 50%." The authors concluded: "Despite the methodological limitations and the variability in degree of signal to noise effect, the consistency of reported reductions in speed and crash outcomes across all studies show that speed cameras are a worthwhile intervention for reducing the number of road traffic injuries and deaths" (Wilson, Willis, Hendrikz, Le Brocque, & Bellamy, 2010).

Despite evidence of their effectiveness speed cameras generate a lot of opposition and on many occasions their proposed use has been defeated by referendum, and some jurisdictions have discontinued their use.[10] In addition, in the UK there are cell phone apps that can alert drivers to the precise locations of the cameras, so that instead of general reductions of speed any reductions may only occur in the immediate vicinities of the cameras.

It has been claimed the roadside electronic signs that display vehicle speeds to warn drivers they are speeding may be as effective at reducing speeds and crashes as cameras, especially where motorists have the ability to identify the exact locations of speed cameras. U.S research has found that mobile roadside speedometers can reduce speeds at the sites of the speedometers, as well as for short distances down the road, and when used in conjunction with police enforcement, the effect of speedometers can last longer (Casey & Lund, 1993). However, whether this can be as effective as speed cameras in reducing crashes is not known.

5 LESSONS FOR LMIC COUNTERMEASURES

What does this mean for LMIC traffic safety countermeasures? First and foremost, all countries should have a broad range of countermeasures aimed at reducing motor vehicle crash injuries and deaths, and they should also have in place data systems which facilitate evaluations of

[10] https://en.wikipedia.org/wiki/Traffic_enforcement_camera

All countries should have a broad range of countermeasures aimed at reducing motor vehicle crash injuries and deaths, and they should also have in place data systems which facilitate evaluations of these programmes.

Figure 8. Mixed traffic in LMICs

Most notable are the different fatality patterns in many LMICs where vulnerable road users -- pedestrians, bicyclists, motorcyclists and motor scooter riders -- account for a much greater proportion of the traffic deaths than in HICs, this means that countermeasure priorities should be different.

these programs. There are, however, some important differences between HICs and LMICs, in particular, many LMICs have much more heterogeneous traffic mixes with proportionately many more vulnerable road users than typical HICs. These different, and often complex, traffic mixes (Figure 8) may make some approaches that have been successful in HICs inappropriate for some LMICs.

Most notable are the different fatality patterns in many LMICs where vulnerable road users -- pedestrians, bicyclists, motorcyclists and motor scooter riders -- account for a much greater proportion of the traffic deaths than in HICs, this means that countermeasure priorities should be different.

5.1 Differences in fatality patterns

The evidence from India suggests that having classes of vehicles with relatively low maximum speeds can result in lower occupant injury rates. This needs further research and if verified should be important for policy making regarding standards for small vehicles restricted to roads with speed limits less than 50 km/h.

In 2015 in the U.S. 64% of the deaths were occupants of passenger vehicles, 15% were pedestrians, and 13% were motorcyclists. In contrast in the same year in India, of occupants cars, vans, and other light motor vehicles accounted for estimated 7% of the deaths, motorized two-wheelers for 34% and pedestrians 33% (D. Mohan, Tiwari, & Bhalla, 2015).

Vietnam is another example, motorcyclists and scooter riders account for more than half of the traffic fatalities. This is a reflection of the fact that these vehicles are the most are common means of transportation. Vietnam has a population of around 92 million people and 45 million registered motorcycles and scooters.[11] In contrast, the U.S. had only 8.4 million registered motorcycles in the same time period. Furthermore, a survey of motorcycle and scooter owners in the U.S reported that they rode an average of only 1,000 miles (1,600 km) per year, and over 80% of the driving was for recreation.[12]

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[11] https://e.vnexpress.net/news/business/vietnam-remains-kingdom-of-motorbikes-as-sales-rev-up-in-2016-3527969.html

[12] https://www.consumerreports.org/cro/news/2010/06/survey-motorcycle-and-scooter-owners-are-very-satisfied-with-their-bikes/index.htm

The four largest motorcycle markets in the world are all in Asia: China, India, Indonesia, and Vietnam.[13] Motorcycle ownership in many African and South American countries is also increasing and as result, fatalities involving motorcycles are increasing (Rodrigues, Villaveces, Sanhueza, & Escamilla-Cejudo, 2014; Vasconcellos, 2013).

5.2 Unique vehicle types

In a number of Asian countries there are also unique vehicle types that do not exist in HICs, for example tuk-tuks in Thailand, jeepneys in Philippines and three-wheeled scooter taxis in India (Figure 9). Obviously, such vehicles are not especially crashworthy, however, these vehicles have low fatality rates for their occupants, and "are probably the most efficient taxi invented for urban areas" (D. Mohan & Bhalla, 2016; Dinesh Mohan, Tiwari, & Mukherjee, 2016).

Figure 9. Three-wheeled scooter taxis in India.

One of the reasons for low fatality rates for such vehicles in India and elsewhere could be that they have low powered engines (usually less than 175 cc) and so they cannot be driven at speeds greater than about 50 km/h and lower when overloaded. The data on the safety of small cars in HICs comes from traffic environments where small cars travel at speeds similar to those of bigger and more powerful cars.

