



## Crash causes, countermeasures, and safety policy implications

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### ABSTRACT

There are interrelationships between crash causes, countermeasures, and policy implications, but they are not necessarily direct and obvious. Part of the problem is the definition of a cause. The seminal 1979 Indiana University "Study of Accident Causes" has cemented some false assumptions that must be overcome to yield an effective crash countermeasures policy. The taxonomy of crash causes and the prevalence of different causes are determined by the investigators, who are biased in different ways. The prevalent notion that approximately 90 percent of the crashes are due to human errors or failures is due to a threshold bias, and the implied notion that 90 percent of the countermeasures should be directed at changing these behaviors is based on an erroneous assumption that the cure must be directly linked to the stated cause. A more balanced approach to the definition of a cause and to the search for crash countermeasures is needed, and the safe system approach appears to be a most promising one.

Crash cause is similar to beauty: it is in the eye of the beholder. Ask any taxi driver and he or she will have a very definite opinion of the causes (and singular solution) for most crashes. And they can be as numerous as the number of taxi drivers, or other stakeholders (such as driver education teachers, crash reconstructionists, automotive engineers, road planners and designers, and epidemiologists). A shared conviction of all of these sources is that crashes are not random unpredictable events. Unfortunately, this is where the commonality ends. Nonetheless, many if not most of these experts believe that as road users the fault lies mostly in ourselves.

In this short treatise, I demonstrate the link between the cause assessment methodology and the resulting causes of crashes, and the assumptions that underlie the linkage between cause and countermeasure. The last section provides a recommended approach to free us from some misperceptions and false assumptions in order to arrive at better, practically feasible improvements in road safety.

### 1. Crash causation assessment depends on:

#### *Who you ask, and what is 'normal'.*

A crash cause is not something we can see, but something we surmise from what we see. In what is arguably the most extensive in-depth multi-disciplinary study of crash causes, the U.S. NHTSA half a century ago (1969) commissioned a seminal study to analyze crash causes. The study followed Ralph Nader's 1966 best-selling book "Unsafe at Any Speed", in which he faulted Detroit for manufacturing and marketing

cars that are death traps. It was therefore not surprising that the study was headed by a physicist (Kent Joscelyn) and an automotive engineer (John Treat). With the aid of a multi-disciplinary team - consisting of at least one automotive engineer, one crash reconstructionist, and one psychologist - they examined crashes very shortly after they occurred. Although the study (1971) was labeled "A study to Determine the Relationship between Vehicle Defects and Crashes" the team's conclusion was that in most crashes of the three principal components - human operator, vehicle, and environment - the human was the one most responsible for the failure that made the crash inevitable. It was the follow-up study by the same team, "Tri-Level Study of Accident Causes", that established the current consensus that the human is responsible for approximately 90% of all crashes. In this study cause was defined as a "deficiency without which the accident would not have occurred". Other, and more recent studies - using similar definitions - conducted in the U.S. and Europe arrived at similar conclusions [NHTSA (2008) NMVCCS - 'Critical reason' for crash - Human 94%; GIDAS (Otte et al., 2009) - 'Human failure' 97% of crashes; SHRP2 (Dingus et al., 2016) - Human failure 88%].

Unfortunately, there is one critical invalid assumption that these studies share: the assumption of what is 'normal' or expected and what is a deviation that should be considered as a 'failure', an 'error', or a 'fault' that underlie a cause. In the case of the human element, normal is an alert and attentive driver (Treat et al., 1971). This assumed 'normal' is exemplified in an early study of 148 fatal crashes in Oxfordshire County, England. In that study crash data were analyzed twice. The first

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analysis was conducted by the police and was based on the police crash investigations of these crashes. It concluded that 146 crashes (98.6%) involved a "human error". However, a reanalysis of the same crash data conducted by roadway engineers concluded that "ordinary and/or major road defects contributed to 76% of the crashes (Gilutz, 1937). This discrepancy highlights a critical difference between the two analyses: who analyzes the data, and the assumed 'normal' situation. The police investigators, for the most part took the road design and condition as a given, while attributing unrealistic capabilities (to remain alert and attentive to the road and traffic *at all times*) to the drivers. A Plethora of studies – from basic cognitive psychology (e.g., Mackworth, 1968) to driving behavior (e.g., Shinar and Drory, 1983) – have demonstrated that this is nearly impossible. The difference between the two analyses also stems from the different orientation of the police investigators and the highway engineers. The former are tasked with identifying violations of the traffic laws while the latter are tasked with designing a safe road. It is true that at the last moment before the crash only the driver could have reacted to the emerging danger to avert the crash, but if we go back in the chain of events, in terms of weeks, months and years, we can definitely fault the designer of the road or its maintenance crews for many of the crashes. The tendency to focus on events that preceded the crash by a few seconds only is very myopic as has been pointed out by Hauer (2016).

*The tools you have for gathering data: objective case details vs. interviews vs. statistical data*

There are essentially three primary methods for crash causation analyses. 1. Post-crash clinical analysis (i.e., subjective evaluations) by experts in 'relevant areas'. 2. Naturalistic driving studies (NDS) that track and monitor vehicles and drivers as part of their normal driving, and record pre-crash and crash events as they happen. 3. Epidemiological studies that typically rely on a crash and a matched non-crash database and then try to tease out factors that are more prevalent in the crash than in the non-crash database. The three approaches employ different tools and differentially focus on prevalence and over-involvement of various causes as illustrated in Table 1.

When the database consists of crashes only, analyzing the data can only yield the frequencies, or prevalence, of the various factors associated with the crashes, not the risk associated with them. To illustrate, clinical in-depth studies typically identify one form of inattention or another as a frequent crash cause (e.g., inattention due to preoccupation with non-driving-related thoughts, distraction from various sources such as a cell phone). Thus, both the early Indiana University study (Treat et al., 1971) and the more recent GIDAS study (Otte et al., 2009) identified inattention as a fairly common cause of crashes: 48% in the former and 40% in the latter. In both studies, the estimates were based on subjective reports, mostly of the drivers involved. Thus, the strength of that conclusion does not rely on the objectivity of the data, but rather on its replicability across studies conducted by different teams in different countries at different times. In-depth interviews can reveal the relative frequencies of causes that are not directly observable but can be derived from a combination of theory (such as human information processing) and driver reports. These have yielded 'causal' human factors such as inattention, improper lookout, emotional upset, roadway unfamiliarity, false assumptions, etc. But these studies cannot reveal which of the prevalent causes are actually a crash risk factor; i.e, to what, if any, extent they increase the likelihood of a crash. To

determine crash risk we need a control database. A typical one is a study of the occurrence of these factors in the general driving population. In the case of inattention, we then need to show that inattention is more frequent in crashes than in non-crash events. For example, if we stop a random sample of drivers on the road and find out that close to fifty percent of them admit to being inattentive to the road just prior to being stopped, then a 50% occurrence of inattention in the crash sample does not indicate that inattention increases the risk of a crash. As an extreme illustration, in the absence of any theory of the role of attention or any other factor in driving, on the basis of frequency of occurrence in the crash sample alone we could easily conclude that wearing shoes is almost an inevitable crash cause as nearly all drivers wear shoes at the time of the crash.

The second type of an in-depth study of crash causes is the naturalistic driving study (NDS). The most extensive study of this sort is SHRP2 NDS (Dingus et al., 2016). In this study data were collected in six U.S. states from over 3000 drivers who drove and were monitored for a total of approximately one million hours covering a total of approximately 35 million miles, that yielded approximately 1000 crashes of which 250 were of police-reportable severity (Njord and Steudle, 2015). The data from this study was richer in some respects from the traditional information available to investigators in post-crash analysis, but in other respects it was lacking. In the SHRP NDS study, the last few seconds that preceded a crash were documented objectively by recorders and vehicle-mounted cameras. This enabled the researchers to actually observe where the driver was looking, what the driver and car were doing, and what the immediate roadway and traffic looked like just prior to the crash. In the previous studies, most notably the Indiana University study, this information had to be deduced from post-crash interviews with the drivers and passengers, and crash reconstructions based on roadway markings and post-crash vehicle condition. This resulted in some very significant differences between the two studies. A prime example, is the prevalence of inattentive or distracted driving. With NDS, one can actually observe whether the driver was looking at the road ahead or not. On the other hand, the SHRP NDS does not include manual in-depth investigations of the driver(s), vehicle, and environment and thus misses some issues, especially the non-observable factors such as fatigue and inattention (i.e., even when the eyes are fixated on the road the driver may be inattentive to it, as in talking on the phone) – key crash causes in most retrospective crash cause studies. For example, the NDS does not consider a fairly common phenomenon as "looked but did not see" where the fixation is directed at the road ahead but the driver's attention is directed elsewhere, such as to other thoughts (often labeled cognitive distraction). Another example is DWI. Alcohol impairment is, among others, manifest in a significant reduction of saccadic eye movements to important sources of information that may not be directly ahead of the driver, such as children on the sidewalk, and crossing or merging vehicles. In such cases NDS data would not reveal any inattention or distraction. On the other hand, in the SHRP2 NDS all glances away from the road (as deduced from the video of the driver's face) are considered distraction, even safe behaviors such as checking the mirrors for other cars. Thus, a crash cause may share the same label, e.g., inattention, but the operational definitions that underlie this concept may differ significantly and consequently so will the involvement of this cause in crashes.

But the NDS does have a very significant advantage over the

**Table 1**  
Principal approaches to crash cause analyses and their outcome measures.

Outcome Measures	Type of Study		
	In-depth crash analyses	Naturalistic Driving Studies	Epidemiological studies
Prevalence (frequencies)	V	V	
Over-involvement (OR or RR)		V	V

traditional post-hoc in-depth investigation of crashes. It also collects data on non-crash driving events by the same drivers. By comparing the frequency of occurrence of a particular cause in the crash data to its frequency of occurrence in the control data of the same drivers (e.g., short driving periods under similar conditions) this type of study can yield information on both the prevalence of various crash causes, and on the risk involved in these factors. The risk is typically stated in terms of odds ratios (ORs) and relative risks (RRs) (for a discussion of the difference see [Shinar, 2017, pp. 78–79](#); [Schechtman, 2002](#)). Thus, the SHRP2 NDS findings ([Dingus et al., 2016](#)) demonstrate that although "sudden or improper braking/stopping" constitutes a huge crash risk (with an average OR = 247.8), its prevalence in the control sample of driving segments is only 0.01% (one hundredth of one percent). This is consistent with most drivers' experience that sudden braking in the normal course of driving is quite rare, but just before an impending crash it is quite likely. On the other hand, "observable distraction" (noted whenever the driver glanced away from the road ahead) was quite frequent in both the crash sample of events (accounting for 68% of the crashes) and the non-crash situations (52%), yielding only a small crash risk (with an average OR = 2.0).

The third type of studies, the epidemiological studies, typically focus on preselected factors that are already hypothesized to be both risky and prevalent in the study population (such as young drivers), on the basis of observational and questionnaire surveys, public media, and police reports, or even a researcher's intuition. Epidemiological studies then test whether or not these factors are over-involved in crashes, and consequently whether or not they constitute a significant crash risk. This approach is or can be nearly theory-free in the sense that the investigator does not pursue a cause-and-effect approach, but only considers the over-involvement of some situations in crashes relative to the traffic in general. The validity of the claim for a cause-and-effect relationship then depends on the care taken in the collection of the crash and control data. Consider, for example, the epidemiological approach to the study of driving under the influence of drugs and alcohol, and driving while distracted by the cell phone. The 'acid test' for both issues came from epidemiological studies. The role of alcohol in crashes was most convincingly first demonstrated by [Borkenstein \(1964\)](#) who showed that significant amounts of alcohol were much more common in crash involved drivers than in non-crash involved drivers. Half a century later, after controlling for some confounding factors in Borkenstein's study, [Blomberg et al. \(2009\)](#) found a similar relationship between blood alcohol level and the likelihood of crash involvement, and further demonstrated that the crash risk of alcohol was even greater than thought before.

The risk of using a cell phone while driving was quantified by [Redelmeier and Tibshirani \(1997\)](#) in Canada and by [McEvoy et al. \(2005\)](#) in Australia. Both teams found that using the cell phone increased the risk of a crash fourfold over driving by the same drivers at the same time-of-day while not using the phone. Incidentally, both studies found that the effect was essentially the same with hand-held phones and with hands-free phones, and for men and women. Nonetheless, since then the effects of talking on the phone while driving - have been hotly debated using both epidemiological investigations ([Young, 2013](#)) and NDS. Estimates of the crash risk have been as high as twenty fold for texting, and as low as nil for conversing ([Kidd and McCartt, 2015](#); [Young, 2013](#)), and anywhere in-between depending mostly on the control sample used for the baseline (e.g., [Elvik, 2011](#); [Shinar, 2017, pp 752–757](#)). Epidemiological examinations have not been limited to 'human' causes of crashes and have included environmental factors, such as billboards ([Gitelman et al., 2014](#)) and various vehicle defects ([Elvik et al., 2009](#)).