The evidence from India suggests that having classes of vehicles with relatively low maximum speeds can result in lower occupant injury rates. This needs further research and if verified should be important for policy making regarding standards for small vehicles restricted to roads with speed limits less than 50 km/h.

5.3 Countermeasures for LMICs

Even though there are significant and important differences in traffic and some vehicle types between LMICs and HICs, there are no reasons to believe that road user behaviour, and responses to driver education and training will be substantially different. The conclusions from the HICs is that driver education and training do not result in fewer crashes and injuries (and may also have some adverse effects) and the same negative results can be expected in LMICs. HICs wasted 60+ years focusing on efforts to change road user behaviour and they did not work, furthermore campaigns to promote helmet or safety belt use also will not work. Despite the overwhelming evidence that this does not work, there are still advocates for education and training who will try to promote "new" educational programs, such as: advanced training (totally discredited); new safety campaigns; etc. It is important to recognize that such advocates are no better than snake oil salesmen!

Road use behaviour change is important, however, and as in HICs this can be accomplished by traffic laws that are enforced. The high use of motorcycles and scooters in many LMICs, indicates that enacting and enforcing helmet use laws should be a high priority in many LMICs. Importantly there also should be ongoing surveys of helmet use, it should not be sufficient to conduct one or two post law surveys and then declare success, especially since such surveys are relatively easy and inexpensive to conduct. At some point helmet use may become normative behaviour as it has in many HICs and then ongoing surveys may not be required (although in the U.S. helmet law repeals have typically resulted in immediate and significant drops in helmet use).

[13] https://en.wikipedia.org/wiki/Motorcycling

Even though car occupant deaths are proportionately fewer than in HICs, belt use laws should also be enacted and enforced, and as with helmet laws there should be some ongoing surveys of use. The experience from most HICs is that it takes more enforcement (plus associated publicity) over time before high levels of belt use becomes normative behaviour.

When it comes to passenger vehicle countermeasures, LMICs with unique low speed vehicles such as tuk-tuks should be developing appropriate standards (based on the death and injury patterns for such vehicles) so that there are some appropriate minimum levels of safety.

Even though there are significant and important differences in traffic and some vehicle types between LMICs and HICs, there are no reasons to believe that road user behaviour, and responses to driver education and training will be substantially different.

For conventional passenger vehicles, it is tempting to suggest that LMICs should adopt the motor vehicle safety standards of HICs, however, the reality is this could mean settling for safety levels that are far below the state-of-the-art. The principal reason is that government rulemaking is incredibly slow. Thus, for example, it took the authorities in Europe more than 25 years to complete the pedestrian protection rules, and the NHTSA airbag rulemaking spanned almost 20 years. In contrast the various NCAP type programs have been able to accelerate safety improvement significantly beyond the minimum levels specified by government standards, these programs have effectively superseded government rulemaking, today vehicle safety improvements in HICs are occurring much faster than is possible through regulations.

It is not feasible for many LMICs to implement their own NCAP type programs, so what can LMICs do to improve the safety of vehicles in their markets? Since there are NCAP programs all over the world today, LMICs without such programs could try to piggyback on nearby programs by arranging for tests of vehicles being sold in their countries and, when appropriate, highlighting the safety deficiencies identified by the tests.

LMICs should be learning from the experiences of HICs and not waste resources on ineffective educational efforts as HICs did for decades, but instead look at successful countermeasures (as determined by scientific evaluations) and where appropriate apply them, with appropriate modifications for local conditions. And most importantly evaluate them for effectiveness.

Another possibility is to adopt a similar approach to that used by IIHS, which doesn't have the resources to conduct all of its tests on every vehicle model. More than 10 years ago, when virtually every vehicle had good performance in its 64 km/h frontal offset test, IIHS requested manufacturers to self-certify the performance of its vehicles in those tests, while reserving the right to periodically run random check tests. This self-certification testing program has worked very well. Perhaps, it could be possible for governments in LMICs to also initiate similar programs with manufacturers by asking them to self-certify performance in a number of tests, for example, the 64 km/h frontal offset test and pedestrian impact tests, for which they have been routinely getting good ratings for many years. Governments could then publicize these results, including the identification of manufacturers that refuse to provide such information.

Traffic engineering countermeasures may pose the biggest challenges for LMICs because of the much more heterogeneous traffic than in HICs. The very high density low speed traffic in many large cities is in some respects a safety countermeasure, however, governments will try to find ways to speed up traffic and as this happens appropriate safety countermeasures should be applied. Thus, where feasible, modern roundabouts should replace signalized intersections, automated enforcement (in particular speed cameras) should be implemented, and roadside hazards should be eliminated on existing high-speed roads and the design criteria for new high-speed roads should specify no roadside hazards. However, much more research needs to be done to evaluate the effectiveness of road designs for high proportion of vulnerable road users including motorcyclists and for stretches of rural roads and highways passing through highly populated areas.

In closing, LMICs should be learning from the experiences of HICs and not waste resources on ineffective educational efforts as HICs did for decades, but instead look at successful countermeasures (as determined by scientific evaluations) and where appropriate apply them, with appropriate modifications for local conditions. And most importantly evaluate them for effectiveness.

ACKNOWLEDGEMENTS

The authors would like to thank Mark Stevenson and his staff for locating information on early motorcycle laws and driver licensing data from Australian states.

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