An interesting example is provided by an epidemiological study that assessed the relationship between car color and its crash involvement ([Furness et al., 2003](#)). In this study the authors found that white cars were involved in more crashes than cars of any other color. To assess the crash risk of white cars they then divided the frequency of their

crashes by their frequency in traffic. This revealed that white cars are not at high risk at all (with an odds ratio = 1). After controlling for additional factors they found that the only color that is associated with a slightly significant above-average crash risk was brown (OR = 2.0). While this study can serve as a good illustration of the epidemiological approach to crash causation, it also leaves us guessing why are brown cars over-involved? Is it because of the drivers who pick that color? The poor nighttime conspicuity of these cars? Or is it just an artifact of statistical error? Thus, without a strong theoretical foundation, high crash risk in an epidemiological study may still leave us guessing as to the cause of these crashes.

*The crash data source: police accident reports (PARs) versus other sources.*

The ubiquitous source of crash data in most countries are the police accident reports (PARs). But there are other sources that researchers use, such as insurance companies' claim files, registries of trauma centers, and independent crash investigation teams. It is important to stress, that except for data from independent (relatively) objective crash investigation teams, all other sources are created for reasons other than finding the prevalence of various causes. For example, police reports are designed to primarily assess who is at fault, i.e., who - if anyone - violated a legal requirement. Insurance records are designed primarily to assess both who is at fault and what is the true nature of the damages. Trauma centers data are excellent at detailing the nature and severity of the injured participants, but not at documenting the crash details, including the possible cause. In addition, pooling of such data from different jurisdictions and countries raises significant issues of compatibility in the data collection methods and definitions. The definition of a crash differs among the different agencies. Police typically have a vehicle damage or injury threshold for PARs, the crash has to be on a public road, and often a motor-vehicle has to be involved. These differences in causality assessment have very significant and practical implications for assessing the prevalence, risk, and counter-measures as discussed below.

One practical implication of these differences is the assessment of cause for different vehicle types. Of particular growing interest are bicycle crashes, which unfortunately are significantly under-reported by the police relative to hospital records ([Schepers et al., 2015](#)), and even those are under-reported relative to self-reports by bicyclists ([Shinar et al., 2018](#)). Another example is rear-end crashes. These are quite frequent among all crashes. (approximately 25–30%), but because they are often mostly minor damage/minor injury or property damage only many of them are not reported in the police data and statistics. For example, in the U.S. in 2015 they constituted 33.4 percent of all injury and property-damage crashes, but only 6.8 percent of all fatal crashes ([NHTSA, 2017](#)). Therefore, in PARs their prevalence and societal cost is significantly underestimated and the cost-benefit analysis of counter-measures to prevent them is quite erroneous. Thus, when the effectiveness of the Center High-Mounted Stop Lamp (CHMSL) had to be evaluated a special database that included minor rear-end crashes had to be created. It showed that the novel CHMSL reduced the relative risk by approximately 50% and even after several years of exposure involving the requirement that all new cars have one, the expected smaller risk reduction was still cost-effective ([Kahane and Hertz, 1998](#)).

*The orientation: focus on 'why' vs. prevention*

One might presume that the only purpose of crash causation analysis is to find crash countermeasures, as would be implied by the medical model (see below). Yet, this is not necessarily the case. Police analyses of the cause of a crash, and in-depth multi-disciplinary clinical analyses, such as the Indiana University ([Treat et al., 1971](#)) and SHRP2 studies (e.g., [Dingus et al., 2016](#)) do not define causes in terms of potential countermeasures, but in terms of conditions and behaviors that immediately preceded the crash and made it inevitable. In fact, most causation studies end with just these conclusions, and not with quantified estimates of the number of crashes that would be prevented by different countermeasures (these are treated in studies of Crash

Modification Factors, or in NHTSA's Countermeasures that Work; Goodwin et al., 2015). For example, commonly cited human causes of crashes such as "inattention" fall quite short of giving us insights into countermeasures. Even objectively determined operationally defined causes such as "failure to obey a STOP sign" do not provide insights into the relevant countermeasures. These could range from making STOP signs more conspicuous or predictable, changing the road geometry, to eliminating sources of distraction, and reducing risky driving. When the prevalence of the behavior is high, it warrants a search for and analyses of the location-specific or driver population specific countermeasures.

If we start from the countermeasure rather than the cause the approach is different. For example, the design-based countermeasures of grooved edge lines or center-lines are not specific to a singular crash cause. The grooved pavement mitigates the tendency to drift off the road or into the opposite lane. This in turn may be caused by different factors such as driver fatigue, distraction, poor wheel alignment, uneven air pressure in the tires, or a poorly designed crown or relative super elevation of the road. Thus, for example, the grooves do not mitigate fatigue or compensate for poor alignment, *but* they are a good environmental treatment to temporarily and momentarily alert a fatigued or sleepy or distracted driver from committing one of the many possible errors; i.e., going off the road or into the opposite lane (Merat and Jamson, 2013). Simply collating many instances of crashes where the cause was labeled "distraction" would most likely not lead to this countermeasure.

To study the potential benefits of various preventions we need to empirically evaluate individual treatments, using methodologically robust study designs, as in quasi-experimental before-after studies (Hauer, 1997). The Causation studies, at best provide the theoretical basis for hypothesizing the effectiveness of potential countermeasures, or for accounting for their effectiveness in retrospect. In contrast, Crash Modification Factors (CMFs) that provide estimates of effectiveness for various countermeasures do not necessarily rely on a strong theoretical foundation and should be regarded as random variables with associated variance and not as constants applicable to all locations and situations (Hauer et al., 2012). As such, they should be treated with caution, because the pooling of different studies conducted at different times, different environments, with slightly different definitions of the independent and/or dependent variables, may yield conflicting or puzzling results. For example, as an extreme example, the benefit/cost estimate for "Traffic surveillance and control system for an urban freeway in Israel" yielded two estimates from two sites with similar geometry along the same road of 1.7 and 6.3; EC, 2003). Only personal and intimate familiarity with the characteristics of the two segments could account of this difference: the higher effectiveness was for the digital sign that preceded several interchanges that allowed the drivers to modify their route, while the one with the lower effectiveness appeared only after the driver was essentially committed to that route. As most readers cannot have all the relevant information for the different results obtained for a given CMF, the larger the sample the more reliable the meta analysis.

## 2. Prevalence versus risk

For years drinking and driving went hand-in-hand, and occasional DWI charges were often dismissed by judges or juries who often identified with the defendant as a 'normative' social drinker, accustomed to driving after a few drinks. All this changed after a succession of three transformative events. Borkenstein published in 1964 the first extensive epidemiological study that demonstrated that the crash risk increases exponentially with the blood alcohol concentration (BAC) level. The newly established U.S. National Highway Traffic Safety Administration began to focus on the issue and promote impaired driving laws. Two very effective anti-drinking and driving grass roots movements were founded: Mothers Against Drunk Driving (1980) and Students Against Driving Drunk (1981). More recent research confirmed the strong

relationship between BAC and the risk of fatal crashes, and better controlled studies indicated that the rate of increase was even higher (Blomberg et al., 2009; Compton and Berning, 2016).

However, as a public safety issue an elevated risk – in terms of relative risk or odds ratio (see Schechtman, 2002) - is a necessary but not a sufficient criterion. Prevalence is also important. Prevalence is a measure of the frequency of a phenomenon in either the at-risk population or the normal driving population. The ratio or relative ratio between the two is the measure of risk. In the case of DWI, both its prevalence in the crash population and its risk are very high (NHTSA, 2017).

Unfortunately, both researchers and laymen often sound the alarm to address a specific behavior even when one of the two criteria is missing. A case in point mentioned above is the crash risk of talking on the phone while driving. Two highly publicized articles, (Redelmeier and Tibshirani, 1997; McEvoy et al., 2005), that looked at the risk of talking on the phone while driving obtained remarkably similar results. Talking on the phone while driving increased the risk of a crash (both property damage and injury crashes) by a factor of 4; for both men and women, and regardless of whether it was hand-held or hands-free. At about the same time an early and much publicized naturalistic driving study involving 100 cars concluded that cell-phone distraction was a major risk factor in all crashes accounting for approximately 25 percent of the 69 crashes documented in the study (Neale et al., 2005).

As the use of cellphone while driving increased over the past 15 years, especially for texting, so did the research on its potential harm. Two patterns emerged over time: talking on the cellphone while driving increased for all age groups and texting and other operations increased most rapidly among the most at-risk: young drivers. During the same period research methods that allowed the separate analyses of the effects of the various tasks involved in talking on the phone (mostly NDS with online monitoring cameras), showed that the process of talking and listening – the most common and time-consuming phone task - did not significantly increase the crash risk. However, the relatively short manual and visual processes involved in dialing/picking up/putting down the phone greatly increased crash risk. In addition, several studies showed that drivers tend to engage in this high risk visually distracting process mostly while standing in traffic. Ignoring these differences in risk, location of the activities, and task duration, may account for the very low U.S. national estimate of the prevalence of phone-related traffic fatalities (approximately 1% of all fatalities according to the NHTSA, 2016). The danger in relying on this estimate is that people may ignore the real risk of injury while engaged in high risk activities such as texting while driving in traffic.

In short, to be of significant public safety sequence, a behavior/factor must be both prevalent in the driving population and significantly more prevalent in the accident or injury population; i.e., be high-risk. When the prevalence of a factor in the driving population is very low, such as driving under the influence of heroin (Shinar, 2017), the safety issue is quite marginal, no matter how high the risk.

## 3. Need for norms for normal and criteria for deviations from the norm

In creating a taxonomy of crash causing factors, we must agree on what is a 'normal', 'expected', or 'safe' behavior or situation. Only then we can define a deviation that can be considered 'crash-causing'. Interestingly, there is often no agreement among researchers in defining what is a "normal" or "expected" behavior. Consequently, without an agreement of the 'normal' situations it is hard to define deviations from it. For example, once we agree on what is required to be an attentive driver, we can agree on what is inattention or distraction. However, while most studies that have investigated inattention are careful to define it, they do not to define attention. If using the cell phone is tested for its distraction, what is the baseline for distraction? Just driving and doing nothing else? Driving while listening to a passenger or the radio?

Driving while thinking about other matters? This is in contrast to simpler observable concepts such as good and bad tires, proper and improper speed, and sober versus an alcohol-impaired driver. In these cases both the "normal/expected" and the deviate are defined operationally in terms of above or below a certain depth of tread, legal speed limit, and maximal allowed blood alcohol level, respectively. Furthermore, when the same – typically unobservable – term, such as inattention, is given different operational definitions, we have a quandary: is it limited to observable glances away from the road (as in the SHRP2 NDS) or does it include "looking but not seeing" (as in the Treat et al. study)? Thus, we get confusing and inconsistent results that are hard to reconcile. Mathematical procedures, such as meta-analysis, typically make a noble attempt to combine results only of similar studies: similar in method, measures of performance, and if possible context variables (Elvik et al., 2009). Yet, behind the obtained averages there is always a variance: explicit variance in the Odds Ratio (in terms of confidence interval) and implicit variance in subtle or glossed over differences in the study designs and in definitions of the independent and dependent measures. Prime examples are speeding and driving while impaired by alcohol. The relationships between these variables and crash risk are typically presented as tables or smoothed curves that mask the large variance due to individual differences and context variables. In the case of speed, some measures of speed variability are just as or possibly more important than the mean speeds (Lave, 1985; Rodriguez, 1990). In the case of impaired driving, most studies that summarize their findings in smoothed curves relating the risk of injury or fatality to BAC (Compton and Berning, 2015; Keall et al., 2004), rarely acknowledge the significant individual differences in the rates of alcohol absorption and elimination (Christoforou et al., 2013). Furthermore, both speed and alcohol are non-linearly related to crash and injury risk, with the impact of speed and alcohol accelerating with linearly increasing levels of the two factors.

At the highest level of analysis, multiple studies have pointed to the overwhelming role of the human in crash causation. Indeed, it is hard to find vehicle components who failed and made the crash inevitable, and most roads do not sprout potholes and obstacles in the middle of the lane just before the crash. And so, the flexible human is the only actor who is often faulted for failing to perceive the imminent danger, failing to take a proper evasive action, or failing to properly execute a correct evasive action.

Our failure to cite environmental and vehicular factors as crash causes is not because they are not there, but because our definition of these causes is very restrictive, while our definition of the baseline or normal is very inclusive. For example, in the case of road geometry and markings we accept the 'current practices' or current design as a standard to which the driver should accommodate himself/herself, without considering how a better possible design would have prevented the crash. For example, it has been shown quite consistently that traffic circles reduce crashes when they replace signal- or sign-controlled intersections (Elvik, 2003; Persaud et al., 2001). Yet, I am not familiar with any study that cited a signalized or sign-controlled intersection for the absence of a roundabout as being the cause of an intersection-related accident. Similarly, functioning drum brakes are not cited as a crash cause when long braking distance or skidding is involved even though presently available disc brakes or ESP could have prevented the crash. In both cases we accept the existing inferior design – of the road or the car – as a given, but we do not accept commonly acknowledged human limitations, such as the well-documented inability to maintain high level of vigilance for more than 30 min. Attention is effortful (Kahneman, 1973). Just attending to all signs is extremely fatiguing (Summala and Näätänen (1974), and therefore it is unreasonable to expect drivers to attend to all of them and all of the immediate traffic all the time. Yet missing a sign is most often cited as a human crash cause.

#### 4. Link between cause and countermeasure

When viewed as a public health issue it is tempting to adopt the medical model to find a cure for this 'disease'. According to this model to provide a 'cure' we need to (1) find the 'cause' (e.g., germ), and then (2) find a way to either kill it (the germ) or eliminate its breeding ground. Thus, in this model there is a direct link between the cause and the cure or countermeasure. The countermeasure can be found if and only if we identify the cause first. This approach has worked very well for medical epidemics such as typhoid, polio, and AIDS.

Unfortunately, this model cannot be so easily applied to crash causes. Faulting the road user's behavior does not imply that we can either stop this behavior (kill the source) or eliminate it by changing the context (eliminate the road). These are definitely not the best approaches to crash prevention. Human causes can often be best eliminated through vehicle and/or environmental changes. In the absence of vehicle and roadway modifications, attempts to directly force drivers and pedestrians to change their behaviors involve enforcement: a Sisyphean, expensive, never-ending, cat-and-mouse game. A more fruitful solution is to use the cause or causes as clues to environmental or vehicular changes that would eliminate this 'cause' and in effect 'kill its breeding ground'. Thus, the impetus to greater safety is not necessarily to identify the underlying (human) cause (e.g., fatigue) but to focus on the descriptive situation that preceded the crash and then try to change the complete context. This, in fact, is also the epidemiological approach to some life-style based chronic diseases such as obesity, where contextual changes such as eliminating sweetened drinks at schools, and eliminating very large cups in fast-food restaurants may be more effective than pursuing direct behavior modification. In the road safety domain, significant progress in this area has been made through the multiple evaluations of environmental modifications often labeled Crash Modification Factors (CMFs) (Carter et al., 2012). Still, one must be careful in the interpretation and generalization of CMFs across different cultures, times, and locations (Hauer et al., 2012). CMFs can be effective means of reducing crashes stemming from several causes, or even from unknown causes, but they are limited to measures that have already been implemented and evaluated, and cannot be applied to new untried measures. Thus, post-hoc identification of crash causes, especially the 'human' ones, can be used to generate ideas for countermeasures that would make these behaviors impractical or even impossible. For example, rather than asking motorists (through public information and education campaigns, and road signs) or threatening motorists (through enforcement) to reduce their speed on streets with high pedestrian volume, the Dutch have developed Woonerf: a living street with traffic calming features that make driving at high speed essentially impossible. These include narrow streets, bumps, and sharp turns (Ben-Joseph, 1995) as well as "share the road" signs at their entrance. Another example is the use of milled median and/or edge lines that provide audio-tactile (jarring) feedback to drivers whenever they cross these lines. Though experimental evidence is still equivocal about their safety benefits (Hatfield et al., 2009; Wu et al., 2018), they seem to be quite effective in waking up drivers who fall asleep at the wheel and drift across the shoulders or median (Phillips et al., 2010). They are probably much more effective than warnings against distractions and fatigue that typically lead to lane deviations. Similarly, in the vehicular domain advanced driver assistance systems (ADAS) such as auto-stop and automated driving can prevent many distraction related collisions (Inman et al., 2016; Noy et al., 2018).

Linking countermeasures to crash cause is also prone to different biases by different stake-holders (e.g., the example of the Oxfordshire crash analysis, above). To illustrate, with the highest rate of guns per inhabitants, the U.S. leads the western world and OECD countries in gunshot homicides (12 per 100,000 inhabitants. Wikipedia, 2018). Yet the countermeasures proposed by the gun lobby (people kill therefore they should be trained) and the safety community (guns kill and therefore they should be banned) are worlds apart. In the realm of

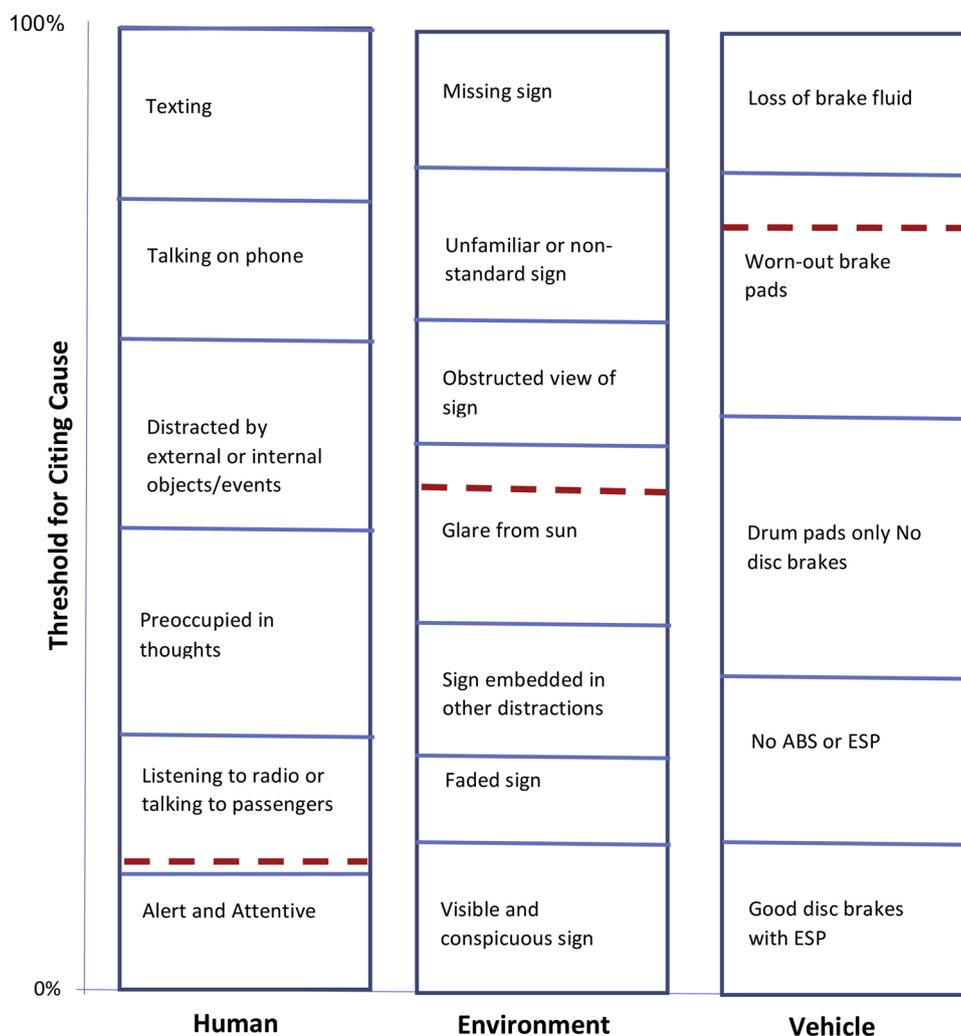


Fig. 1. Hypothetical thresholds for different 'causes' that may be associated with failure to stop in time at a STOP sign. (Note: the Percent cited is inversely related to the threshold that is noted by the dashed line).

traffic safety, although the Indiana University study defined a cause as one that "in its absence the accident would have been prevented", the study team members were highly biased in their definition of the "acceptable" human, environment, and vehicle standards for "normal" and "appropriate" versus deficient/causal. The threshold was very low for the human errors – meaning intolerant of errors even when they could be expected as a part of 'normal' behavior. For example, expecting the driver to be attentive and alert at all times, contrary to the literature that notes that sustained attention is effortful (Kahneman, 1973) and in a long drive it is quite fatiguing (Summala and Näätänen, 1974). In contrast, the thresholds were very high for the environment and the vehicle – meaning tolerant of vehicle and roadway design deficiencies even if research had identified technologically feasible better designs. For example, accepting drum brakes as a standard even though disc brakes were already introduced in mass production in 1955 (American Motors) and 1965 (Ford and GM) and were quite common by the mid-seventies. This is schematically illustrated by the hypothetical levels presented in Fig. 1 below.

In summary, the prevalence of various causes changes as a function of the thresholds we adopt for normal and faulty. In addition, the lower the threshold in each domain, the more causes can be listed for a crash. Similarly, causes can be treated and eliminated by multiple countermeasures; not necessarily ones that are directly derived from them. Consequently, a given crash can be described in terms of both multiple causes and multiple countermeasures, with some of the causes linked to

several countermeasures and some countermeasures linked to several causes. With so many options for defining a crash and its prevention, how do we choose? This is where external factors enter to yield policy implications.

### 5. Safety policy implications

Like any good policy, a sensible safety policy would be one that would both minimize costs of crash countermeasures and maximize their value (in terms of lives saved, injuries reduced, and property damage reduced), within some constraints such as accessible mobility. As such, there is probably no universal optimal policy, as the costs, the values, and the constraints can vary greatly among cultures and countries. Policy cost can be calculated in terms of cash or less tangible measure such as inconvenience and time loss. Values can be measured by simple means such as fatalities and injuries reduced, or more sophisticated measures of savings in Quality Adjusted Life Years (QALYs). Value is also related to national policies on sustainable mobility and healthy living (e.g., to promote healthy modes of transport such as bicycling and walking, or to facilitate motor-vehicle traffic societal expectations from the government and the user population), and these tend to vary across countries.

Given the interrelatedness of the different issues, the safe system approach seems to be an appropriate one. Its unifying principle is that safety can be improved only if all of the traffic system components

(vehicles, road users, and infrastructure) and stake-holders (users, government, manufacturers, planners) are considered simultaneously. This approach also assumes that traffic safety – like basic health, security, and education – is the ultimate responsibility of the government. Furthermore, the government should acknowledge human failures by ensuring that when they occur their injury consequences are minimized. This approach has been embraced by the European Commission in its most recent 2018 10-year plan which includes strategies for vehicle safety standards, infrastructure safety, and even automated driving safety. For example, infrastructure should be consistent with the speed limits that should be set according to the functional road use, such as 30 kph in built-up areas and roads shared with vulnerable road users, 70 kph in rural roads without a median barrier, etc. (ITF, 2018). In short, though the safe system approach includes strategies for behavior modifications "the buck stops" with the regulators and not with the users.

In accordance with these assumptions, the two often cited applications of the safe system approach are considerate of all the system components, but put most of the responsibility for the safety of the road users on the government, and consequently focus on government controlled countermeasures, especially the infrastructure, with vehicle regulations and road user education taking a secondary role. The two approaches, Sweden's Vision Zero (Fahlquist, 2006; Johansson, 2009; Larsson et al., 2010) and The Netherlands' Sustainable Safety (Wegman and Aarts, 2006; Wegman et al., 2012; Weijermars and Wegman, 2011) both emphasize infrastructure-based solutions. Putting the responsibility on the road user is then a solution of last resort – as in the case of creating and enforcing laws against DWI, and requiring installation of alcohol ignition interlock systems on repeat DWI offenders. Albeit, this approach is an expensive one; certainly more expensive than passing restrictive traffic regulations and heavy fines for their violations. However, in the long run it is more efficient as infrastructure modifications apply at once to all road users in that location, whereas changing driver behavior relies on repeated expenditures to sustain the desired effect. Similarly, for the same reasons, regulating vehicles can be more cost-effective as it applies at once to all vehicles at all locations. The safety record of the few countries that champion the safe systems approach is a testimonial to its effectiveness (ITF, 2018). Furthermore, it is likely that government intervention in vehicle safety systems will only increase following the rapid integration of 'smart' safety systems such as auto braking, blind spot vehicle detection, rear view cameras, and lane position control, just as governments currently require electronic stability control.

In brief, the safety system approach is a counter-measure oriented approach to crash causation. Though the prevalence and risk related to human causes are still useful starting points, the orientation is to consider the countermeasures that would be most effective in eliminating these causes, and not necessarily the ones that would deter and punish these behaviors. The International Transport Forum summarized it most succinctly by highlighting these central principles of the safe system approach: "First, people make mistakes that can lead to road crashes. Second, the human body has a known, limited physical ability to tolerate crash forces before harm occurs. Third, while individuals have a responsibility to act with care and within traffic laws, a shared responsibility exists with those who design, build, manage and use roads and vehicles to prevent crashes resulting in serious injury or death and to provide post-crash care. Fourth, all parts of the system must be strengthened in combination to multiply their effects, and road users are still protected if one part fails ... (Furthermore) there is no single way for the adoption, establishment, and implementation of a Safe System .... The experiences of the pioneering countries show that each follows its own journey, shaped by the cultural, temporal and local context, but guided by the four underlying principles" (ITF, 2016, p. 12).

To be effectively utilized, the safe system approach to road safety must be spearheaded by the regulator/government, with the

commitment to spend the necessary funds to implement it. This means that policy must be (1) intimately linked to scientifically proven countermeasures, that (2) it can be linked to empirically determined crash causes (based on both prevalence and risk), and that (3) it must be followed by valid evaluation studies. Though this appears to be an intuitively obvious conclusion, it is not yet commonly practiced in many countries.

## References

- Ben-Joseph, E., 1995. Changing the residential street scene: Adapting the shared street (woonerf) concept to the suburban environment. *J. Am. Plan. Assoc.* 61 (4), 504–515.
- Blomberg, R.D., Peck, R.C., Moskowitz, H., Burns, M., Fiorentino, D., 2009. The long Beach/Fort Lauderdale relative risk study. *J. Safety Res.* 40 (4), 285–292.
- Borkenstein, R.F., 1964. The Role of the Drinking Driver in Traffic Accidents. Indiana University, Bloomington Indiana.
- Carter, D., Srinivasan, R., Gross, F., Council, F., 2012. Recommended protocols for developing crash modification factors. Final Report NCHRP. pp. 20–27.
- Christoforou, Z., Karlaftis, M.G., Yannis, G., 2013. Reaction times of young alcohol-impaired drivers. *Accid. Anal. Prev.* 61, 54–62.
- Compton, R.P., Berning, A., 2015. Drug and alcohol crash risk. *J. Drug Addict. Educ. Erad.* 11 (1), 29–46.
- Dingus, T.A., Guo, F., Lee, S.E., Antin, J., Perez, M., Buchanan-King, M., Hankey, J., 2016. Driver crash risk factors and prevalence evaluation using naturalistic driving data. *Proc. National Acad. Sci.* <https://doi.org/10.1073/pnas.1513271113>.
- EC, 2003. R0ad Safety and Environmental Benefit-cost and Cost-effectiveness Analyses for Use in Decision-making (ROSEBUD). European Commission Contract GTC2/2000/33020. Thematic Network Funded by the European Commission, Directorate General for Energy and Transport. EU 5th Framework Programme. Brussels, Belgium.
- Elvik, R., 2003. Effects on road safety of converting intersections to roundabouts: review of evidence from non-US studies. *Trans. Res. Rec.: J. Trans. Res. Board* (1847), 1–10.
- Elvik, R., 2011. Effects of mobile phone use on accident risk: problems of meta-analysis when studies are few and bad. *Trans. Res. Rec.: J. Trans. Res. Board* (2236), 20–26.
- Elvik, R., Vaa, T., Høy, A., Sørensen, M., 2009. The Handbook of Road Safety Measures. Emerald Group Publishing.
- Fahlquist, J.N., 2006. Responsibility ascriptions and vision zero. *Accid. Anal. Prev.* 38, 1113–1118.
- Furness, S., Connor, J., Robinson, E., Norton, R., Ameratunga, S., Jackson, R., 2003. Car colour and risk of car crash injury: Population based case control study. *Br. Med. J.* 327 (7429), 1455–1456 Health Module.
- Gilutz, M.S., 1937. An Investigation and Report on Four Years' Fatal Accidents in Oxfordshire. The Vincent Works, Oxford, England.
- Gitelman, V., Zaidel, D., Duba, E., Zilberstein, R., 2014. The effects of advertising signs on crashes in Ayalon Highway: Comparisons between three periods: with, without, and again with signs. Final Report to Israel's National Road Safety Authority. Jerusalem, Israel. (in Hebrew).
- Goodwin, A., Thomas, L., Kirley, B., Hall, W., O'Brien, N., Hill, K., 2015. Countermeasures that work: A Highway Safety countermeasures guide for State Highway Safety Offices. NHTSA Report No. DOT HS 812 202, 8th edition. U.S. Department of Transportation, Washington, DC.
- Hatfield, J., Murphy, S., Job, R.S., Du, W., 2009. The effectiveness of audio-tactile lane-marking in reducing various types of crash: a review of evidence, template for evaluation, and preliminary findings from Australia. *Accid. Anal. Prev.* 41 (3), 365–379.
- Hauer, E., 1997. Observational before/after Studies in Road Safety. Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety. Pergamon Press, Oxford, UK.
- Hauer, E., 2016. An exemplum and its road safety morals. *Accid. Anal. Prev.* 94, 168–179.
- Hauer, E., Bonneson, J., Council, F., Srinivasan, R., Zegeer, C., 2012. Crash modification factors: foundational issues. *Trans. Res. Rec.: J. Trans. Res. Board* (2279), 67–74.
- Inman, V.W., Jackson, S., Phillips, B.H., 2016. Driver performance in a cooperative adaptive cruise control string. Proceedings of the Human Factors and Ergonomics Society Annual Meeting Vol. 60, 1184–1188 No. 1.
- ITF, 2016. Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System. OECD Publishing. Paris. <https://doi.org/10.1787/9789282108055-en>.
- ITF (International Transport Forum), 2018. Road Safety Annual Report 2018, OECD. [https://www.itf-oecd.org/sites/default/files/docs/irtad-road-safety-annual-report-2018\\_0.pdf](https://www.itf-oecd.org/sites/default/files/docs/irtad-road-safety-annual-report-2018_0.pdf).
- Johansson, R., 2009. Vision Zero. Implementing a policy for traffic safety. *Safety Sci.* 47 (6), 826–831.
- Kahane, C.J., Hertz, E., 1998. The Long-term Effectiveness of the Center High Mounted Stop Lamp in Passenger Cars and Light Trucks. NHTSA Technical Report No. DOT HS 808 696. U.S. Department of Transportation, Washington, DC.
- Kahneman, D., 1973. Attention and Effort Vol. 1063 Prentice-Hall, Englewood Cliffs, NJ.
- Keall, M.D., Frith, W.J., Patterson, T.L., 2004. The influence of alcohol, age and number of passengers on the night-time risk of driver fatal injury in New Zealand. *Accid. Anal. Prev.* 36, 49–61.
- Kidd, D.G., McCartt, A.T., 2015. The relevance of crash type and severity when estimating crash risk using the SHRP2 naturalistic driving data. International Conference on Driver Distraction and Inattention, 4th, 2015.
- Larsson, P., Dekker, S.W., Tingvall, C., 2010. The need for a systems theory approach to road safety. *Safety Sci.* 48 (9), 1167–1174.
- Lave, C., 1985. Speeding, coordination, and the 55-mph limit. *Am. Econ. Rev.* 75, 1159–1164.

- Mackworth, J.F., 1968. Vigilance, arousal, and habituation. *Psychol. Rev.* 75 (4), 308.
- McEvoy, S.P., Stevenson, M.R., McCartt, A.T., Woodward, M., Haworth, C., Palamara, P., Cercarelli, R., 2005. Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study. *Br. Med. J.* 331 (7514), 428.
- Merat, N., Jamson, A.H., 2013. The effect of three low-cost engineering treatments on driver fatigue: a driving simulator study. *Accid. Anal. Prev.* 50, 8–15.
- Neale, V.L., Dingus, T.A., Klauer, S.G., Sudweeks, J., Goodman, M., 2005. An overview of the 100-car naturalistic study and findings. *Experimental Safety Vehicles (ESV) Conference Paper Number 05-0400*.
- NHTSA, 2008. National Motor Vehicle Crash Causation Survey: a Report to Congress. DOT HS 811 059. U.S. Department of Transportation, Washington, DC.
- NHTSA, 2016. Distracted Driving 2014. Traffic Safety Facts, National Highway Traffic Safety Administration Report DOT HS 812 260. U.S. Department of Transportation, Washington, DC.
- NHTSA, 2017. Traffic Safety Facts 2015. National Highway Traffic Safety Administration Report DOT HS 812 384. U.S. Department of Transportation, Washington, DC.
- Njord, J., Steudle, K., 2015. Big Data Hit the Road: the First Year of Use of the SHRP2 Safety Databases. TR News, No. 300. November–December 3–7. Transportation Research Board, Washington, DC.
- Noy, I.Y., Shinar, D., Horrey, W.J., 2018. Automated driving: safety blind spots. *Saf. Sci.* 102, 68–78.
- Otte, D., Pund, B., Ja'nsch, M., 2009. A new approach of accident causation analysis by seven steps ACASS. 21st ESV Conference.
- Persaud, B., Retting, R., Garder, P., Lord, D., 2001. Safety effect of roundabout conversions in the United States: Empirical bayes observational before–after study. *Trans. Res. Rec.: J. Trans. Res. Board* (1751), 1–8.
- Phillips, R.O., Sagberg, F., 2010. Woken by Rumble Strips: Reports From Drivers Who Have Fallen Asleep at the Wheel (No. TOI-1094-2010). Institute of Transport Economics TOI, Oslo, Norway.
- Redelmeier, D.A., Tibshirani, R.J., 1997. Association between cellular-telephone calls and motor vehicle collisions. *N. Engl. J. Med.* 336 (7), 453–458.
- Rodriguez, R.J., 1990. Speed, speed dispersion, and the highway fatality rate. *Southern Econ. J.* 349–356.
- Schechtman, E., 2002. Odds ratio, relative risk, absolute risk reduction, and the number needed to treat—which of these should we use? *Value Health* 5 (5), 431–436.
- Schepers, P., Agerholm, N., Amoros, E., Benington, R., Bjørnskau, T., Dhondt, S., Geus, B., Hagemester, C., Loo, B., Niska, A., 2015. An international review of the frequency of single-bicycle crashes (SBCs) and their relation to bicycle modal share. *Inj. Prev.* 21 (e1), e138–e143.
- Shinar, D., 2017. *Traffic Safety and Human Behavior*. Emerald Publishing, Bingley, UK.
- Shinar, D., Drory, A., 1983. Sign registration in daytime and nighttime driving. *Hum. Factors* 25 (1), 117–122.
- Shinar, D., Valero-Mora, P., van Strijp-Houtenbos, M., Haworth, N., Schramm, A., De Bruyne, G., et al., 2018. Under-reporting bicycle accidents to police in the COST TU1101 international survey: cross-country comparisons and associated factors. *Accid. Anal. Prev.* 110, 177–186.
- Summala, H., Näätänen, R., 1974. Perception of highway traffic signs and motivation. *J. Safety Res.* 6, 150–153.
- Treat, J.R., Joscelyn, K.B., 1971. A Study to Determine the Relationship Between Vehicle Defects and Crashes. Indiana University, Bloomington IN (Int Rept).
- Wegman, F., Aarts, L., 2006. *Advancing Sustainable Safety: National Road Safety Exploration for 2005-2020*. SWOV Institute for Road Safety Research, Leidschendam, Netherlands.
- Wegman, F., Zhang, F., Dijkstra, A., 2012. How to make more cycling good for road safety? *Accid. Anal. Prev.* 44 (1), 19–29.
- Weijermars, W.A.M., Wegman, F.C.M., 2011. Ten years of sustainable safety in the Netherlands. *Trans. Res. Rec.* 2213, 1–6.
- Wikipedia (2018). [https://en.wikipedia.org/wiki/List\\_of\\_countries\\_by\\_firearm-relateddeathrate](https://en.wikipedia.org/wiki/List_of_countries_by_firearm-relateddeathrate). (Accessed 27 November 2018).
- Wu, L., Geedipally, S.R., Pike, A.M., 2018. Safety evaluation of alternative audible lane departure warning treatments in reducing traffic crashes: an empirical bayes observational before–after study. *Transp. Res. Rec.* 0361198118776481.
- Young, R.A., 2013. Cell phone conversation and automobile crashes: relative risk is near 1, not 4. September. *Proceedings of Third International Conference on Driver Distraction and Inattention* 4–6. <http://document.chalmers.se/download>.